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## Brief Communication

# The Focus on Chemicals Alone in Human-dominated Ecosystems Is Inappropriate

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## ABSTRACT

As the earth's human population continues to increase, megacities rapidly expand, and agriculture tries to meet their needs, ecosystems are increasingly dominated by humans. This domination, of course, equates to increased loadings of eroded soils, nutrients, and chemicals, along with more degraded habitat. Governments will continue to struggle to address these conflicting issues and must adapt into more effective and efficient management modes. The traditional focus on using chemical-specific guidelines as the foundation of environmental protection and restoration no longer is sufficient and must move to a more realistic and effective approach. Improving environmental quality in aquatic systems to near an appropriate reference condition cannot occur without removing habitat and flow stressors, which in turn will be tied to removal of runoff loadings of soils, nutrients, and chemical pollutants. These issues cannot be resolved without a strategically designed, advanced weight-of-evidence approach to prioritize those stressors. This approach should subsequently improve the effectiveness and cost-benefit of site remediation and restoration. *Integr Environ Assess Manag* 2017;13:568–572. © 2017 SETAC

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## A CHANGING WORLD WITH UNCHANGING ENVIRONMENTAL MANAGEMENT

Our world is a rapidly changing ecosystem, with change being driven by the massive growth in human populations. By 2050 it is likely that 86% of the developed world and 64% of the developing world will be urbanized (Openair...2012). The population will reach approximately 8 billion in 2024 and 10 billion in 2056 and has doubled in the past 60 y.

This increased growth is directly related to an increase in ecosystem stressors. The increasing human domination of our ecosystems obviously results in habitat destruction and alteration. The runoff from urban areas increases in quantity while decreasing in quality, primarily as a result of impervious areas (rooftops, parking lots, roads, compacted soils) and loss of vegetative cover (Burton and Pitt 2001). The well-known "urban stream syndrome" is the common occurrence of degraded urban waterways, due to habitat alteration, altered flows, sedimentation, elevated sunlight and temperature, and loadings of nutrients, metals, and organic chemicals. Agricultural ecosystems have many of the same nonpoint source issues as urban areas, differing only in loading characteristics of solids, nutrients, and other chemicals (Burton et al. 2000). These increasing multiple stressor exposures make environmental assessment and management more challenging.

Developed countries and increasingly developing countries, such as China, are using similar approaches to protect and restore their waterways. In the United States, the Clean Water Act (1972) has the noble goal of "restoring the physical, chemical and biological integrity of our nation's waters." In Europe, the Water Framework Directive (WFD) has put in place a comprehensive program for assessing water quality in differing ecoregions. Other European Union (EU) programs include the Nitrates Directive for diffuse pollution and the Urban Wastewater Treatment Directive. All of the relevant environmental management programs in the EU link to the WFD, yet the implementation of these regulations has been problematic (Burton et al. 2012). The mechanism of meeting the goals of the programs is based primarily on Environmental Quality Standards (chemical-specific criteria) for ambient waters and point source wastewater loadings (permit limits). Are we considering nonpoint source diffuse loadings, habitat alteration, and biological integrity of populations and communities?

A handful of places, however, are doing things the right way and recognizing that multiple stressors exist in addition to those that are chemical. For example, in urban areas, green infrastructure approaches, including Sustainable

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Urban Drainage Systems (SUDS), originally developed in the United Kingdom (UK), go a long way toward addressing these runoff problems but are used in only a small fraction of municipalities in North America, western Europe, and Australia (USEPA 2006). These approaches can greatly reduce runoff volume, thereby reducing flow and habitat destruction while also reducing nutrients, pesticides, and metals loadings. In Australia, a couple of comprehensive water management programs not only look at the various stressors but also translate the information effectively to the public (Alexander et al. 2009; Kellar et al. 2014; GHHP 2016). Nevertheless, these approaches are rarely adopted in most human-dominated systems, particularly in developing countries.

Johnson and Sumpter (2016) recently raised the question of whether chemical risk assessments were being done the wrong way. They pointed to the historical and current focus of using laboratory-based testing of single species to assess toxicity and sublethal endpoints such as endocrine disruption and wondering whether these results are transferable to wildlife populations. It is of course the populations and communities that should be the focus of protection, and they are affected by a myriad of other stressors.

