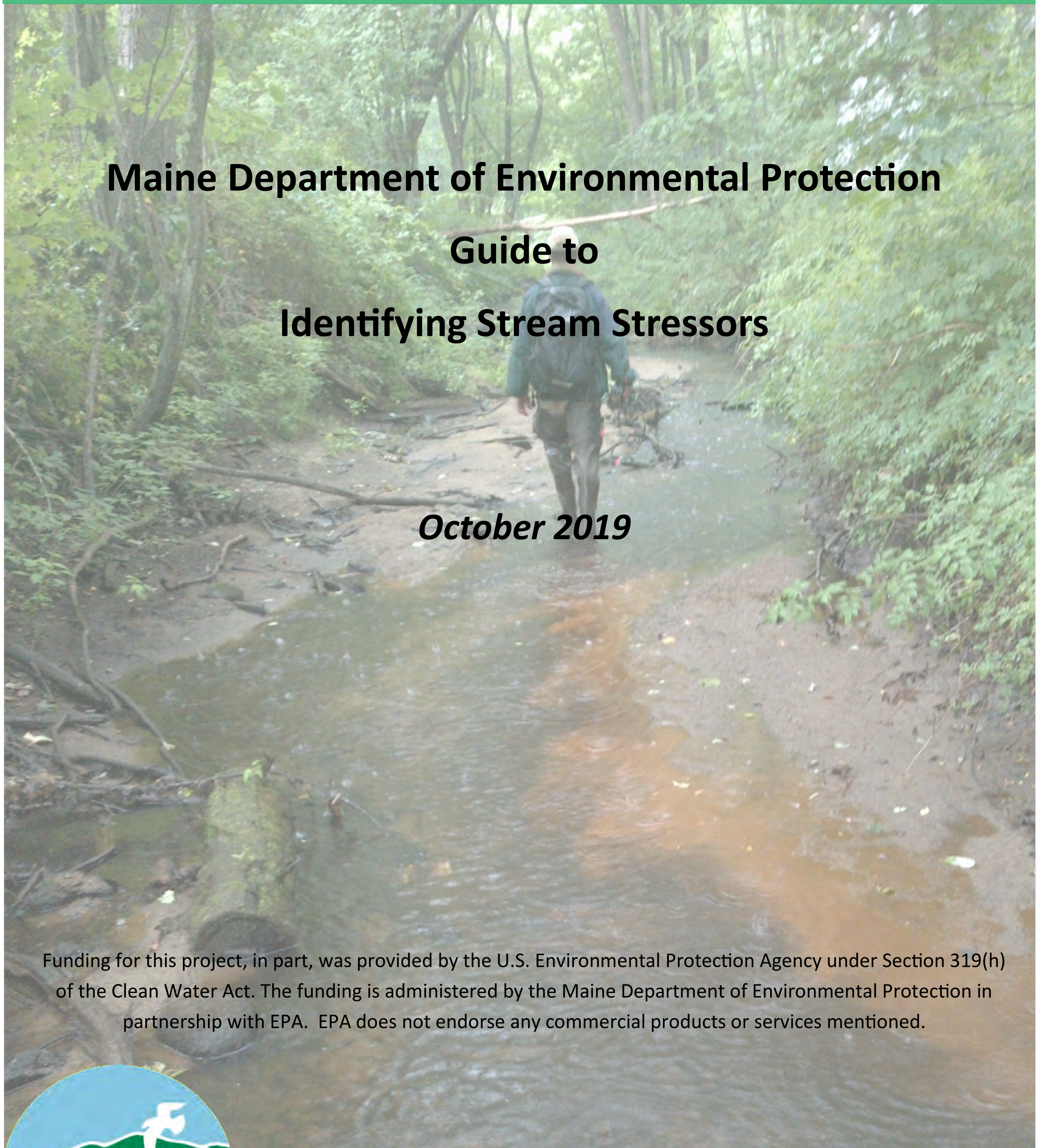

Maine Department of Environmental Protection

Guide to

Identifying Stream Stressors

October 2019

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Sculpin, Hockenhull Brook, Ft. Fairfield.

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Definitions

Base flow. Sustained flow of a stream in the absence of direct runoff. Natural base flow is sustained largely by groundwater discharges.

Biological Community. For this guide, the term is meant to apply to aquatic macroinvertebrates and benthic algae.

BOD. Biological Oxygen Demand. The amount of dissolved oxygen used by microorganisms in the biological process of metabolizing organic matter in water.

Catastrophic drift. The large-scale displacement of invertebrates occurring during periods of increased river discharge.

Measuring dissolved oxygen (DO) and conductivity.

Catchment. A small watershed, often the area that drains to a stormwater outfall.

Conductivity. A measure of the degree to which a specified material conducts electricity, calculated as the ratio of the current density in the material to the electric field that causes the flow of current.

CSO. Combined Sewer Overflow. Combined sewer systems are sewers that collect rainwater runoff, domestic sewage, and/or industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant and discharge directly into a nearby water body.

Dissolved oxygen (DO). The amount of oxygen that is present in water.

Eurythermal. An organism able to tolerate a wide range of temperatures.

Fluvial Geomorphology: The study of the form and function of streams and the interaction between streams and the landscape around them.

Geographic information system (GIS). A framework for gathering, managing, and analyzing data, rooted in the science of geography. By integrating many types of data, it is able to analyze spatial location and organize layers of information into visualizations using maps.

Definitions Continued

Impaired water body. The water body does not meet applicable Maine water quality standards and is listed in the Maine Integrated Water Quality Monitoring and Assessment Reports (https://www.maine.gov/dep/water/monitoring/305b/index.html).

Recruitment potential. The potential for a juvenile organism to join a population, either by birth or immigration.

Proximate stressor. The primary environmental condition (pollutants or habitat) causing the biological impairment.

Rapid geomorphic assessment (RGA). Involves the identification of in-stream features resulting from a variety of geomorphic processes to provide a semi-quantitative assessment of a stream's stability and mode-of-adjustment. The processes are represented by four factors: aggradation (AF), widening (WF), downcutting (DF), and planimetric form adjustment (PF).[1]

Specific Conductance. A measure of how well water can conduct an electrical current. In water quality, specific conductance is used as an indication of the presence of ions that maybe a contaminant (e.g. chloride).

Stenthermal. An organism able to tolerate only a small range of temperature.

Stressor. Any environmental condition (pollutants or habitat) that contributes to biological impairment.

Subwatershed. A portion of a larger stream watershed being discussed that drains to the stream via a discrete tributary stream or channel.

Watershed. Land area that drains to a particular water body, such as a lake, stream, river or estuary.

1. New York DEC webpage http://www.dec.ny.gov/docs/water_pdf/swdmappendixj.pdf

Preface: Lessons Learned

Of the roughly 32,000 miles of rivers and streams in Maine, only a small fraction (<5%) are considered impaired (DEP, 2014). In the 1990s, DEP started to more closely investigate a subset of impaired streams located in urban and agricultural areas. DEP completed the Long Creek and Red Brook study (DEP, 2002) in the Portland Maine Mall area, the Urban Streams Study (DEP, 2005) in the Bangor and Portland areas, and the Prestile and Dudley Brook studies in Aroostook County's agricultural area (DEP 2010). This work led to an improved understanding of these specific stream systems, identified many of the common stressors in urban and agricultural watersheds, and provided general management recommendations. However, as urban and agricultural communities started to develop watershed-based plans, DEP and local partners (Soil & Water Conservation Districts, municipalities, consultants) needed to go a step further to provide targeted roadmaps for stream restoration. Over the past decade, DEP has learned from these community planning efforts and refined its approach to identifying proximate stressors to urban and agricultural streams with impaired biological communities.

Undisturbed Maine stream with intact forested riparian area.

This document is meant to serve as a practical guide for DEP staff, professional partners like Soil & Water Conservation Districts, environmental consultants and local stakeholders starting this process. This document is not meant for the lay person, but rather those experienced in stream and watershed work.

DEP's proximate stressor identification process has been shaped over time, in part, from mistakes made and lessons learned. For example, early urban watershed plans focused on classic urban pollutants transported in stormwater from developed surfaces (e.g. nutrients, metals and hydrocarbons) and prescribed mostly stormwater management and low impact development BMPs to address them. However, as staff and partners became more knowledgeable and looked more closely at the proximate stressor identification process, two other often dominant stressors emerged – habitat alteration and base flow (predominately groundwater flow) chloride toxicity. Many of the BMP strategies typically used to address the classic urban pollutants do not address instream habitat issues and may in fact exacerbate base flow chloride toxicity. Hence this guidance document is designed to provide a focused process of identifying the operative proximate stressors so that streams are more likely to see improvement in the health of the biological community and attainment of aquatic life criteria.

1 Introduction

Understanding and then restoring urban and agricultural streams is challenging because of the many impacts associated with urban development and agricultural practices. Given the limited resources to implement watershed plans, it is critical that plans identify and then target the primary stressor(s) associated with a particular stream's impairment. Jumping to unsubstantiated conclusions about restoration needs would be both costly and unlikely to result in restoration success. For example, many watershed managers are tempted to identify impervious cover as the reason for an urban stream's impairment and recommend widespread stormwater retrofits. Based on DEP experience, however, this approach could be both prohibitively expensive as well as ineffective in some stream watersheds.

This document outlines a science-based proximate stressor identification process to examine a stream's watershed, past and current land uses and monitoring data to identify potential stressors, and rule out other stressors. Hypotheses about possible proximate stressors are then tested through field assessments and monitoring. Once the proximate stressor(s) are determined, specific pollution sources and actions can then be identified and targeted in restoration action plans. Although this document does not focus on the process used to identify sources, oftentimes these sources become clear during the proximate stressor identification process. There are several other points to keep in mind when reviewing and using this document.

> **Proximate stressor**: the primary environmental condition (pollutants or habitat) causing the biological impairment.
>
> **Stressor**: any environmental condition (pollutants or habitat) that contributes to the biological impairment.

- Following this guidance might not always yield clear-cut answers and almost always leads to more questions than you can afford to answer. However, the approach aims to use available resources wisely to create the best possible plan with the best possible chance for successful restoration.
- This document does not focus on bacteria impairments, except that bacteria monitoring may be part of a sampling process used to investigate a stream with potential nutrient stressors. Some of the approaches described, however, may also be useful for planning efforts in bacteria-impaired streams.
- The stressor identification process described in this document is not the same as EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS)[2] or its Stressor Identification Guidance Document[3]. These tools provide a methodology for determining the most probable cause of an observed biological impairment, using elimination, diagnosis, and strength-of-evidence analysis.

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2. US EPA. Causal Analysis/Diagnosis Decision Information System (CADDIS): https://www.epa.gov/causal-analysisdiagnosis-decision-information-system-caddis/caddis-basic-information#cite 2017.
3. Cormier, S., S. Norton, G. Suter, AND D. Reed-Judkins. Stressor Identification Guidance Document. U.S. Environmental Protection Agency, Washington, DC, EPA/822/B-00/025, 2000.

2 Proximate stressors to the stream biological community

Stressors to the stream biological macroinvertebrate and algal community

Natural free flowing streams in Maine, except for some of the largest streams and rivers, generally have cool summer temperatures, reasonably high levels of dissolved oxygen, and a diversity of habitats in terms of structure, substrate and velocity (Fig. 1). They also have wooded riparian canopies that provide leaf fall into the stream and shade which limits the growth of algae. As a result, leaf biomass is at the base of the natural stream's food web and the major, though limited, source of nutrients to the system. The organisms that inhabit natural Maine streams are ones that do well in these conditions. Maine's Water Quality Standards for flowing waters include biological criteria that limit the amount that a stream's biological community can deviate from the natural condition.

Figure 1. Natural free flowing stream with forested riparian area and good canopy cover.

When stream corridors and their watersheds are altered, many of the aspects of the stream's water quality and its habitats may change, resulting in changes in the abundance, composition and diversity of organisms in the aquatic community. The aquatic life in the changing and altered community will include taxa that can tolerate, or even capitalize on the changes that have occurred. If the changes are extreme there may be comparatively few taxa left. Lost from the community are the intolerant taxa, those that cannot effectively adapt to an altered environment. These changes to the community are generally considered detrimental because they indicate a deviation from the natural condition. The altered physical, chemical, and biological conditions that cause the detrimental change in the community are called **stressors**. Evaluation of the composition and structure of the altered community, particularly which taxa are dominant and which taxa are absent, may indicate which stressors have been most important in precipitating the detrimental response in the community.

Proximate stressors (or causal agents) are directly responsible for these responses; other stressors may be indirectly responsible for the responses via their effects on proximate stressors (from EPA's CADDIS website https://www.epa.gov/caddis). For example, low dissolved oxygen (DO) could be a proximate stressor that would eliminate some sensitive organisms from a community. However, there are a variety of other stressors that could cause or contribute to the low dissolved oxygen levels. These include increased nutrient load resulting in high levels of plant respiration, high temperatures that reduce the solubility of O_2, reduced water velocity and surface area that reduce opportunities for reaeration, and embedded sediments which reduce circulation of DO to the habitat of many macroinvertebrates and fish eggs. Of these contributing stressors, some, if not all, may also be proximate stressors in their own right.

While climate change is not a proximate stressor it can and will amplify many of the proximate stressors. With spring ice-out occurring earlier and ice-in later,[4] the duration of open water exposed to sunlight and warmer air temperatures will drive the temperature of impounded waters and waters lacking canopy cover even higher. In turn, warmer water pushes DO concentrations down. Extreme weather events, both large intense storms and long periods of drought, are happening more frequently. More frequent storms increase levels of channel disturbance and habitat alteration, especially in highly impervious watersheds where floodplains have been filled and culverts are undersized or misaligned. Long periods of drought result in lower baseflow as the groundwater table drops, and there is associated loss of habitat and velocity.

Causes/Sources are the factors that result in the presence of a stressor. For example, urban or agricultural runoff could be the source of nutrients that support excessive plant growth whose respiration results in a diurnal depression in DO. The progression from runoff to reduction in DO is the **causal pathway** linking the original cause or source to the proximate stressor (Fig. 2).

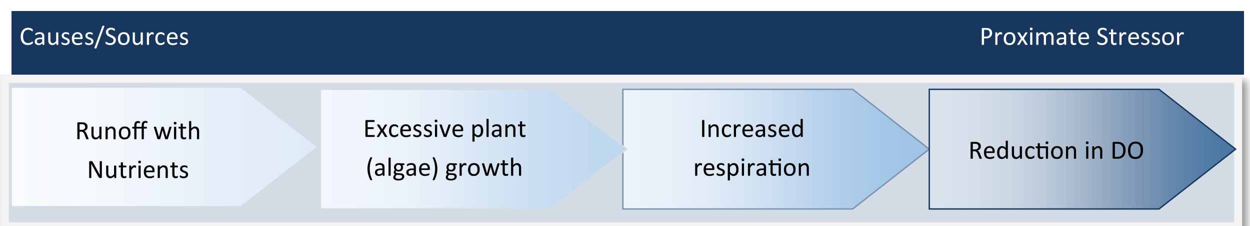


Figure 2. Example causal pathway.

The following describes the proximate stressors that are most likely to contribute to degradation of aquatic communities in free flowing streams in Maine. Appendix 1 presents the causal pathways that are likely to lead to each proximate stressor which are: Altered Physical Habitat, Dissolved Oxygen (DO), Food Source, Low Recruitment Potential, Temperature, Toxicity/Chloride, Toxicity/Other, and Velocity.

2.1 Temperature. Some aquatic taxa are tolerant of a broad range of water temperature (referred to as eurythermal) while others can tolerate only a narrow temperature range (stenothermal). Given the relatively cold temperature of Maine's groundwater and the fact

4. *Historical Changes in Lake Ice-Out Dates as Indicators of Climate Change in New England, 1850-2000*. U.S. Department of the Interior. U.S. Geological Survey. Fact Sheet FS 2005-3002. January 2005.

that, in a natural condition, most Maine streams are well shaded, many of the taxa indigenous to Maine streams are cold water stenothermal, and cannot tolerate prolonged periods of warmer water temperatures. Brook trout will look for colder refugia if water temperatures are above 20° C for more than a few days, and cannot survive if temperatures are above 24° C for an extended period. Most stoneflies prefer even colder water, as do many of the indigenous mayfly, caddisfly and midge taxa.

Streams naturally have warmer temperatures during the summer and during the day when the sun or atmosphere naturally warm it. During extended periods of hot weather, streams below lake outlets, as well as some types of wetlands and beaver flowages are likely to have increased temperatures that will limit the presence of at least some indigenous taxa. As a result of this and the fact that plankton from the impounded waters provide an alternative food source, the communities below these outlets usually contain more temperature tolerant filter feeders.

In many instances temperature stress may not be great enough to significantly impair a community by itself, but it can be a contributing factor to impairment when combined with other stressors. There are many anthropogenic causes of unnaturally high summer temperatures in streams including loss of canopy shading, impoundments, and stormwater from warm impervious surfaces and stormwater retention ponds.

2.2 Dissolved Oxygen (DO). Nearly all aquatic organisms require at least some DO in the water, some species more than others. Since natural concentrations of DO in Maine streams tend to be quite high (75% saturation or higher), many of the organisms that are native to these streams require fairly high levels of DO and are not tolerant of prolonged depression of DO concentration. If they are exposed to depressed DO they may die, have reduced growth and/or reproduction, or, if the opportunity is available, move upstream or downstream to avoid the stress. In the Maine water quality standards for flowing fresh waters, the DO standard for Class A & B streams is 7.0 ppm or 75% saturation, whichever is higher. For Class C waters it is 5.0 ppm or 60% saturation.

Figure 3. Embedded rocky substrate with biofelt (mat of algae and fine sediments) on rock surface.

Several stressors can contribute to depression of DO concentrations. DO becomes less soluble as water temperature increases, so DO concentrations will drop as water warms (though % saturation may stay the same). Stream water absorbs O_2 from the atmosphere (re-aeration) so anything that decreases the amount of water that is exposed to the atmosphere (e.g. reduction in velocity, and hence turbulence, as well as reduced surface area) has the potential to lower DO concentrations. Many organisms live in the stream substrate and rely on water flow through the interstitial voids for their oxygen supply. If the substrate is embedded (voids are filled with fine particles), than oxygen delivery to the organisms may be inadequate even though the concentration of DO in the water is fairly high (Fig. 3).

2.3 Velocity. Velocity refers to the speed at which water is moving in the stream channel and is usually expressed in centimeters/second. Velocity can be a proximate stressor, but it can also be an important secondary stressor to both dissolved oxygen and altered habitat.

Many of the aquatic organisms native to Maine streams are adapted to take advantage of the benefits of living in flowing water, and some require more flow than others. Taxa that are adapted to higher velocities live in the riffles, cascades, and woody debris dams where velocities are highest. One very significant benefit of flowing water is that it can deliver more oxygen to fish and insect gills than can stagnant water. The minimum level of oxygen that many aquatic insects can tolerate is a function of the rate at which oxygen is passing over their gills. At higher velocities they can tolerate lower dissolved oxygen concentrations. Many insects and some other types of aquatic organisms are adapted to filter their food from the water, and the greater the water velocity the more food is delivered to the filters. Any altered watershed or stream channel conditions that result in significantly lower than natural base flow velocities will compromise the ability of these taxa to thrive, or even survive, in a stream reach.

Figure 4. Filling along stream channel is preventing the stream from accessing the floodplain. Filling also resulted in straightening stream channel causing increased velocity and loss of habitat.

If watershed conditions (e.g. impervious surfaces, loss of floodplain) result in much higher than natural stream velocities, particularly in relatively high gradient streams, the energy in the passing water may be too great for many taxa to hang on to the substrate, resulting in catastrophic drift (large-scale displacement of invertebrates occurring during periods of increased river discharge) of the organisms downstream (Fig. 4). The remaining community will have lower diversity and be dominated by taxa such as black flies that have very effective anchoring adaptations.

Higher than natural water velocity is a secondary stressor that contributes to many of the proximate stressors in the next category – altered physical habitat.

2.4 Altered Physical Habitat. The biota indigenous to free flowing streams in Maine are adapted to physical habitats that:

- Have a variety of substrate, water velocity and depth conditions to support a diverse and resilient community
- Have stable substrates that are not frequently disturbed or altered
- Have an abundance of structural components (e.g. rocks, woody debris) to trap food and prevent it from being washed downstream
- Have sufficient wetted habitat during base flow to maintain a diverse community

Figure 5. Stream channel straightened and confined via concrete drainage half pipe resulting in loss of habitat.

Any alteration that reduces these physical qualities will potentially affect the composition of taxa in the community and, in some instances, the abundance of organisms. Many taxa have preferences for a particular combination of substrate and water velocity, and if that substrate is lost or buried, the taxa that colonize it are likely to be lost as well. If alterations result in the loss of structural elements, not only is the substrate that those elements provided lost, but food (i.e. leaves) retention and diversity in velocity will also be reduced (Fig. 5). Activities/conditions that affect the amount (e.g. watershed imperviousness) or distribution (e.g. channel widening) of base flow can dramatically affect the abundance and composition of both invertebrate and fish taxa.

Maine DEP and others have studied urban streams with impaired biological communities and found that stressors associated with altered physical habitat to be important. Often these stressors involve loss of habitat from unnaturally high rates of sediment erosion from channel bottom and stream bank because of elevated storm flows, sometimes followed by unnaturally high rates of deposition of the eroded sediment on downstream habitats. These alterations in sediment dynamics, along with intentional alteration of the channel by historical channelization projects, often result in a channel that is much wider than it would naturally be. The consequence of a widened channel is that base flow velocity and depth becomes a limiting factor for many taxa. The scouring of sediment from channel bottoms (incision) that results from elevated stormwater volumes and loss of floodplain often disconnects the stream from its remaining floodplains, further exacerbating the problem by increasing the stormwater velocities that the stream must accommodate. The increase in watershed imperviousness that is often responsible for elevated storm flows can also reduce the level of base flow in the stream, thus reducing the availability of habitat during low flows.

The many causal pathways that result in altered habitat that stresses the biological community in streams are presented in Appendix 1 (p. 43-46).

Figure 6. Unforested riparian area resulting in loss of leaf fall and primary food source.

2.5 Altered Food Source. The organisms, particularly the macroinvertebrates, that are found in a stream are, in part, a function of the food resources that are available to them. In a small, free flowing stream with adjacent forest and overhanging canopy, the principle primary (i.e. plant) food source is usually leaf fall into the stream. The non-predatory taxa that are found in such streams are ones with feeding strategies that take advantage of leaves as the primary food source. Shredders break up the leaves and consume the bacteria and detritus on leaf surfaces. Collectors and gatherers feed on the leavings of the shredders. Filter feeders feed on the fine leaf particles and detritus that drift downstream in the current. Predators feed on the other macroinvertebrates. In wider streams and rivers and in small streams that lack canopy cover to provide leaf fall and shade, the principle primary food source is algae that are growing on the benthic substrate and plants. This food source supports a different community, one where the primary consumers are scrapers and grazers, and potentially some shredders for macroalgae and vascular plants. In streams below the outlet of a lake, the phytoplankton and zooplankton in the lake water are added to the leaves and/or algae as another food source in the stream. In these instances, the dominant taxa are likely to be filter feeders, and they may be very abundant if the lake is productive.

If the riparian area of a forested stream is cleared, leaf fall is lost as a primary food source and shading of the stream bed is eliminated (Fig. 6). Algal growth on the substrates in the stream quickly increases, taking advantage of the available light. In the macroinvertebrate community many of the shredders are replaced by scrapers and grazers. If there are no other concurrent changes in the watershed or the stream's habitat and water quality, the new community is likely to shift to less stonefly taxa and more grazers such as the mayfly *Baeti*s. The removal of a stream's riparian cover is often accompanied by other impacts associated with agricultural, residential, or urban development (e.g. elevated nutrients, higher stormwater flows, inadequate stream crossings), and the resulting algae-based community will be degraded in one or more ways.

While the macroinvertebrates living in the stream provide much of the food for fish, the drop of terrestrial insects and arachnids from the overhanging canopy can also be a very important food source. If the canopy is removed, this source of food is lost.

2.6 Low Recruitment Potential. Most of the insects in the stream macroinvertebrate community spend their early (egg) and middle (nymph or larvae/pupa) life stages in the water or the wetted bottom sediments. The adult reproductive stage is usually not aquatic. Adults hatch and feed on terrestrial algae, lichens, and pollen. Adult female stoneflies may double their weight over 2 to 6 weeks before oviposition. The riparian area aids with humidity levels and dispersal of adults as well. Since most of the taxa indigenous to Maine streams evolved in a forested setting, the preferred, sometimes required, adult habitat is forest. If riparian forest cover is lost, the recruitment of new generations will likely be compromised unless there is a sufficient number of larvae and nymphs that can drift downstream from healthy upstream habitat.

Even in a natural setting, there are events that can dramatically alter a stream's biota. A particularly intense hurricane can alter channel geomorphology and scour benthic habitats, causing catastrophic drift of many taxa downstream. In natural settings, the biota recover relatively quickly from such events through recolonization via (1) downstream drift from less disturbed upstream habitats or (2) movement of adults from adjacent streams.

When watersheds become heavily developed or agriculture is a significant landuse in the watershed, the frequency of potentially catastrophic disturbances (e.g. elevated stormwater flows from impervious areas, base flow chloride toxicity during a very dry summer) is much greater. Extreme events that might naturally occur several times a decade may now occur several times a year. Even in these situations, if the most upstream parts of the watershed are only lightly developed and the riparian corridor is intact, drift from upstream may provide sufficient recruitment to allow for quick recovery. If the headwaters are disturbed, then recruitment to the community must rely on adult fly movement and re-colonialization from downstream habitats and adjacent streams. The macroinvertebrate community in streams subject to frequent disturbance without intact upstream habitats is likely to be dominated by taxa with short life cycles (e.g. midges, amphipods, isopods), with few annual (e.g. mayflies, caddisflies, stoneflies) and multiyear life cycles taxa (some dragonflies and dobsonflies).

If an impaired stream drains to tidal waters and its headwaters plus adjacent stream watersheds are similarly impaired, recovery of the streams biota may be very slow, even if all other stressors have been addressed.

2.7 Toxicity. There are many substances that can be toxic to aquatic life, and many pathways by which sensitive organisms can be exposed to these substances. Exposure can be directly from contact with a toxic chemical dissolved in the water, or it can be through contact with or ingestion of toxic chemicals adsorbed or otherwise attached to sediment or organic particles.

The toxicity of a substance is often a function of frequency, duration and magnitude. If an organism exhibits a toxic effect (e.g. death, loss of critical functions or growth, reproductive interference) after only a short exposure time, say 48 hours or less, that substance is considered **acutely** toxic at the concentration of the substance during the period of exposure. If a toxic effect is exhibited only over a much longer period of exposure (4 days or longer), the substance is considered **chronically** toxic at the concentration of exposure. EPA and others have developed guideline criteria for the acute and chronic toxicity of many chemicals, based primarily on laboratory studies exposing test organisms to a variety of concentrations and applying risk analytics to the test results[5]. These values are reported as the CMC (criterion maximum concentration) for acute toxicity and the CCC (criterion continuous concentration) for chronic toxicity[6].

> <u>Toxic</u> effect includes death, loss of critical functions or growth, and reproductive interference.
>
> <u>Acute toxicity</u> results after only short exposure time, 48 hours or less, of the substance.
>
> <u>Chronic toxicity</u> results with exposure to the substance over a much longer period of exposure (4 days or longer).

The idea of acute and chronic toxicity is particularly important when evaluating stream water quality data. If a substance is detected in the water during storm event conditions when the duration of exposure is fairly short, it would not be considered potentially toxic unless it exceeded the acute criteria (CMC). If it was detected during base flow conditions when it would

5. US EPA webpage https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table
6. US EPA webpage https://www.epa.gov/sites/production/files/2015-06/documents/nrwqc-2004.pdf

be reasonable to assume a longer duration of exposure, it would be considered potentially toxic if it exceeded the chronic criteria (CCC).

These guideline criteria concentrations should be used with caution when determining the stressors that are most likely to be causing or contributing to the impairment of a stream community for several reasons:

1. The criteria are conservative. They attempt to define a concentration below which there will not be a toxic effect, and above which there **may** be a toxic effect. When prioritizing potential stream stressors in order to determine the best strategies for restoring the community, a conservative criteria may be misleading.

2. The taxa used in the tests on which the criteria are based may have been either more or less sensitive (often less) than the most sensitive taxa that would be in the stream absent the impairment.

3. The impairment is based on the health of the macroinvertebrate or fish community as a whole, usually not the success or failure of an individual taxon. Communities provide some resilience, so it may not be appropriate to extrapolate individual effects to effects at the community level.

4. The toxicity of the substance may be enhanced by synergistic effects or interactions with other stressors or stream conditions (e.g. other toxics, ionic strength).

5. The amount of water quality data for the stream in question may not be sufficient to characterize the period of exposure.

6. These criteria apply when the affected organisms are exposed to toxic substances that are dissolved in the water. Filter feeding taxa (e.g. many caddisflies, black flies) may collect and ingest some particulate bound toxics. Evaluation of the potential toxicity of a substance and its impact on the community is even more challenging if the exposure is through contact with particulate toxics in the substrate in or on which the vulnerable taxa live or feed. Most particulate-bound, potentially toxic substances are attached to fine soil or dust particles and are delivered to the stream during storm events. These will most likely accumulate only in areas where fine sediment is being deposited (e.g. large pools and wetlands). There is also a possibility that some particulate toxics may remain in faster flowing parts of the stream by being trapped in or adhered to periphyton, moss, or plants growing on substrates in the stream bottom where they may be ingested by scrapers and grazers and thus brought into the food chain. EPA and others have developed guidelines

7. US EPA webpage https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=513400

8. USGS webpage https://www.cerc.usgs.gov/pubs/sedtox/volumeiii.pdf

on sediment toxicity including ESGs (Equilibrium Partitioning Sediment Guidelines)[7] and SQGs (Sediment Quality Guidelines)[8], but their application to stressor analysis presents some of the same limitations as the water quality criteria discussed above.

There are many potentially toxic chemicals that may be found in the groundwater and stormwater that drain to streams, particularly streams with significant agriculture or urbanization in their watersheds. The ones that have been most studied are chloride, heavy metals, polycyclic aromatic hydrocarbons and pesticides.

2.7.1 Chloride Toxicity. There are many chemical substances that may be present in Maine streams in concentrations potentially toxic to aquatic life, but we will discuss chloride toxicity independently because it has been found to be one of the most important stressors in small, commercially developed urban or suburban stream watersheds. Most of the deicing salts that are applied to our roads, parking lots and sidewalks are sodium chloride (NaCl) or, less frequently, calcium chloride ($CaCl_2$). When the salt is dissolved in water, either in the process of melting snow and ice or in rainfall, the chloride anion dissociates with the cations leaving chloride (Cl^-) ions in the water. The chloride ion is highly soluble and non-reactive, so it stays in solution and can be delivered to streams very efficiently in either stormwater runoff or in groundwater. Unfortunately, it is also toxic to aquatic organisms with low salt tolerance, which includes many of the macroinvertebrates and some of the fish found in a typical stream. EPA's acute water quality criterion (CMC) for chloride is 860 mg/l. The chronic criterion (CCC) is 230 mg/l.

Figure 7 . Chloride runoff from municipal sand/salt storage area discharging to stream and wetland.

Chloride may be delivered to the stream directly via stormwater or meltwater runoff or it may reach the stream more slowly via contaminated groundwater (Fig. 7). If the delivery vector is stormwater or meltwater (warm day or light precipitation melting with little rainfall dilution), the concentration of chloride in the runoff can be very high.

Stream chloride concentrations can be dramatically elevated for relatively short periods of time if in-stream dilution is limited. If the delivery vector is contaminated groundwater, the chloride is delivered to the stream continuously over a long period, and chloride concentrations during base flow conditions will be elevated. When groundwater contamination is the source, chloride concentrations in the stream will be lowest during and shortly after non-winter storm events, often quickly rising as dilution with uncontaminated stormwater diminishes and groundwater sources become the dominant source of streamflow.

If chloride is delivered during winter and early spring storm or melt events, the duration of exposure of aquatic organisms to the elevated chloride concentrations is likely to be relatively short. In this case, acute toxicity is the concern. On the other hand, if delivery is via groundwater during baseflow conditions, exposure to elevated concentrations will be continuous over long periods and chronic toxicity, which will be at a much lower concentration than acute toxicity, is the concern. In a small stream watershed with high levels of deicing salt use, both acute melt event toxicity and chronic base flow toxicity are likely.

Streams most likely to have aquatic communities impaired due to chloride toxicity are small headwater streams with commercial, institutional, office or large multifamily residential land use, or a combination thereof, or have current or historical sand/salt storage facilities in their watersheds. Many of the highly contaminated streams also have an interstate interchange in the watershed. These land uses tend to apply more deicing salts than residential areas typically do.