Thus, it is reasonable to conclude that seemingly commonsense issues are not being considered by many scientists in the fields of ecology and ecotoxicological research, as well as by a majority of regulatory institutions charged with protection of our environment. Our nearly 50-y focus on using chemical-specific regulatory guidelines as the foundation for environmental protection and restoration is no longer sufficient to meet the human and environmental health challenges posed by population growth. The Clean Water Act of 1972 in the United States resulted in steadily improving water quality until the 1990s; then the improvements leveled off. This is likely due to the fact that at least 50% of water quality problems have been linked to nonpoint source runoff, which is poorly regulated (USEPA 2016, 2017). Scientists, together with political leaders, must move to a more realistic and effective approach for safeguarding our environment.

## REGULATORY MANAGED STRESSORS AND THEIR SUCCESS

The approach to managing water quality in the United States identifies which streams, rivers, and lakes are likely impaired and which pollutants are implicated in those impairments (USEPA 2004). The latest summary of all 50 states by the US Environmental Protection Agency (USEPA) has the following ranking of causes of impairments, ranked from highest to lowest (USEPA 2017):

1) Human pathogens (based on municipal wastewater permit exceedances)
2) Metals (other than Hg but based on total metal concentrations)
3) Sediment (e.g., siltation or embeddedness)
4) Nutrients
5) Organic enrichments or O depletion (overlaps with nutrient problems)
6) PCBs
7) Habitat degradation (overlaps with flow alterations)
8) Flow alterations (increasing drought and high flows)
9) Temperature (generally elevated temperatures)
10) Cause unknown
11) Salinity, total dissolved solids, chlorides, or sulfates
12) pH, acidity, or caustic conditions
13) Turbidity (total suspended solids, tied to development)
14) Pesticides
15) Ammonia

These rankings include a large amount of best professional judgment by state environmental scientists because these waterways usually contain many potential stressors that are not ranked by any scientific process. It is interesting, however, that habitat, flow, temperature, and solids are ranked as stressors though they are rarely used to mandate enforcement actions or to reduce nonpoint source loadings. The focus for restoring aquatic ecosystems where legacy contamination has occurred is driven largely by identifying the contaminants of concern. In the United States, PCBs or Hg (to a lesser extent metals, pesticides, and PAHs) in depositional sediments are the drivers most often identified for setting chemical-specific cleanup goals (NRC 2007).

Removing or isolating the sediments by dredging and/or capping with clean sediments is a crude process, and usually about 10% of the original sediment remains in place after dredging (NRC 2007). Follow-up monitoring conducted to determine if beneficial uses have been restored to the waterway often reveals that benthic macroinvertebrate and fish populations have not improved substantially. Physical restoration of coastal areas and streams does not equate to biological restoration. This begs the question, how can the removal of tons of contaminated sediments not improve an ecosystem?

There are many reasons why current remediation and restoration approaches, based on single chemical targets and costing many billions of dollars, have an unknown benefit to ecosystem improvement. If there is inadequate monitoring of water and sediment stressors and their associated biological integrity pre- or postremediation, then there is no way of knowing if the remedial or restoration action has been effective. These remedial activities usually fail to remove upstream sources of other stressors, rather often focusing on 1 legacy contaminant such as PCBs or Hg. Success (i.e., cleanup goal) is measured by mass of contaminated material removed.

Extensive studies of stream restoration have shown that few restore to ecologically stable status with desirable fish and benthic communities. The improvements are mainly physical and aesthetic, and dominant stressors and sources have not been removed. Few restorations achieve ecologically stable status with desirable fish and benthic communities (Palmer et al. 2005, 2010; NRC 2007; Cockerill and Anderson 2014). Billions have been spent to "perpetuate a false sense of optimism" (Cockerill and Anderson 2014).

## IT IS ALL ABOUT EXPOSURES

High concentrations of many metals and organic chemicals are often nontoxic in environments where sufficient ligands bind them so tightly that they are biologically unavailable. In environments low in ligands, such as oligotrophic waters, similar chemicals can be highly toxic at low concentrations. Overlying waters, prey, periphyton, bulk sediment, and pore waters are exposure pathways that vary in importance, depending on where an organism resides and feeds. Seldom do we measure exposures of contaminants from periphyton or hyporheic waters—hugely important for some species. Do single, specific chemical criteria protect those species?