2.7.2 Metals The potentially toxic metals most likely to be found in urban streams that are not associated with industrial or municipal point source discharges are cadmium, copper, lead, and zinc, and they may be in either a dissolved or particulate state. When measuring these metals in the water it is important to distinguish the dissolved fraction from the particulate fraction. Exposure to particle bound metals in the water as it passes by has much less potential to cause a toxic response than do metals that are dissolved in the water. Particulate metals may accumulate in downstream sediments or in biofilms on substrates in the stream bottom where benthic taxa may be exposed to, or even ingest them. When measuring metals in stream water it is also important to make sure that the detection and reporting limits for the analytical procedure being used is low enough to detect potentially toxic concentrations (i.e. below the CCC and/or CMC whichever is appropriate for the situation).

Concentrations of metals (both the particulate and dissolved fractions) that exceed the CCC, and even the CMC, are not uncommon in urban streams during storm events, even in streams with apparently healthy aquatic communities. For this reason, and for reasons discussed in section 2.7, it is difficult to determine whether the presence of metals in concentrations that exceed the CCC or CMC are a significant contributor to a biological impairment, especially if the data indicating metal exceedance are for total metals collected during a storm event.

2.7.3 Hydrocarbons The stormwater-delivered hydrocarbons most often associated with aquatic life impairments are polycyclic aromatic hydrocarbons (PAHs), particularly those derived from the application of coal tar sealants on parking lots and driveways. PAHs are hydrophobic so they tend to attach to particles and accumulate in fine sediments deposited in slow moving reaches of streams. They may also accumulate on biofilms. Many of the other hydrocarbons that are incorporated in stormwater or contaminate groundwater feeding baseflow are volatile, and therefore do not persist in the stream environment.

2.7.4 Pesticides Adequate information about the impact and effect of pesticides in Maine was not available at the time of publication. While not added to the stressor table, pesticides should still be considered as a possible proximate stressor depending on local landuse.

3.0 Identifying the proximate stressors to biological impairment

Use the following steps to identify the proximate stressor(s) that are driving impairment of the biological community in a given stream. These steps have been developed over time based on experience gained through the completion of multiple watershed-based plans .

3.1 Determine Water Quality Impairment Listing Information

The first step in the proximate stressor identification process is to determine what is known about the impairment listing. Stressor identification targets the causes (stressors) of a biological impairment listing.

To locate known information regarding a specific stream biological impairment, start with DEP's "*Integrated Water Quality Monitoring and Assessment Report*" (IR). The IR "summarizes water quality data collected by the DEP as well as numerous other state, federal and tribal government agencies, volunteer water monitoring organizations, and other sources. The Clean Water Act requires states to submit an Integrated Report to EPA every even-numbered year. Monitoring Information is analyzed by the DEP to assess the ability of Maine's water resources to meet uses such as drinking water, aquatic life support, fishing or recreation as established by Maine's Water Classification Law."

Biological monitoring has advantages over chemical/physical monitoring for several reasons:

- Chemical/physical monitoring indirectly measures the health of the resource versus assessment of the biological response to pollution.
- Chemical monitoring provides only a measure of the water quality for a limited time period (i.e. for the particular dates/times that samples are collected) and rarely describes the variability associated with factors such as weather and flow conditions.
- It is prohibitively expensive to measure all the many possible toxins that could be present in the water.

"Biological communities integrate all of the environmental stress caused by human and natural activities over a larger period of time. As a result, the numbers and types of organisms present in a water body reflect the quality of their surroundings."[9]

To find information about the resources of interest, review the most recent IR available on DEP's webpage. The Appendices provide a listing of the waters by attainment category and sorted by drainage basin. For example, to find out information about Whitney Brook in Augusta, either do a word search for "Whitney Brook" or identify which drainage basin it is located in by looking at the drainage basin maps at the beginning of the appendices. Whitney Brook is in

9. Maine DEP webpage http://www.maine.gov/dep/water/monitoring/biomonitoring/why.html

the HUC Drainage Kennebec River Merrymeeting Bay (ME010300312). The IR lists Whitney Brook as follows:

- Category 4-A: Rivers and Streams with Impaired Use other than Mercury, TMDL completed.
- Whitney Brook- 1.86 miles-Class B
- Benthic macroinvertebrate sampling showed non-attainment in 2012 (biomonitoring Station S-601).
- Non-attainment for periphyton (2010).

Output: IR listing information.

3.2 Find Existing Biological and Water Quality Data

Figure 8. Biomonitoring (macroinvertebrates) rock bag.

Maine DEP assesses two types of biological data in streams: macroinvertebrate and algal communities. Macroinvertebrate assessment consists of collecting macroinvertebrate samples using the rock bag method (FMI see http://maine.gov/dep/water/monitoring/biomonitoring/index.html) (Fig. 8). Collected macroinvertebrates are identified to the lowest possible level (genus or species). This information is plugged into a multivariate statistical model which uses a number of biological metrics such as abundance, generic richness, and Hilsenhoff Biotic Index (index based on organic pollution tolerance) to determine the likelihood of the site attaining its assigned water quality classification. For algal communities, a similar process is followed where algae is collected and identified to the lowest practical taxonomic level and this information is inputted into a statistical model.

While these models are used to determine classification attainment, they do not indicate what the potential proximate stressors are for the monitoring site. By further examination of the metric results from the model and the presence or absence of species known to be particularly sensitive or tolerant of a given stressor, DEP may be able to glean ideas about what proximate stressors are affecting the communities. To do this, biologists with expertise and experience in these fields take a closer look. The biologists use their best professional judgment and perhaps literature studies to provide initial assessment of what the biological data is telling us. For example, low diversity and low abundance of macroinvertebrates can indicate that toxics are an issue or high abundance of certain types of caddisflies indicate nutrient enrichment. Therefore, before proceeding, request that a biologist provide an initial assessment of the biological data. Later on, after additional information has been gathered, the biological results can be used to help enhance/confirm the presence or absence of possible stressors. This initial assessment also helps to determine what additional information needs to be gathered.

To obtain the biological monitoring data, follow these steps:

- Go to the DEP Biomonitoring webpage: www.maine.gov/dep/water/biomonitoring/index.html; click on "Data and Maps" and then "Click here to see sampling locations and associated biological, physical and chemical data." This opens up to a Google Earth application.
- Type in the site of interest. For example, to find information on Whitney Brook, type in 'Whitney Brook, Augusta'. The map then zooms into the stream showing monitoring stations by type (macroinvertebrate, algae or wetlands). Whitney Brook has a wetland station in the headwaters and macroinvertebrate and algae stations at the mouth of the brook.
- Click on the station of interest and a table pops ups (Fig. 9). The table includes dates the stream was sampled and attainment results. For example, the Whitney Brook macroinvertebrate station (#601) was sampled in 2007 and 2012 and did not attain Class B for either year.

S-601

Station:	WHITNEY BROOK - STATION 601
Station Number:	S-601
Town:	AUGUSTA
County:	KENNEBEC
Major Drainage:	KENNEBEC
Site Type:	STREAM/RIVER BIOMONITORING
Sample Type:	MACROINVERTEBRATE
Latitude:	44.32747962
Longitude:	-69.76586401

Sample(s):

Sample ID	Sample Date	Statutory Class	Attained Class	Report	Final Determination
1633	8/8/2007	B	No	View	NA
2098	8/9/2012	B	No	View	NA

Figure 9. Biological monitoring Google Earth popup sample site table.

- Click on "report" for associated water quality data collected as part of the biomonitoring sampling. Additional water quality data may or may not be included.

Next, obtain any other water quality data that exists for the stream. The primary places to find water quality data include the following:

- Maine Department of Environmental Protection's "Environmental and Geographic Analysis Database" or EGAD. Contact DEP Bureau of Water Quality, Division of Environmental Assessment's Watershed Management Unit to obtain data.
- Maine Department of Environmental Protection's Surface Water Ambient Toxics Monitoring Program (SWAT) produces biannual reports which include waterbody specific information https://www.maine.gov/dep/water/monitoring/toxics/swat/index.htm
- Local watershed organizations may have data. Many watershed groups send their data to DEP so EGAD may already include that data if the group has a QAPP and DEP has

agreed to accept the data. Even if DEP does have the data, if is worth checking as the group may have data not yet submitted to DEP, as well as additional information such as data summaries or reports.

- Larger municipalities may have data. The municipalities that are MS4 communities and/or have impaired streams often are doing water quality monitoring independent of DEP.

Output: Biomonitoring data results and water quality data (e.g. EGAD Excel spreadsheet results, data summaries and reports).

3.3 Desktop Analysis - Collecting Other Available Information & Data

The next step is to gather pertinent information that can be obtained before getting out in the field. This includes information available electronically, hard copies of reports, and personal communication. The gathered data should help in providing the following information, some of which are not important in the identification of proximate stressors, but will be important in determining the causal pathways leading to the identified stressors:

- Physical information:
  - Stream size and watershed boundaries.
  - Topography of the stream and watershed.
  - Stream morphology- what is the general shape of the stream and any changes over time.
  - Stream barriers present (dams, hanging culverts).
  - Water withdrawals present.
- Land Use:
  - Current land uses within the watershed.
  - Past land use changes over time.
- Impacts:
  - Other current potential impacts (e.g. landfill, residual disposal or utilization sites, uncovered sand/salt piles) within the watershed.
  - Historic sources that affected and/or continue to affect the stream (e.g. RCRA, old dumps, dams).

Resources to consider to complete this step include the following;

- Google maps: available at http://maps/google.com or Google Earth https://www.google.com/earth/

- Quick and easy way to view aerial photography.
- Includes basic mapping tools that may be used to create placemarks, measure distances and areas, draw paths and polygons, overlay images, import GIS points and import vector data.
- Includes a time slide bar that shows changes in the watershed over time.

- GIS Maps: available from Maine Office of GIS < www.maine.gov/megis/
    - Access to digital geographic data to include the following categories: administrative and political boundaries, biological and ecological/environment and conservation, elevation, geological and geophysical, imagery/base maps/land cover, oceans and estuaries/inland water resources, and transportation networks.
    - Maine Stream Habitat Viewer: view survey information for dams and other barriers (http://maine.gov/dmr/mcp/environment/streamviewer/index.htm).
- DEP Interactive Maps and Data; available at http://www.maine.gov/dep/gis/datamaps/index.html
    - Extensive information about potential sources of pollution and other information.
    - Pertinent information is primarily under these links:
        - Bureau of Remediation and Waste Management.
        - Bureau of Land Resources and Bureau of Water Quality.
        - Other Maps and Data-links.
- Other Resources/Information:
    - Municipal websites: land use ordinances, stormwater program, comprehensive plans, reports.
    - Soil & Water Conservation Districts: district projects, management plans, reports.
    - USGS New England Water Science Center: real time water data, meteorological data and historical data.
    - Local libraries and historical societies: historical town reports, historical maps, other historical documents.

To complete the desktop analysis, first check with DEP to see if the watershed boundaries have already been delineated. If not, use either GIS or Google Earth to create a project map using available GIS layers and aerial photos. The map should include watershed boundaries and, if available, subwatersheds. Boundaries are generally available from the National Hydrography dataset layer (https://www.usgs.gov/core-science-systems/ngp/national-hydrography). In highly developed urban areas, stream watersheds are likely altered due to the presence of stormwater systems (ditches, storm sewers) and high-intensity development which may re-route stormwater underground or through different pathways. Because of this, some of the urban streams have been mapped in the field by DEP-Division of Environmental Assessment staff. Check with DEP to see if the watershed has been mapped.

Next, review on-line sources of information pertaining to potential impacts to the stream. Find out if there have been any studies or surveys done on the stream; DEP is generally a source of this information. At this point or perhaps later depending on the types of problems that arise, find historical information. Review all of the information gathered to develop an initial summary of potential stressors.

Figure 10. Stream walk documenting in-stream and riparian area conditions.

Output: Map of the stream to include watershed boundaries and water quality monitoring stations, summmary/table of other sources of information, and summary of potential proximate stressors.

3.4 Initial Screening (Field Work)

After completing the desktop analysis, the next step is to get out to the stream and do some type of field survey/stream walk (Fig. 10). Walk all or most of the stream allowing a minimum of half a day if possible. Be sure to obtain permission before accessing the stream if on private land. If the stream is very large, some sections may be prioritized (e.g. most developed sections) or eliminated (e.g. sections that go through conservation land or extensive wetlands/marsh). Unimpaired or reference reaches of the same stream should be included if possible. This is especially important for comparing geomorphic conditions. If reference reaches are not available on the same stream, try to find a comparable stream (i.e. size, topography, soils) in the same geographic regions to use as a reference.

Direct observations of stream conditions are imperative to obtaining an understanding of the stream's ecology, dynamics and condition. Invariably, walking the stream results in interesting or surprisingly useful information including locating old dams or foundations, outfall pipes, and historic trash disposal/fill sites.

In addition to informal observations of stream conditions, field surveys may include:

- Documenting stream habitat and/or corridor conditions.
- Documenting geomorphological conditions.
- Basic monitoring/screening for water quality/biological conditions.

See Appendix 2 for a list of potential stream survey parameters.

The following is a summary of basic aquatic environment screening techniques including the pros and cons for each:

Informal Walk:

- Walk along the stream and make observations.
- Take notes and photos; mark problem sites on a map and/or take GPS coordinates (Fig. 10).
- Locate possible monitoring sites.

Pro: Quick and easy assessment.

Con: Qualitative assessment, non-standardized approach.

Formal or Standardized Survey (e.g. DEP Stream Corridor Survey which can be found in the Stream Survey Manual[10] or Maryland Stream Corridor Assessment Survey[11]):

- Uses standardized forms to document stream habitat conditions, stream corridor conditions and/or geomorphic conditions.
- Assessments are completed on the reach (stream segment) basis.

Pro: Allows comparison between reaches; standardized approach and documentation. Also documents specific potential sources/sites.

Con: Time consuming, might be more information than needed.

Rapid Geomorphic Assessment (RGA) involves the identification of the presence of in-stream features resulting from a variety of geomorphic processes to provide a semi-quantitative assessment of a stream's stability and mode-of-adjustment. The processes are represented by four factors: aggradation (AF), widening (WF), downcutting (DF), and planimetric form adjustment (PF).[12]

Rapid Geomorphic Assessment (RGA):

- Quick assessment of geomorphic conditions.
- This may be done as part of approach above or done separately.

10. Maine DEP webpage http://www.maine.gov/dep/water/monitoring/rivers_and_streams/vrmp/stream-survey-manual/survmanv1_mainbody.pdf
11. Maryland DNR webpage http://dnr.maryland.gov/streams/Publications/SCAProtocols.pdf
12. New York DEC webpage http://www.dec.ny.gov/docs/water_pdf/swdmappendixj.pdf

Pro: Standardized approach for assessment of geomorphic conditions, good first assessment for subsequent higher level geomorphic assessments, can be used to rank reaches based on RGA factors.

Con: Need some experience or expertise to complete.

Figure 11. Conductivity screening.

Conductivity Screening:

- Conductivity is directly related to the quantity of dissolved ions in the water and therefore provides a general measure of water quality (Fig. 11). In urban streams, high chloride from winter salt is often the most significant source contributing to high conductivity. Chloride concentrations in urban streams are most likely to be high during winter and early spring melt events and, if the ground water has been contaminated, during low base flow conditions. Because of this, it is important to do the conductivity screening during low summer base flow, preferably after a week or two of relatively dry weather.

Pro: Quick first screening of water quality conditions, can be used to track sources of pollution-particularly related to high chloride.

Con: Need to have water quality meter that measures specific conductivity.

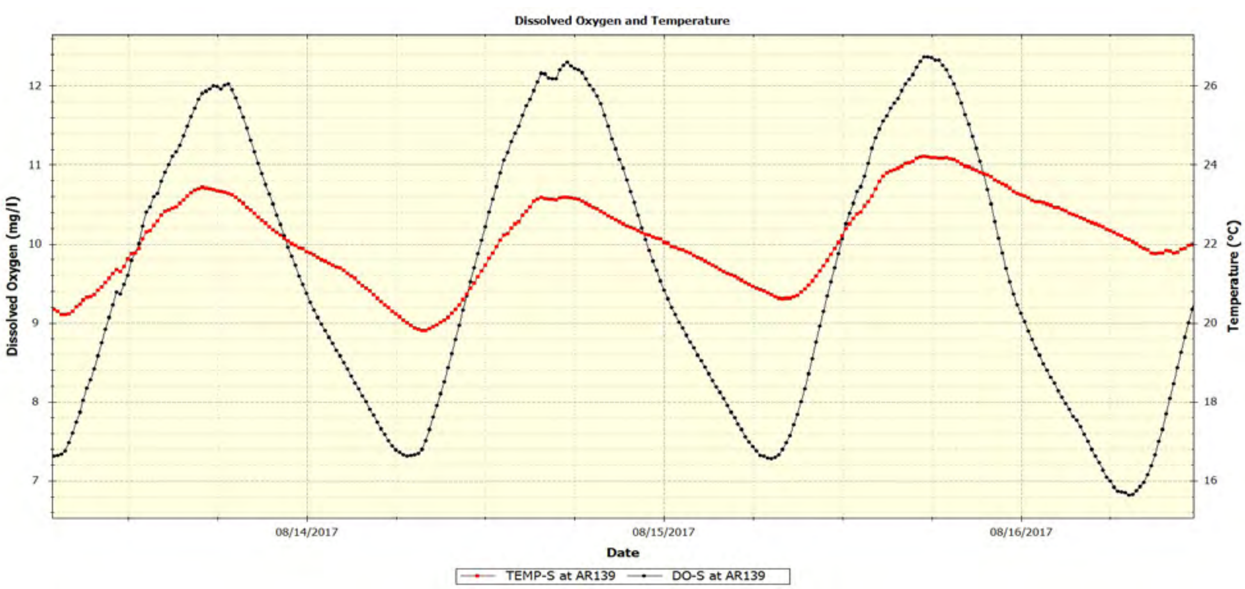


Figure 12. Diurnal DO and temperature fluctuations. DO fluctuations due to large algal biomass.

Dissolved Oxygen (DO) & Temperature Screening:

- Large diurnal fluctuations in DO can be indicative of a large algal biomass which is the result of nutrient enrichment (phosphorus). DO levels fall during respiration and rise during photosynthesis (Fig. 12), so screening must include early morning DO measurements. If DO concentrations are depressed during the day as much as in the early morning, it is likely that an external source of organic matter (e.g. sewage) is contributing to the depression.
- Since temperature sensors are always included with DO sensors it is worth evaluating temperature. High temperatures impact both DO concentrations and habitat suitability for cold water organisms (e.g. trout).

Pro: Easy first screening to determine if nutrient driven algal respiration (large DO swings) is a likely cause prior to incurring expensive lab costs for nutrient analyses. Inexpensive screening to determine if water temperature may be impacting the biological community.

Con: Need to have water quality meter that measures DO/temperature or, if looking at temperature only, a thermometer or meter. Need to measure DO when DO is at the lowest (just before sunrise for streams where DO is driven by photosynthesis/

Proximate Stressor	Data/Evidence	Likely stressor? Yes, no, maybe	More information needed?
Low DO	Field meter data DO<7mg/l	Yes	Yes, continuous DO
Low DO, high diurnal DO swings	Field meter data (DO <7 AM, >12PM)	Maybe	Yes, continuous DO, Stream habitat walk
Low DO, high diurnal DO swings	Periphyton, Field meter data (DO <7 AM, >12PM)	Maybe	Yes, phosphorus sampling
Altered physical habitat: Frequent disturbance of substrate	Bug community composition, mid-channel bars, disconnection from floodplain	Maybe	Yes, stream habitat walk, geomorphic assessment
Altered physical habitat: Loss of sand and gravel habitat	Bug community composition, scouring to marine clay	Maybe	Yes, stream habitat walk
Toxic: Chloride	Baseflow specific conductance >1,500µS	Yes	Yes, continuous conductivity and chloride sampling

Figure 13. Example of preliminary stream stressor table.

respiration or just before midnight when DO is driven by water temperature) which isn't when most DO readings are collected, especially if using volunteers.

Output: Informal walk maps/notes; completed Stream Walk forms and summary report; completed rapid geomorphic assessment forms and summary; initial water quality results.

3.5 Review Existing and Initial Screening Data

After completing the desktop analysis and initial field screening, the next step is to review this information and develop the initial stressor results. Use this information to complete a summary or table that includes the following: Proximate stressor (Appendix 1), data/evidence, yes/no/maybe a stressor, more information that is needed and potential sources of stressors identified. If possible, rank the stressors in order of importance. Other experts may be consulted to review part or all of the data. DEP staff can help with interpretation of water quality data.

Output: Initial summary or Stream Stressor Table (Fig. 13).

3.6 Sampling Plan

Review the information in the Stream Stressor Summary Table and identify where additional information and data are needed. Consider what specific questions remain to be answered so you can make sure you design your data collection and analysis in a way that will provide the answers you need. To collect the additional data there are two options. The first is to develop a relatively simple sampling plan. This is appropriate if the data is to be used solely for diagnostic purposes – figuring out what the proximate stressors are. If the data are intended to also be used to determine attainment of water quality standards or for some other regulatory purpose, the second, more formal option of developing a Quality Assurance Project Plan (QAPP) and an associated Sample and Analysis Plan (SAP) may be required. If this is the situation, rather than developing a separate QAPP for your project, it may be possible to work under an existing QAPP. Regardless of whether you do a simple plan, work under an existing QAPP, or develop your own QAPP, it is essential that you use the most appropriate and current methods for collecting and analyzing your data, and that this information be included in your sampling plan. Consult with DEP, Bureau of Water Quality, Division of Environmental Assessment, Watershed Management Unit staff to be sure your methods meet this standard.

3.6.1 Simple Sampling Plan

Based on what is known about the stressors and monitoring gaps, develop a sampling plan for additional monitoring. Consider consulting with DEP, Bureau of Water Quality, Division of Environmental Assessment, Watershed Management Unit staff during plan development. The sampling plan should include the following:

- Design of the sampling network (i.e. sampling locations). How many stations are needed to represent stream conditions? Will existing stations be used or are new stations needed?
- Specific water quality, hydrology, habitat and biomonitoring parameters to be sampled or monitored.
- Sampling frequencies including sampling season(s), number of samples and monitoring period.
- Sampling methods: What kind of equipment is needed? Does equipment need to be purchased or can it be borrowed? Will samples need to be analyzed at a lab? If so, what analytical procedures, detection limits, reporting limits and holding times will be required?
- Other considerations: Who will do the sampling, specific training needs, assistance needed from DEP or consultant(s)? Is there a budget for sampling? How will data be managed?

Output: Sampling plan for obtaining additional data.

3.7 Collect Additional Data and Final Evaluation

The final steps are to review and evaluate the data, and then finalize the proximate stressor table (Section 3.5):

- Do an initial review of the data including quality assurance/quality control review of the data.
- Enter the data into electronic format (spreadsheet or database).
- Perform some type of data compilation and/or analysis of the data. This might include summaries, graphs and/or statistical analyses.
- Evaluate the data in light of the questions you were trying to answer, perhaps with review from other experts.
- Update the stressor table.

Output: Final proximate stressor(s) summary table.

4.0 Identifying Causal Pathways

Once you have identified the proximate stressors that are most likely contributing the biological impairment, the next step toward defining an effective strategy for stream restoration is to identify the causal pathway(s) that, for the stream and watershed in question, are potentially resulting in each of the stressors.

The table in Appendix 1 (page 39), which describes many of the causal pathways that may be operative in impaired or threatened streams in Maine, can be helpful. An excerpt from the table is presented here, showing some of the causal pathways that can lead to depressed dissolved oxygen levels. To use the table, first locate the section headed by the identified proximate stressor (circled in red). Next look down the far-right side locating the specific characteristics that match the proximate stressor (yellow arrow with blue outline). Next work backwards to the left following the chain back to the causal agent/ source (green arrow with yellow outline).

Example 1. Diurnal dissolved oxygen depression

For example, if low DO has been identified at the proximate stressor: (1) locate "DO Related" subsection in the table (page 43), (2) locate the far right box showing low DO and (3) Moving to the left consider the possible activities or conditions driving the low DO, each of which have an identifying label. In the example shown here (Fig. 14), the proximate stressor is depressed DO levels during the early morning hours followed by increasing DO as the day progresses. The direct cause of this type of diurnal oxygen depression is respiration of plants, usually periphytic algae, during the night when there is no photosynthetic production of oxygen to compensate for the algae's respiration. Moving left in the table one sees that the conditions that are most likely to contribute to this type of oxygen depression are DO7, a lack of canopy to shade the stream and limit the exposure of stream substrates to sunlight; and DO8, agricultural or urban runoff contributing nutrients, particularly phosphorus, to the system.

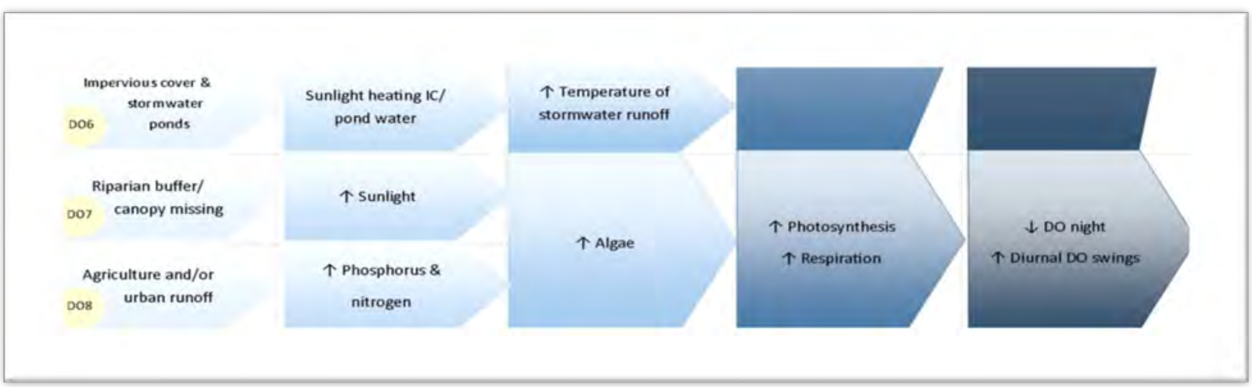


Figure 14. Identifying causal pathway for low DO due to lack of canopy.

The next step is to determine if either of these causal pathways is operative in the stream or its watershed. In this example, it is likely that information already collected will indicate whether or not the stream has good riparian cover and/or significant agricultural land or urban land use. What may not be known is whether there is excessive growth of periphytic algae on substrates upstream of the impairment. It's a good idea to confirm all the steps in the causal pathway, so it would be worthwhile to walk the stream during a week when the stream is experiencing early morning DO depression to assess the level of upstream algal production.

Example 2. Altered habitat, excessive sediment deposition

The causal pathways presented on page 45 of Appendix 1 and shown below offer a more complex scenario to consider (Fig. 15). For this example, let's say that the proximate stressor is altered habitat due to excessive sediment deposition in the stream bed. There are a number of pathways that can lead to this stressor. Since deposition of sediment naturally occurs in slower portions of a stream channel, it is important to first make sure that the observed deposition is either greater than or different from what would naturally be expected. For instance, the presence of point bars on the inside of a meander is an expected condition in stable stream chan-

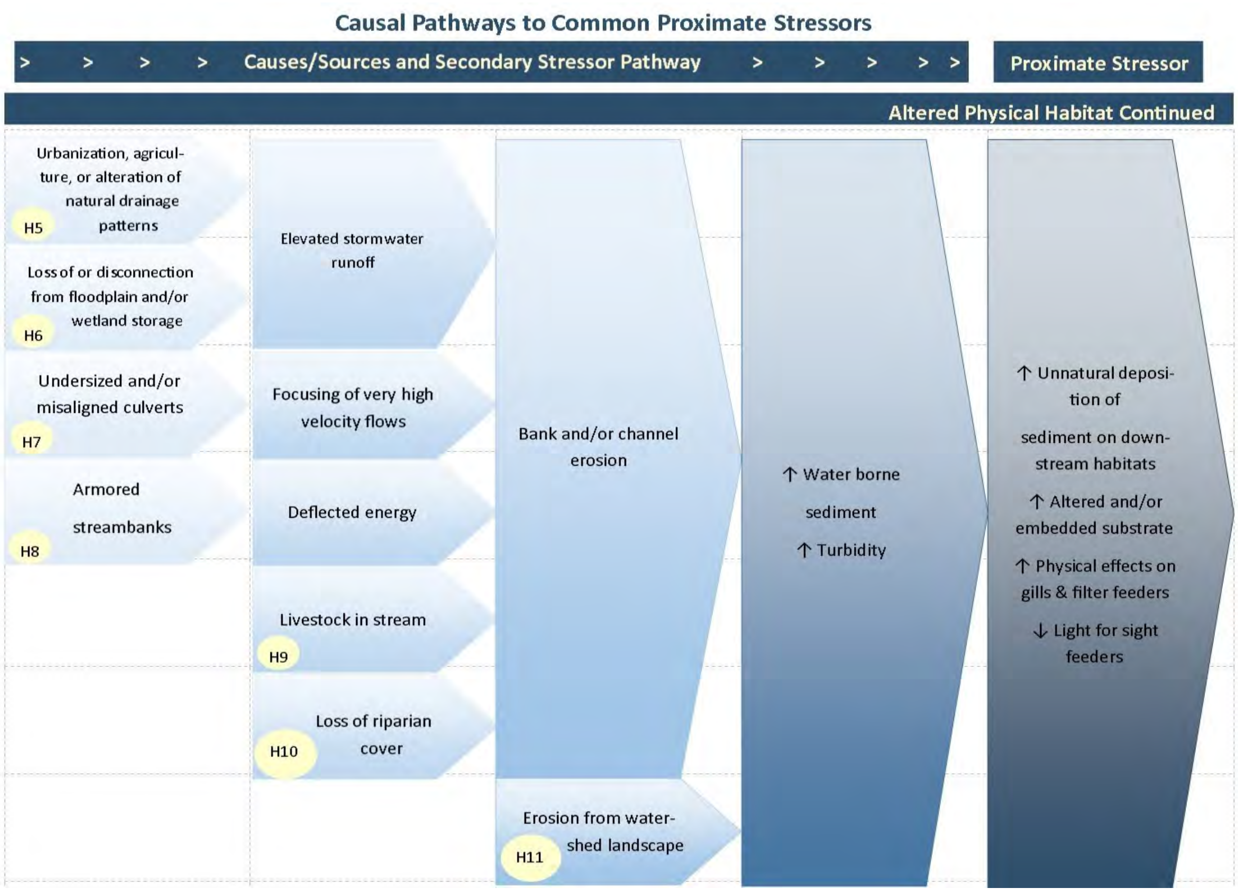


Figure 15. Identifying possible causal pathways for excessive sediment deposition.

nels, but the presence of lateral bars, mid-channel bars or embedded riffles suggest excessive sedimentation.

> **Lateral bars:** are attached to a bank and are usually located on straighter segments of meandering streams or on stream types with very little sinuosity. Side bars are either devoid of vegetation or have only sparse non-woody vegetation.
>
> **Mid-channel bars:** are not attached to the banks and are generally found in straight reaches They form as a result of the flow divergence that occurs around obstructions such as large boulders or rock outcrops or due to an overwidening of the channel. [12]

Note that all the possible causal pathways of this particular stressor require waterborne sediment in the stream. While the most likely immediate cause of unnaturally high amounts of waterborne sediment is upstream erosion of either the stream's banks or its channel, there are instances when heavy erosion of the watershed's landscape (e.g. severe ditch or gulley erosion, erosion from tilled fields) can cause very high levels of waterborne sediment, especially during exceptionally large, intense runoff events. A walk up the stream from the areas of sediment deposition will indicate whether there is significant bank or channel erosion, and may also give some clues as to why the bank/channel is eroding (e.g. undersized or misaligned culverts, livestock in the stream corridor, armored streambanks, or destabilized banks due to harvesting of riparian vegetation). If the watershed is urbanized or highly agricultural, elevated runoff is likely a contributing factor. Alteration of natural drainage patterns, particularly interception and concentration of intermittent channels in road infrastructure, can lead to severe erosion of downstream channels and deposition of sediment in the stream bed. In many cases of severe sediment deposition, several of these causal pathways will be contributing to the problem.

Example 3. Chloride Toxicity

For a third example, consider the causal pathways on page 48 of Appendix 1 that deal with chloride toxicity. Chronic chloride toxicity is a very common, and often dominant stressor in headwater urban streams, particularly streams with commercial, office, or institutional land uses in their watersheds. Chronic toxicity of any kind requires the affected organisms to be exposed to the toxic agent for many days, usually a week or more. This kind of toxicity, which, occurs at much lower concentrations than acute toxicity, usually requires a continuous discharge of the toxic agent that might occur with a wastewater discharge or a discharge to the stream of contaminated groundwater.