## EXPOSURES ARE CHANGING AND SO MUST THE REGULATORY FOCUS

It has been well known that climate change is drastically changing the physical and biological characteristics of many environments around the planet. In the upper US Midwest around the Laurentian Great Lakes, the frequency of extreme precipitation events has been steadily increasing since the 1940s, accompanied by increased flows in our rivers. This increasing tendency for drought and extreme precipitation increases the loadings and bioavailability of many stressors, such as nutrients, metals, organic chemicals, and flow. Loss of vegetative cover due to drought and fire causes increased loadings of soils and nutrients into aquatic systems and elevated water temperatures due to loss of shading. Sadly, these events serve only to exacerbate and possibly cause synergistic effects related to our corresponding population growth and increased urban and agricultural land uses.

## HOW CAN MANAGEMENT BETTER MEET REGULATORY GOALS OF PROTECTING OUR ECOSYSTEMS?

The ultimate goal of water quality protection is to ensure the "ecosystem services" are protected, but in terms of current regulatory language, it is to maintain the biological integrity of the ecosystem. If the appropriate "clean" water biota that live in an ecosystem are stressed and cannot reproduce and maintain a healthy population, then there is a problem.

It is overly simplistic to assume that measuring single chemical concentrations will ensure that our "clean water" goals are met. We must understand what stressors exist, which are most important, and which stressors the resident biota are most affected by. At present this understanding is often based on "best professional judgment," but rarely are stressors quantitatively ranked and compared. This requires more advanced weight-of-evidence (WoE)–based assessments that evaluate physical and chemical exposures in terms of what the sensitive organisms in the ecosystem are affected by (Burton et al. 2012). An advanced WoE approach dictates that multiple (preferably 4 or 5) lines of assessment are utilized (e.g., resident biological communities [presence or absence and ecogenomics], toxicity testing, habitat characterization, chemical testing, comparisons to Environmental Quality Guidelines, tissue residues) (e.g., Burton et al. 2012; Kellar et al. 2014; Buchwalter et al. 2017). The optimal lines of evidence depend on the problem, with some characterizing exposure whereas others characterize effects. These lines of evidence must be strategically combined in an almost experimental manner to derive statistical power and linkages to causality. Developing a site conceptual model linking possible stressors, exposures, and linkages to receptors as is done in ecological risk assessments is helpful. These more advanced assessment approaches will then allow for a ranking of the stressors of concern in terms of an appropriate "reference condition."

Biota in an urban or agricultural watershed (catchment) will never be as sensitive and of as high quality as those in pristine areas that are not human impacted. Therefore, modified biotic criteria are needed that strive to make our human-dominated systems as high quality as is reasonable. The state of Ohio in the United States has adopted this approach and has separate water quality and biotic criteria for their "modified" waterways where channelization has occurred. No one would assume a channelized waterway could attain as high a quality as one that is not channelized within the same ecoregion.

Once the stressors are identified and ranked, as best as possible, then productive management strategies can be developed. This development will require a joint effort of hydrologists, environmental chemists, aquatic biologists, and ecotoxicologists. Important but challenging questions are these: Which key resident organisms are exposed to multiple compartments (e.g., surface water, periphyton, surficial sediment, pore water, hyporheic waters, food)? Which exposures are most important? Why pretend benthic macroinvertebrates see only sediment metals and synthetic organics? How do occasional water quality standards (WQS) exceedances in overlying waters (and associated hyporheic waters) affect benthic responses? How does siltation and embeddedness (poor habitat) affect use of sediment quality guidelines (SQGs)? How does eutrophication affect use of SQGs?

## WHERE DO METALS AND ORGANICS LIKELY RANK AS STRESSORS?

Human-dominated areas with good effluent treatment reduce nutrients, metals, and organics to concentrations at which they are most likely not the stressors of concern. Nevertheless, these point source loadings are usually in watersheds where nonpoint source loadings are of equal or greater importance. Both metals and organic chemicals are associated with urban and agricultural inputs as pulse inputs from runoff. For example, the application of fertilizers on crops must be highly managed or else nutrient and