In the instance of contaminated groundwater, deep groundwater is always discharging to the stream, but when there is also stormwater runoff or shallow groundwater flow after a storm, any contaminants in the deep groundwater discharge are diluted by the stormwater. Unlike

12. http://www.uvm.edu/~wbowden/Teaching/Stream_Geomorph_Assess/Resources/Public/SGAT05/21_Phase2_Handbook_(April05)/17%20-%20Phase%202%20Step%205.pdf

pollutants that are delivered to the stream via stormwater, the concentrations of any groundwater contaminant in the stream will be lowest during and shortly after storm events, and will rise as flow decreases and groundwater becomes the dominant component of the stream's baseflow (Fig. 16).

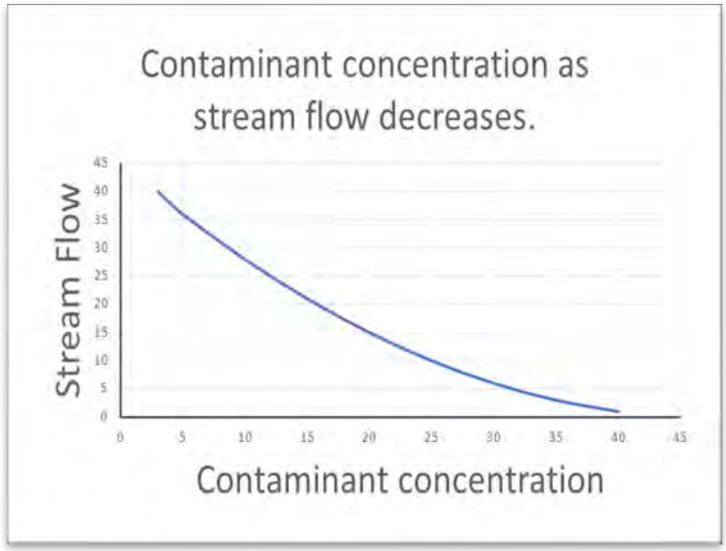


Figure 16. A hypothetical graph illustrating how the concentrations of groundwater contaminants in the stream will be lowest during and shortly after storm events, and will increase as flow decreases.

Many of the pollutants of concern – nutrients (except for nitrate), metals and hydrocarbons – do not move easily through the soil and are therefore rarely a significant contaminant in groundwater or in stream baseflow unless they are being recycled from the stream sediments. Chloride is the major exception to this rule. Chloride (Cl^{-1}) dissolves readily in water and, unlike most other anions and cations, it does not react with the minerals in the soil or adsorb to the surface of soil particles. It moves with the groundwater, and is still in the groundwater when it surfaces as a spring or emerges as stream flow.

Because of its extreme solubility, chloride is the anion that is most likely to stay in solution and therefore, in settings where it is abundant, its concentration correlates very strongly with measures of specific conductance. Streams with baseflow chloride contamination typically

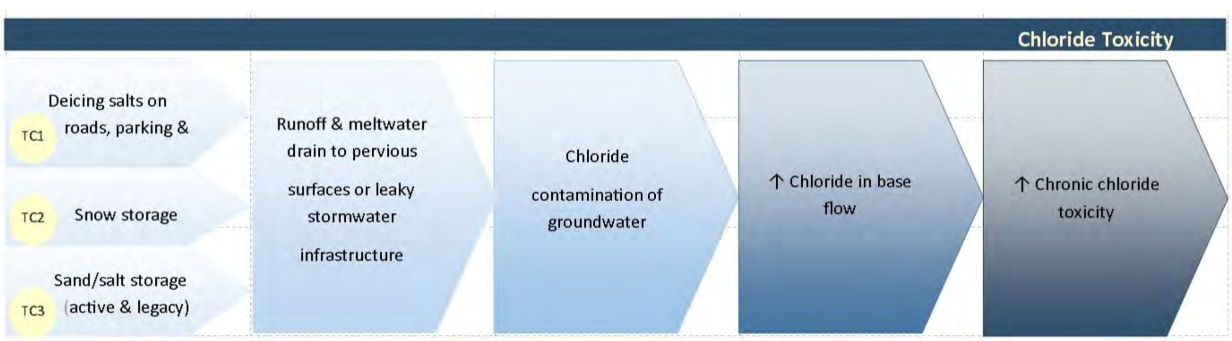


Figure 17. Causal pathway for chronic chloride toxicity.

have their lowest conductance readings during and shortly after storm events with conductance increasing as flow drops after the storm and continuing to increase until the next storm comes along. The CCC for chloride is 230 mg/l, which typically correlates with a specific conductance of 900 to 1000 µs. There are exceptions, such as parts of Aroostook County, where baseflow calcite concentrations can contribute significantly to specific conductance levels (e.g. 900 µS/cm may only be 130 mg/l chloride). For most of the state, if specific conductance stays at or above 900 to 1000 µS/cm for a week or more there will likely be a chronic effect on many of the salt intolerant freshwater taxa living in the stream. If this signature is present in the stream, then it is a good idea to confirm that chloride is an issue by taking a few chloride samples, but in general, specific conductance is a strong screening tool for chloride contamination.

As you can see in the causal pathway table and Figure 17, baseflow chloride toxicity requires chloride contaminated groundwater. This in turn requires: (1) the presence of land uses in the watershed that apply significant amounts of deicing salts and (2) the opportunity for at least some of the runoff, particularly the meltwater, from the surfaces to which the salt is applied or on which it is stored to infiltrate into the ground. If both of these conditions exist, and if conductivity screening indicates extended periods of specific conductance ≥ 900 µS/cm, it is likely that chronic chloride toxicity can be confirmed as a principle stressor, especially if the composition of the macroinvertebrate community suggests a toxic effect.

5.0 Next Steps

The information derived from the stressor identification process is essential to the development of an effective strategy to address impairments of, or threats to, a stream's biological community. Specifically, the information will be used to: (1) identify and prioritize specific sources/causes in the watershed, or the reach subwatershed in question, and (2) identify the BMPs that are appropriate for addressing the stressors of concern.

5.1 Identifying and prioritizing specific sources/causes in the watershed

The causal pathways that have been confirmed will point to one or more types of land use, activities, or conditions that are the cause or source of the stressors of concern in the stream. These could include such things as untreated or detained stormwater runoff from impervious surfaces or agricultural activities, undersized or misaligned culverts, loss of riparian cover and/or floodplain, channelization, or infiltration of salt laden runoff to name a few. You may notice that some of these causes contribute to more than one of the stressors of concern that you have identified.

In the process of confirming the causal pathways operating in the watershed you may have identified a single, specific cause for a stressor to a reach of your stream – an undersized and misaligned culvert for example – in which case it is obvious that this situation must be prioritized for action. On the other hand, there may be many instances of some causes/sources in the watershed of the reach in question – untreated stormwater from impervious surfaces for example – and it is probably not feasible to address each one of these instances. In this case you must identify the subset of specific sources that are likely ***most*** responsible for the stressor in question. For example, if the quality of stormwater was of concern, as it would be if nutrients or hydrocarbons were an issue, the catch basins draining a particularly busy intersection or the runoff from a high turnover convenience store/gas station might be given a much higher priority than a church parking lot that was only heavily used once a week. If, instead, the volume of stormwater reaching the stream was a concern, as it would be in many instances of altered habitat, it might be more important to provide channel protection storage for the runoff from a large church parking lot. This prioritization process will provide the basis for the list of action items in a plan to restore or protect the stream.

Sometimes it is not feasible to address enough of the initial causes of a stressor to eliminate the impairment. For instance, you might not be able to retrofit enough channel protection storage or restore enough floodplain access to reduce storm event stream flows to the point where damage to the stream's habitat can be sufficiently reduced. In this case it may be necessary to mitigate the effects of the elevated stormwater flow by prioritizing in-stream practices that improve the stream's resiliency and help it recover valuable habitat.

5.2 Selection of BMPs to Address Stressors Associated with Aquatic Life Impairments

Prior to selecting BMPs, a stressor identification process should be conducted to ensure that actions address the likely or actual causes of the impairment. Note that all BMPs are not equal. Most are good at addressing some pollutants/issues but not others. When selecting BMPs, it is important to choose ones that (a) address the stressor(s) of concern both in your stream and in downstream waters and (b) do not exacerbate other stressors.

Example 1. Many stormwater management BMPs (bioretention, tree box filters, vegetated buffers, wet ponds) provide good removal for phosphorus, hydrocarbons and metals as well as storage or infiltration for mitigation of high flows. Unless specifically designed to do so, few stormwater BMPs do a good job of removing nitrate and none of them remove chloride. If nitrate is a concern, which it may be if your stream drains to a coastal wetland or embayment, it is important to consider BMPs such as gravel wetlands or modified bioretention with an anaerobic cell above the underdrain rather than classic filter or pond designs.

Example 2. BMPs that provide intentional or incidental infiltration (LID practices such as unlined bioretention and ponds, natural vegetated buffers, swales as opposed to pipes) are great for removing most pollutants, for reducing stormwater runoff and for providing groundwater recharge that improves the volume of base flow in the stream. However, if baseflow chloride toxicity is a significant or potential stressor in your stream, infiltration of meltwater from surfaces where salt is applied or snow is stored could do much more damage than good to the freshwater stream biota. In this case, which unfortunately is fairly common in small urban streams in Maine, it is important to implement BMPs that (1) are lined with an impermeable membrane or otherwise secured to prevent infiltration, including secure pipe systems to deliver the high chloride meltwater directly to the stream during melt events, (2) reduce the amount of salt applied and/or the area to which it is applied and/or (3) infiltrate, to the greatest extent possible, stormwater from surfaces, such as roof, that are not treated with salt in order to dilute the contaminated groundwater with low chloride water.

5.2.1 Chloride - Structural and Non-Structural BMPs for Watersheds with Chloride as Stressor

- Follow or require the use of BMPs for snow and ice control product selection, application processes, application equipment, loading and washing, per the *Maine Environmental Best Management Practices Manual for Snow and Ice Control* (2015). Cover sand/salt piles and manage loading area to reduce runoff from becoming contaminated with salt.
- Develop, or require the development of a salt management plan, to ensure BMPs are used, and only areas that truly need to be salted are. Consider

whether all the impervious area needs to be plowed and salted, or if some of the area could be out of service for the winter. For instance, after the busy holiday season, consider only plowing the area of a commercial parking lot that is actually used during that time period.

- For developments currently being planned, consider reducing the number of parking spaces and/or reducing road widths. If there are municipal requirements, consider revising those requirements to allow for less parking spaces or smaller road widths in certain areas.
- Reduce infiltration of salty water in vulnerable areas. While stormwater BMPs that infiltrate, or simply allow stormwater to infiltrate, are recommended for treating nutrients, metals, and other pollutants, when chloride impact to a small stream is the biggest current or future concern, infiltration is discouraged.
- Don't infiltrate salty water if possible. For instance, don't plow onto pervious areas, and capture salty runoff so it goes to the stormwater system. Since stormwater systems can often have leaks which would allow salty water to exfiltrate into the groundwater, ensure stormwater systems in vulnerable areas are secure. Stormwater ponds should be lined so the salty water doesn't infiltrate.
- Infiltrate clean, non-salty water (e.g. roof runoff) since infiltration is still a good practice if the water is not salty. The non-salty water will help flush the groundwater, and any contaminated water with it. It also will not be adding to the volume of salt-laden water that needs to be managed.
- For new development being planned, don't allow or encourage (through infiltration BMPs) future infiltration of areas likely to be salted.
- Install solar parking canopies - The canopy provides protection from the elements (and therefore reduction of salt use) and shaded parking in summer, along with the benefit of producing energy.
- Install heated sidewalks or roads to reduce the need for shoveling and salt.

6.0 Case Studies

6.1 Case Study I. Trout Brook

Background

Trout Brook is a 2.5 mile stream located in Cape Elizabeth and South Portland. The stream's 2.3 square mile watershed includes both high density residential areas in the lower and middle watershed as well as rural residential and a few agricultural properties in the upper watershed. Although recognized for its brook trout fishery, Trout Brook does not meet Class C standards for aquatic life and habitat (Fig. 18).

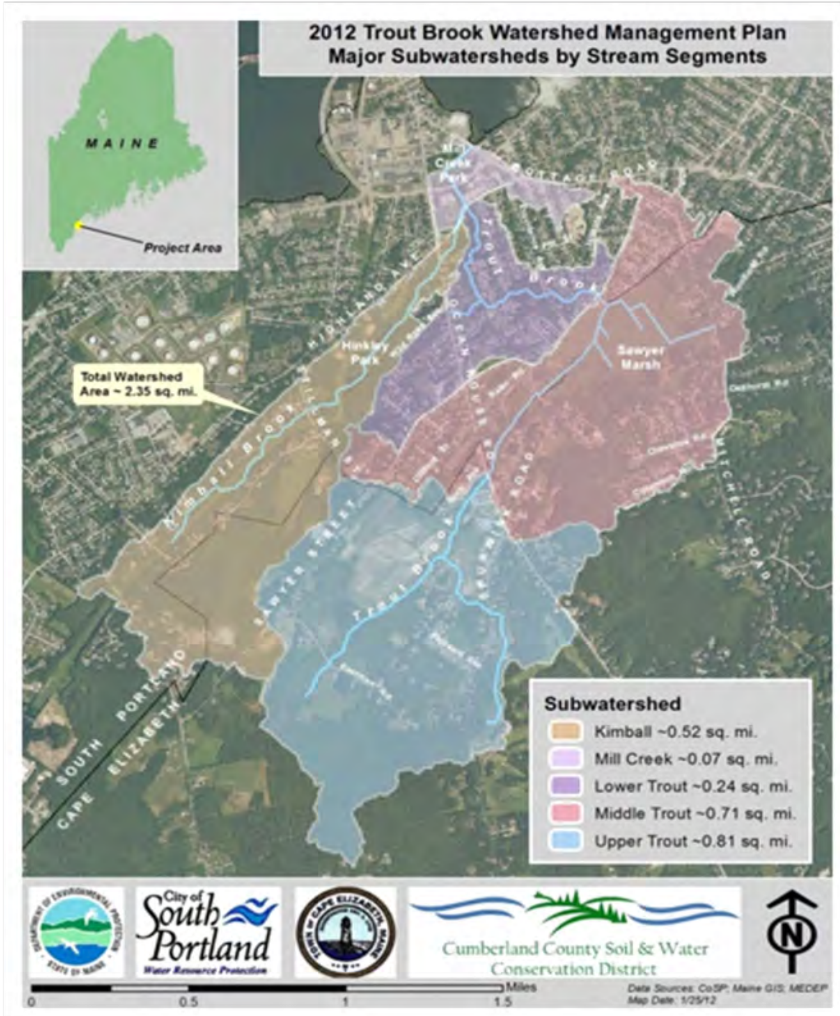


Figure 18. Trout Brook watershed.

In 2010, the City of South Portland received a US EPA Clean Water Act Section 604(b) grant from Maine DEP to develop a watershed-based plan. The project was guided by a steering committee, which included municipal staff, Maine DEP, Cumberland County SWCD and interested citizens. During the first field seasons of the project, staff reviewed existing data, collected additional water quality data, and mapped the watershed catchments. Project staff and several DEP biologists attended a Stressor Identification meeting to examine available information. Due to distinct differences in land use and water quality, the stream and watershed was divided into four areas. The following section describes the stressor identification process for two of these segments, Upper Trout Brook and Lower Trout Brook.

Stressor Identification Process

Upper Trout Brook - Although biomonitoring had not been conducted along Upper Trout Brook at the time, water quality data were available at the downstream end of this stream segment. The project team found that stream temperature, specific conductance and chloride were quite low. Although information on toxics was not available, it was ruled out as a stressor due to the rural and forested watershed land uses. However, diurnal and continuous DO data revealed that early morning DO fell below Class B and C standards and there were large diurnal swings (> 3 mg/L).

Thus, the team identified low dissolved oxygen as the primary stressor for aquatic life. Further, the high diurnal DO swings indicated that nutrients were the likely cause of the depressed DO. Nutrients in the stream feed plants and algae in the water, which increase oxygen in the stream during daytime photosynthesis. Overnight plant respiration uses up the oxygen in the stream, creating low oxygen conditions in the early morning. CCSWCD staff tested and confirmed this hypothesis by conducting storm sampling for phosphorus. Data indicated that there was indeed high phosphorus loading upstream of the monitoring station. Since several locations were sampled along the stream, this work also helped bracket the primary source as the adjacent horse farm rather than the other upstream farms. The causal pathway is DO8 (p. 43).

Lower Trout Brook – Five years of biomonitoring data were available for this part of the stream. Biomonitoring staff indicated that there were many tolerant organisms, including several that live buried in the streambed. This indicated that a pesticide or other toxic stressor that would accumulate in stream sediments was unlikely. As with Upper Trout Brook, water quality data revealed cold stream temperatures. Dissolved oxygen, however, sometimes fell below Class C standards (<5ppm or 60% of saturation). Since the diurnal swing was muted, the project team determined that nutrients were not likely the stressor and that low DO was likely caused by abundant springs and possible habitat alterations (i.e., over-widened and small cobble dams) along this part of the stream. Specific conductance measurements in this reach, however, were elevated during summer baseflow to values typically correlating with toxic levels of chloride (above 1000 us/cm) for extended periods.

Chloride levels were analyzed in several water samples in the stream and two adjacent springs to test the hypothesis that chloride from the groundwater was a priority stressor. The values fit the correlation established for Long Creek, and confirmed that the high Specific conductance (SpC) values correlated with chronic toxicity levels for chloride. To follow up on the stressor ID process, the project team discussed potential chloride sources and hypothesized that it could be groundwater contamination from the municipal sand/salt pile, which wasn't located on pavement. DEP staff then conducted a terrain conductivity study, which tracked a plume of elevated underground conductance from the hotspot to the stream. The causal pathway is TC3 (p. 48).

6.2 Case Study 2. Topsham Fair Mall Stream

Background

The Topsham Fair Mall Stream is an urban impaired stream which drains 320 acres in the Topsham Fair Mall area. The 1.4-mile-long stream flows through an area of high density commercial development and a section of Route 295, with small areas of residential development at the upper and lower edges of the watershed. The headwaters originate in the northeastern border of the watershed near Route 196 (Lewiston Road), and the stream flows southwest to its confluence with the Androscoggin River (Fig. 19).

This Class B stream was listed as impaired in 2008 due to non-attainment of aquatic life criteria and habitat assessment. The stream was included in the Impervious Cover TMDL (2011). Undeveloped portions of the watershed are slated for growth in Topsham's Comprehensive Plan. In 2012, the Town of Topsham received a US EPA 604(b) grant from Maine DEP to develop a watershed-based plan. The plan was developed by the Town of Topsham, local consultants, and an advisory committee of watershed stakeholders including local business owners and managers, engineers, environmental professionals, and residents.

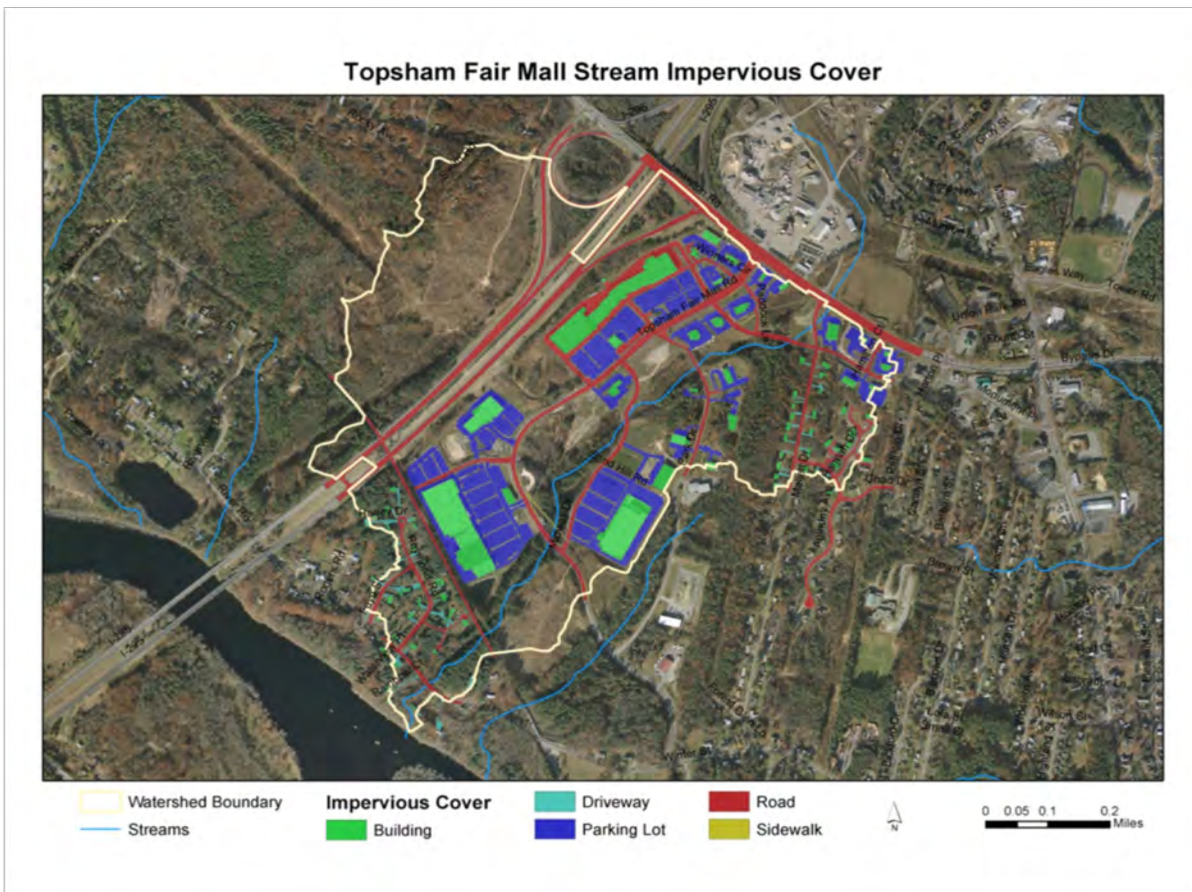


Figure 19. Topsham Fair Mall Stream watershed.

Stressor Identification Process

Background information was compiled, and several desktop analyses were conducted. The watershed and catchments were delineated in the field, and an impervious cover analysis was conducted (Fig. 19). The watershed is 79% developed, and 30% of the land area is impervious cover. An analysis of the soil maps indicated 91% of the watershed is Adams loamy sand and Hollis fine sandy loam, both of which are high permeability soils.

A review of existing data was conducted, including DEP Biomonitoring macroinvertebrate, algae, and wetland data, and water quality data available through DEP's EGAD. Biomonitoring results at the time showed an overall decrease of generic diversity since 2002. Fed mostly by groundwater, the stream had good, cold water temperatures year-round. Overall the dissolved oxygen levels were good and there did not appear to be large diurnal swings. However, specific con-

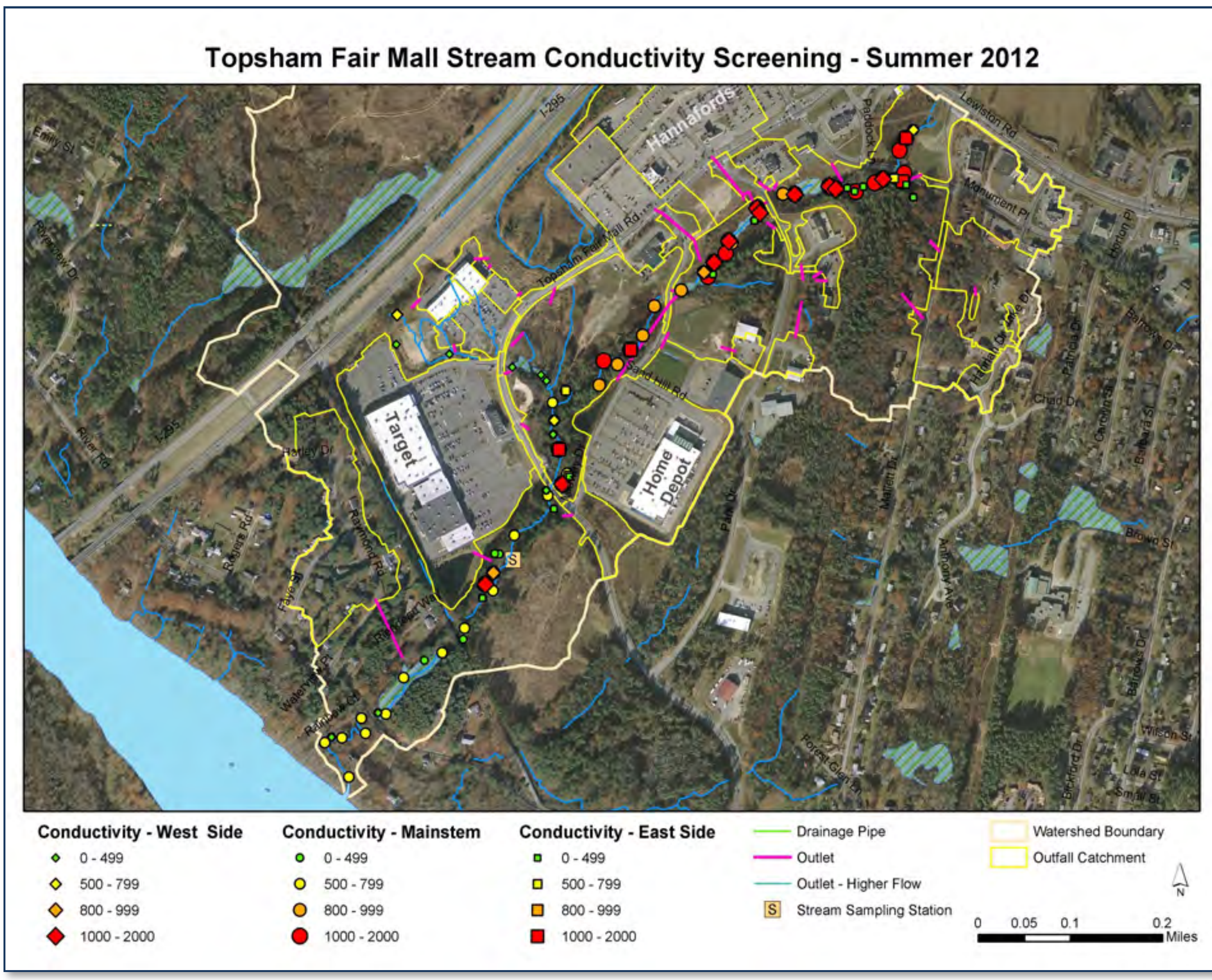


Figure 20. Topsham Fair Mall Stream conductivity screening.

ductance levels were high (e.g. 706 uS/cm on 7/16/08), even for an urban stream. There were only a couple years of data, so a monitoring plan was developed to deploy continuous monitors for dissolved oxygen, temperature, and specific conductance. A stream habitat and geomorphological assessment were also planned.

To investigate the extent of the high conductivity, DEP conducted a conductivity screening (Fig. 20) by walking the stream during baseflow and measuring specific conductance every 50 feet or so, and at any tributary or groundwater seep. There were high conductivity readings in the upper half of the stream and in seeps from the commercially developed area to the west of the stream. Chloride grab samples were taken at several locations on several dates. Chloride and specific conductance were strongly correlated, similar to those of Long Creek and Trout Brook in South Portland.

The continuous in-stream monitoring data indicated that chloride was a pollutant of concern in Topsham Fair Mall Stream throughout the year. Chloride concentrations in the middle and upper portion of the stream were constantly above the chronic pollution threshold of 230 mg/L during summer baseflow periods, and nearly so in winter. In the winter, they were over the acute threshold of 860 mg/L about 2% of the time, coinciding with salt application during storm periods. Chloride concentrations were much lower in the downstream reaches, where they met the chronic pollution threshold during summer baseflow, and in winter only exceeded chronic thresholds one third of the time, and acute standards about 1% of the time. DEP conducted a terrain conductivity study in the area of concern to help further define the location of the groundwater contamination.

Figure 21. Topsham Fair Mall road crossing.

Project partners (FB Environmental, Field Geology Services and DEP) assessed the stream corridor itself through a Rapid Habitat Assessment and a reconnaissance-level fluvial geomorphic assessment. The road crossings were found to have a major impact on the stream by constricting the stream channel to a narrow culvert and greatly altering flood flows and overall sediment transport dynamics, creating poor aquatic habitat upstream and downstream of each crossing (Fig. 21). The assessments also found the stream reaches were dominated by sand that was in continual movement, evidenced by high levels of embeddedness (50-100%). An unstable, highly embedded stream bed is considered poor habitat for fish and aquatic life. The degradation of natural streamside vegetation and undercut banks was found to be common, as were discharging pipes and ditches.

Macroinvertebrate sampling in 2018 found that Total Mean Abundance and Generic Richness were adequate but there were very few sensitive organisms present even though the temperature of the water was cold. Specific conductance was very high (1081 uS/cm) and indicated probable salt contamination in this small ground water-fed waterbody. In addition, the stream substrate was comprised of 80% sand and the remainder detritus, which is very unstable during storm surges. Biomonitoring staff believe these two stressors probably play a large role in the fluctuating aquatic community.

This case study illustrates causal pathways H5, H7 and TC1, TC2 (pages 45 & 48).

Lessons Learned

If the stressors were assumed to be typical general stormwater runoff due to the high impervious cover in the area, the watershed based plan likely would have recommended infiltration BMPs in all areas. Use of typical infiltration BMPs for salty runoff could result in increasing the contamination of the groundwater with chloride, further impairing the stream rather than improving it. Macroinvertebrate sampling and analysis in subsequent years helped to confirm the proximate stressors as not only chloride toxicity, but altered habitat as well.

Appendix 1 - Causal Pathways to Common Proximate Stressors

Using the data and information gathered from *Section 3: Steps to identifying the proximate stressor to biological impairment,* work to identify the causal pathway using the table on the following pages.

To use the table first locate the section headed by the identified proximate stressor (circled in red below). Next look down the far right side locating the specific characteristics that match the proximate stressor (yellow arrow with blue outline). Next work backwards to the left following the chain back to the causal agent/source (green arrow with yellow outline).

For example, if low DO has been identified as the proximate stressor (1) locate "Dissolved Oxygen Related" subsection in the table (Fig. 22), (2) locate the far right box showing low DO, (3) moving to the left consider the possible activities driving the low DO that were identified through the investigative process outlined in Section 3. In this example assume elevated temperature is the driving force and that the temperature was elevated as a result of increased detention time and sunlight due to an impoundment, maybe one or more undersized stream crossings. The causal agent is the impounded water behind the stream crossing.

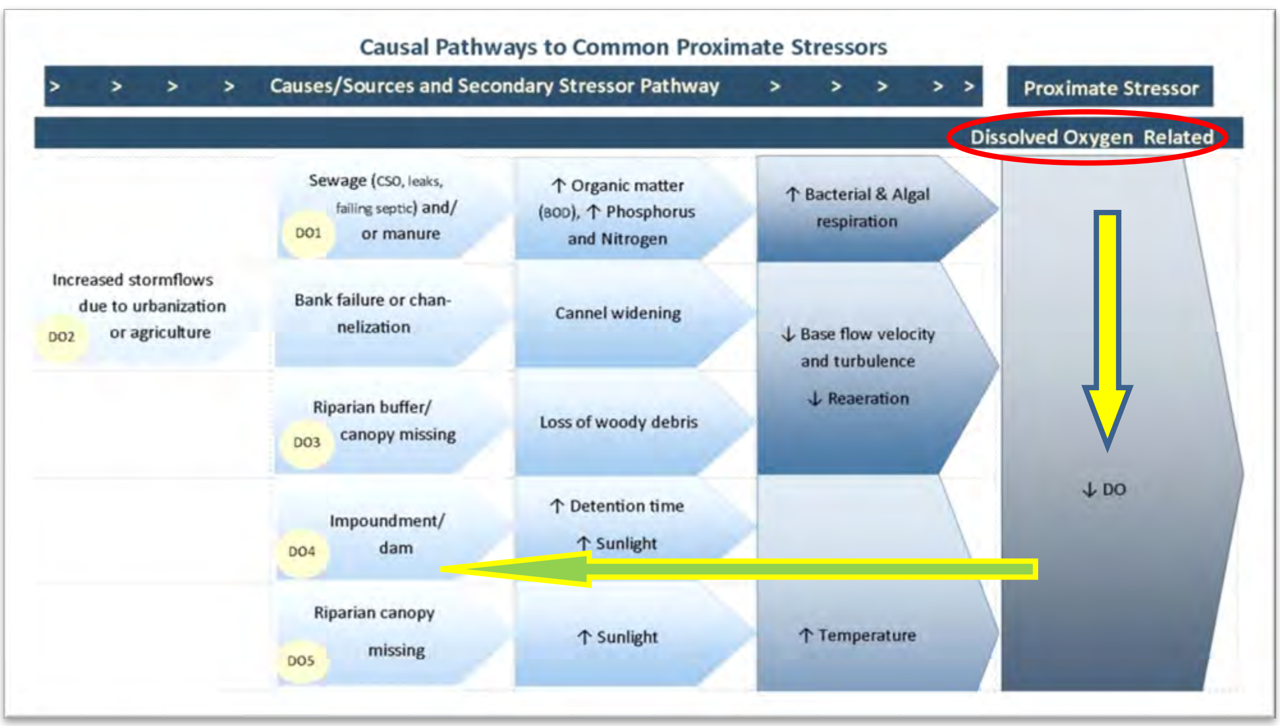


Figure 22. Identifying the causal pathway.