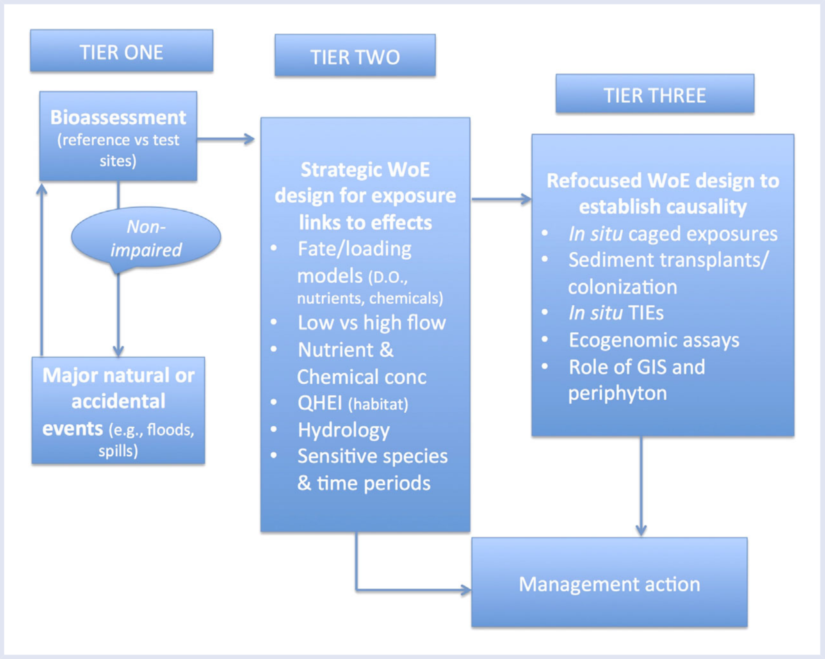

Figure 1. Management framework example. Tier 1 is a fish and benthic macroinvertebrate bioassessment (or review of site data) to assess whether impairments exist. Tier 2 is a comprehensive weight-of-evidence approach using at least 5 lines of evidence. Tier 3 assists in establishing impairment causality to the proper physical or chemical stressors. DO = dissolved oxygen; GIS = groundwater–surface water interactions; QHEI = qualitative habitat evaluation index; TIE = toxicity identification evaluation procedures.

metal inputs will result following precipitation events. Also the common application of biosolids to farmland from municipal wastewater treatment plants adds additional potential loadings of pathogens, nutrients, metals, and organics. At the same time, the co-occurring stressors of temperature, sunlight, altered flow, and habitat may be more important stressors than metals and organics.

## A MANAGEMENT FRAMEWORK EXAMPLE

Regulators are typically passionate about doing the right thing and protecting the environment but are often hampered by the wording of regulations, too few personnel and monetary resources, and the complexity of the human-dominated systems that they are trying to protect. What follows in this section is a potential framework that could be adopted to improve the traditional management approaches to environmental quality.

A multitiered assessment structure is appropriate to best survey all ecosystems and then focus on those with more uncertainty and potential challenges (Figure 1). In Tier 1, ambient assessments of biological integrity (the sentinel fish and benthic species) versus realistic reference condition would be surveyed—rather than chemical concentrations. Although this approach tends to more laborious and expensive, it provides more interpretable data and thus has a cost–benefit advantage. The results of the biological survey would be converted to metrics such as those used by the state of Ohio. Biological metrics would be compared to relevant reference ecoregion conditions. If potential impairments are identified, then Tier 2 WoE screening would follow. If no impairments are identified, then the results would be revisited after big events (drought, increased flows, spills, etc.). The WoE screening includes point source exposure loading models; habitat and source characterizations (up- vs downstream); reviewing biological data, key receptors, sensitive time periods, low versus high flows, water quality or permit exceedances, and determine likely stressors. If potential stressor linkages to effects are identified, then Tier 3 WoE diagnosis would follow. Tier 3 WoE diagnosis would involve selection of optimal assessment tools for potential stressor diagnostics (e.g., ecogenomics, in situ caged – colonization – transplant studies) and definition of exposure linkages (sediment, hyporheous, low or high flow, effluents, periphyton, prey). These WoE data would likely provide the ability to identify likely dominant stressors. At this point management decisions could be made on the need for continued monitoring, restoration, or treatment actions.

A best first management approach is simply to reduce runoff, thereby reducing loadings of nutrients, solids, metals, organics, and pathogens. For human-dominated areas with poor effluent treatment, metal and organic chemical exposures are higher and longer so chemicals may be a greater stressor than nutrients or habitat. The goal in these developing areas is improved wastewater treatment in conjunction with reduced runoff. This framework considers the multiple stressors found in human-dominated watersheds and will allow for a more effective and efficient management mode.

*Data availability*—Data referenced in this commentary is available by writing to the corresponding author at burtonal@umich.edu.

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