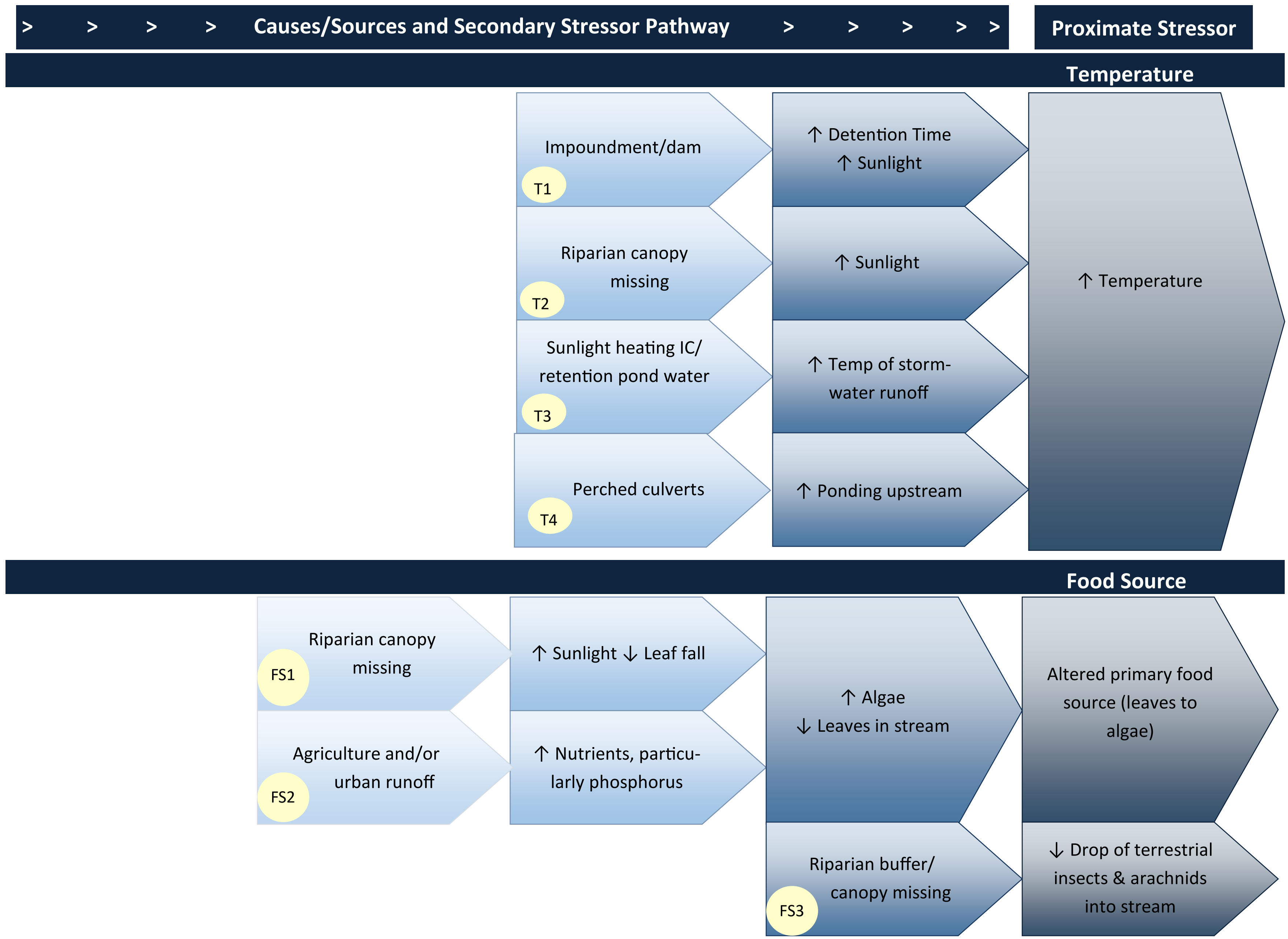
To facilitate referencing specific causal pathways, each pathway has been labeled for each proximate stressor. The reference for the example above is DO4.

Proximate stressor key:

DO = DO Related	T = Temperature
FS = Food Source	TC = Toxicity Chloride
H = Altered Physical Habitat	TO = Toxicity Other
LR = Low Recruitment Potential	V = Velocity

Beaver Brook, T13 R5, Maine.

Appendix 1. Causal Pathways to Common Proximate Stressors



Causal Pathways to Common Proximate Stressors

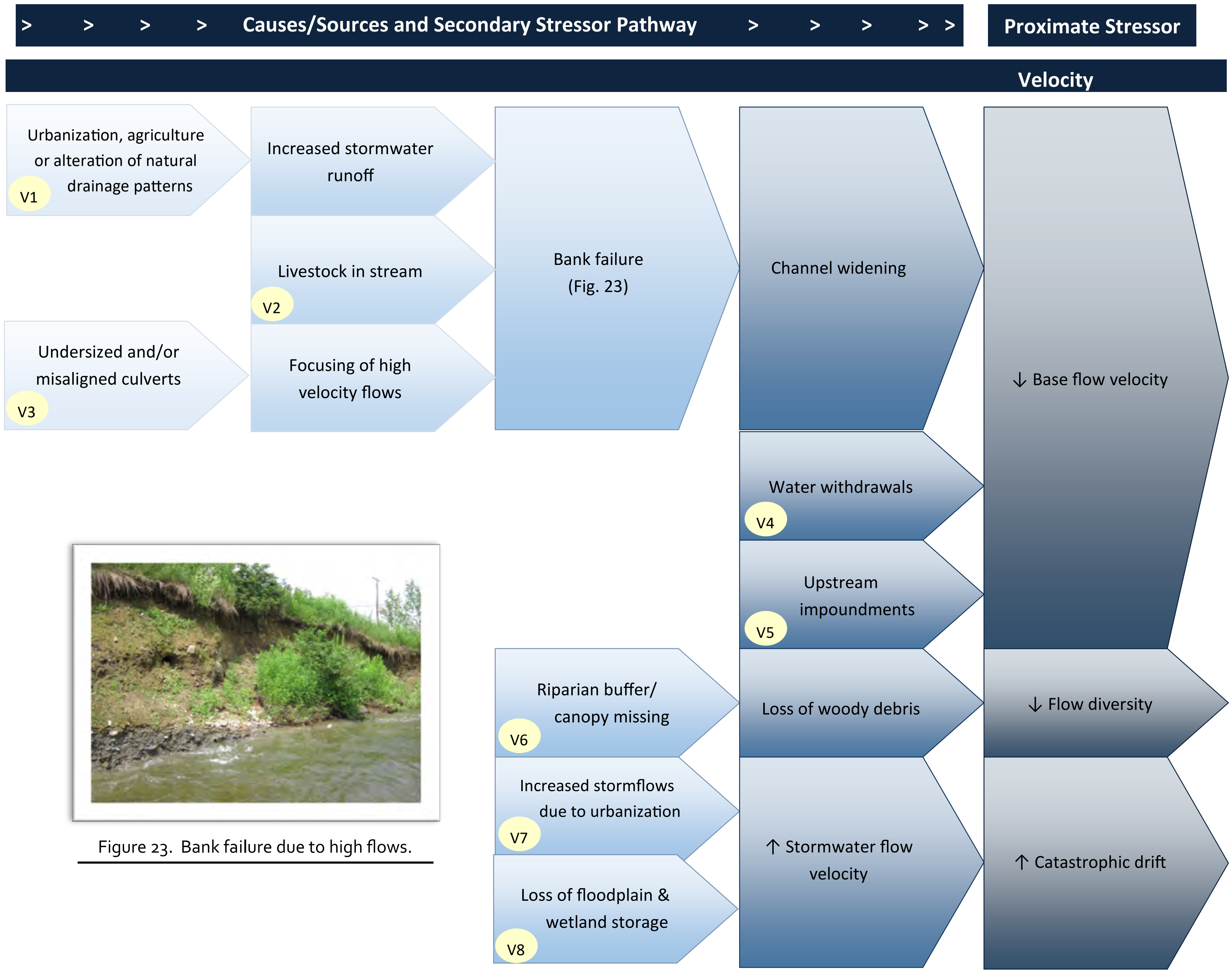
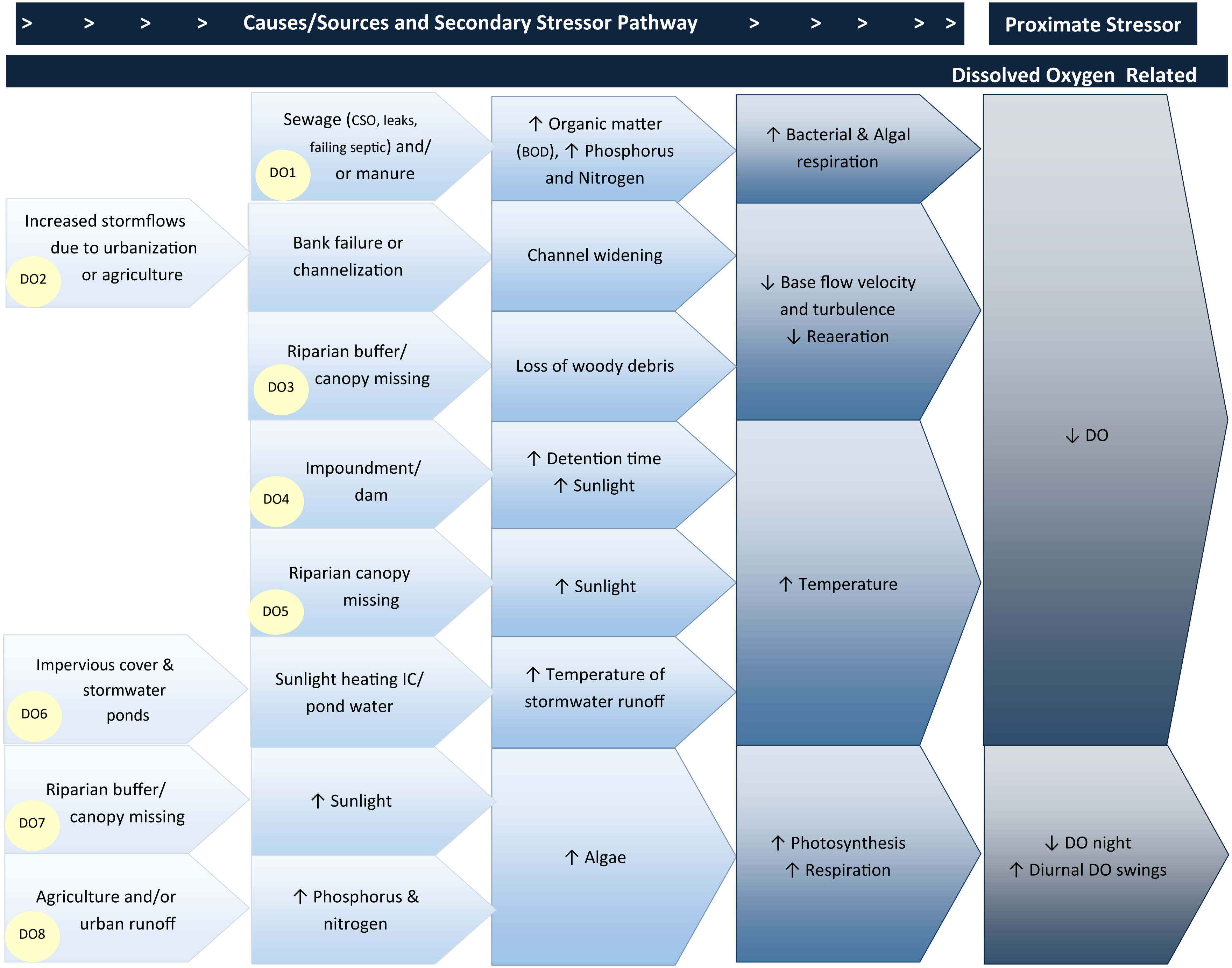
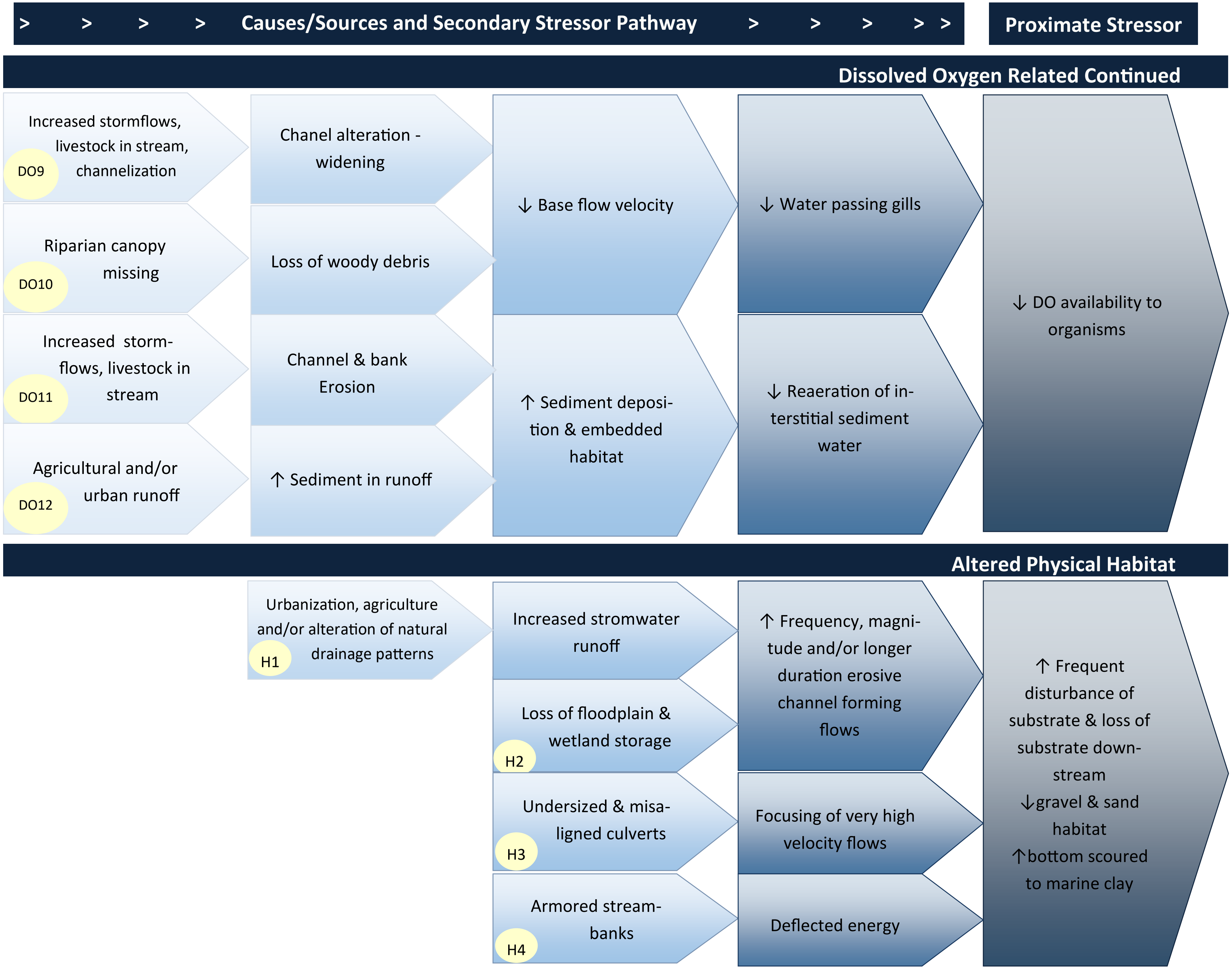


Figure 23. Bank failure due to high flows.

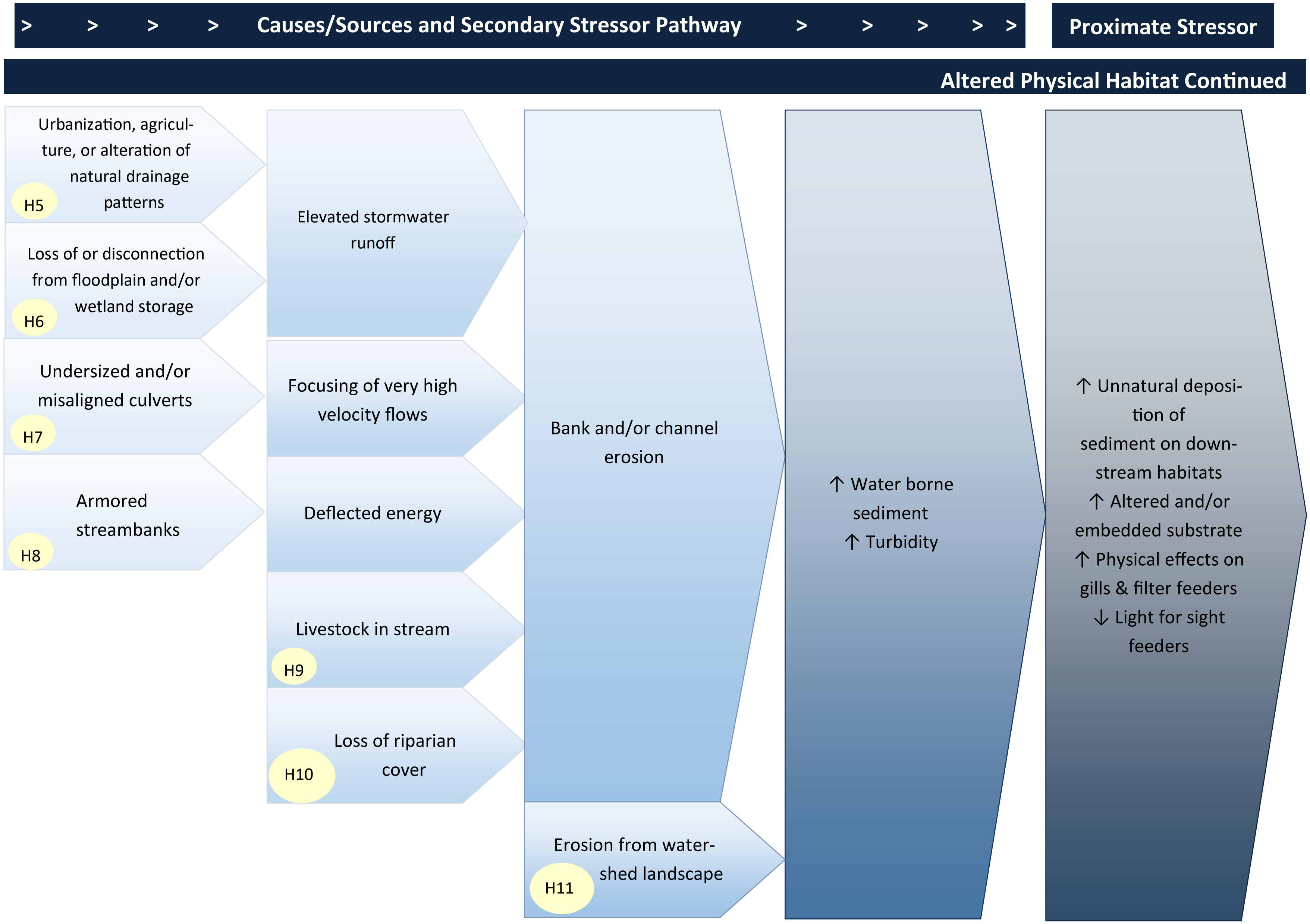
Causal Pathways to Common Proximate Stressors



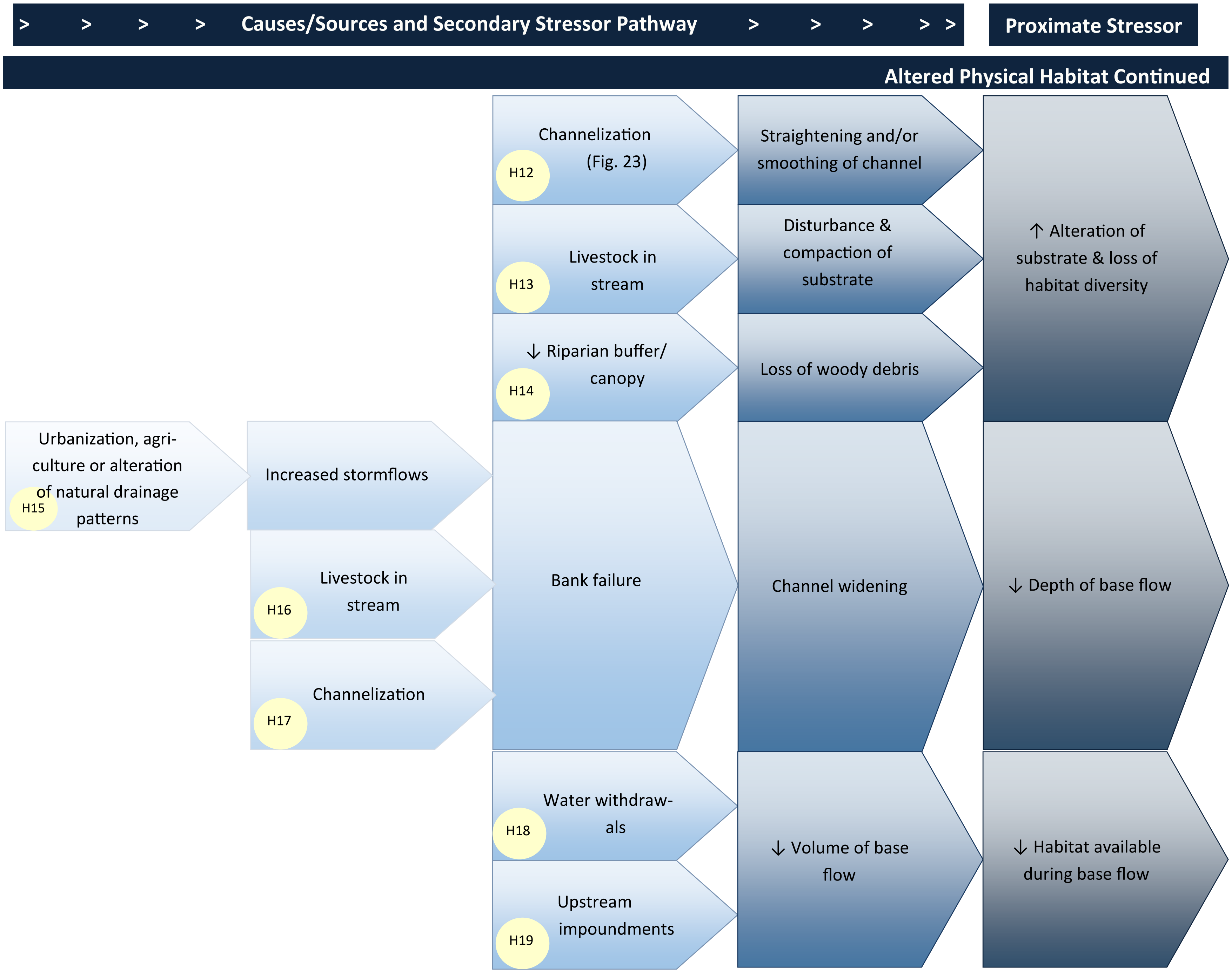
Causal Pathways to Common Proximate Stressors



Causal Pathways to Common Proximate Stressors



Causal Pathways to Common Proximate Stressors



Causal Pathways to Common Proximate Stressors

> > > > Causes/Sources and Secondary Stressor Pathway > > > > >

Proximate Stressor

Altered Physical Habitat Continued

Urbanization, agriculture or alteration of natural drainage patterns H20 → Elevated stormflows → Channel widening → ↓ Flow velocity → ↑ Unnatural deposition of sediment

Livestock in stream H21 → Channel widening

Channelization (Fig. 24) H22 → Channel widening

Ponding upstream of undersized culverts H23 → ↓ Flow Velocity → ↑ Deposition of sediments on upstream habitats

Stream underground for long distances H24 → ↓ Available habitat

Figure 24. Channelization.

Causal Pathways to Common Proximate Stressors

> > > > Causes/Sources and Secondary Stressor Pathway > > > > > | **Proximate Stressor**

Low Recruitment Potential

Figure 25. Hanging culvert interfering with fish and macroinvertebrate movement upstream.

LR3 Loss of riparian cover

LR4 Culverts (Fig. 25)

LR1 Developed or impaired head-waters

LR2 Extensive urbanization

Loss of adult insect habitat

↓ Upstream migration of adult caddisflies

LR5 Inadequate stream crossings & dams

↓ Recolonization via drift from upstream habitats

↓ Recolonization via adults from adjacent streams

↓ Oviposition of eggs in stream

↓ Upstream fish migration

Chloride Toxicity

TC1 Deicing salts on roads, parking & sidewalks

TC2 Snow storage

TC3 Sand/salt storage (active & legacy)

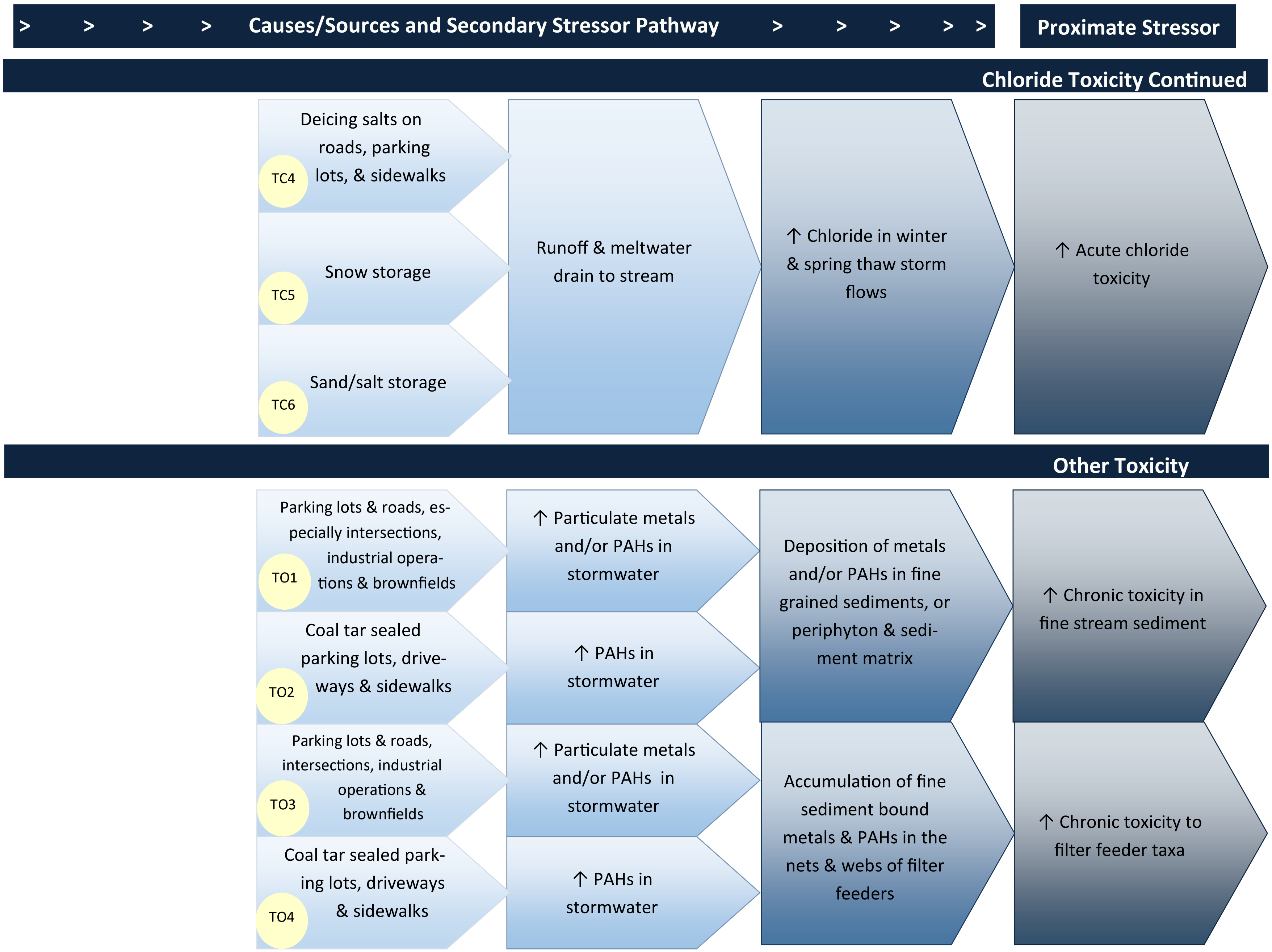
Runoff & meltwater drain to pervious surfaces or leaky stormwater infrastructure

Chloride contamination of groundwater

↑ Chloride in base flow

↑ Chronic chloride toxicity

Causal Pathways to Common Proximate Stressors



Causal Pathways to Common Proximate Stressors

> > > > Causes/Sources and Secondary Stressor Pathway > > > > >			Proximate Stressor
Other Toxicity Continued			
	TO5 Parking lots & roads, especially intersection, industrial operations & brownfields (Fig. 26)	↑ Dissolved metals and/or hydrocarbons in stormwater	Potential acute toxicity in stormflow
	TO6 Brownfields & other industrial soil contamination	↑ Dissolved metals and/or hydrocarbons in stormwater	Potential acute toxicity in base flow
TO7 Agricultural & land-scaping pesticides	↑ Particulate pesticides in stormwater	Deposition of pesticides in fine grained sediments	Potential chronic toxicity in fine grained stream sediments
		TO8 Agricultural & landscaping pesti-cides in stormflow	Potential acute toxicity in stormflow

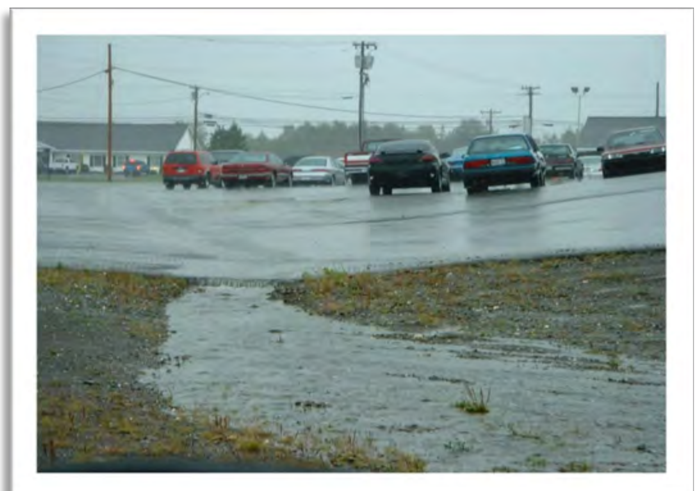


Figure 26. Paved surface runoff can contain toxics.

Appendix 2 - Potential Stream Survey Parameters

The following is a partial listing of characteristics that could be observed and recorded during a stream corridor survey. For more detailed information and field sheet examples see DEP's Stream Survey Manual Volume 1 https://www.maine.gov/dep/water/monitoring/rivers_and_streams/vrmp/stream-survey-manual/survmanv1_mainbody.pdf

Stream habitat and/or corridor conditions

In-Stream:

- Pools, Riffles, Rapids, Deadwater, Runs
- Bottom: sand, coarse gravel, cobble, rubble, boulders, bedrock, embeddedness
- Woody debris (logs, trees), other natural material (leaves, macrophytes)
- Water appearance: clear, light brown, milky, foamy, oily sheen, greenish, orange, turbid
- Water odor: fishy, sewage, chlorine, rotten eggs, none
- Measurable parameters: temperature, depth, width, stream velocity
- Observable aquatic life: fish, macroinvertebrates, algae, beaver dams
- Obstructions: dams, undersized culverts
- Unstable stream crossings: erosion around culvert/bridge, ford crossing for ATV or farm road

Corridor conditions:

- Stream bank: natural (forested), brush/early successional, grass, collapsed/eroded banks, garbage/trash, yard waste, livestock
- Riparian corridor : natural (forested), brush, grass, residential, commercial, industrial, road, golf course, agriculture (crops, livestock), gravel pits, trails (ATV, snowsled, hiking)

Geomorphological conditions:

- Alteration of stream channel: armoring, straightening
- Flow restrictions: undersized crossing, impoundment/dam
- Evidence of aggradation (sediment piles in channel)
- Evidence of degradation (stream cutting deeper, cutting banks)
- Evidence of widening (banks collapse, stream shallower, tree roots exposed)
- Evidence of planimetric form adjustment (stream channel pattern changing, occurs in flood-plain)

Basic monitoring/screening for water quality/biological conditions:

- Meter parameters: DO, temperature, pH, conductivity, turbidity, salinity
- Observable: extent of algae, type of algae (long filamentous)