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INVITED COMMENTARY

Single-Indicator Strategies Treat Symptoms, Not Sources of Sewage Contamination, Hampering Water Quality Improvement in Urban Areas

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Infrastructure challenges and water pollution are endemic to major urban centers worldwide [1], causing eutrophication [2], hypoxia [3], and infection risk from fecal pathogens in coastal waters. In New York City, coastal water quality is still unacceptable because nearly 100 billion liters of untreated sewage-contaminated waste are delivered to receiving waters each year. Sewage pollution is even worse in cities with less developed infrastructure, and has been exacerbated by the global trend toward urbanization. The roots of this problem lie in the challenges of modernizing aging sewage infrastructure: both increasing capacity and overcoming a legacy of delivering untreated sewage directly to waterways. As public expectations and regulatory requirements have improved, driven by enforcement of the Clean Water Act in the USA, an increasing fraction of this sewage is now being captured for modern secondary and tertiary treatment in many regions. However, retrofitting of infrastructure to address water quality deficiencies is difficult, and failure to restore healthy waterways remains common in urban settings.

In New York City, and in many other older cities, major progress has occurred by updating existing wastewater treatment plants, including expanded capacity and increasing efficiency of microbial and nutrient removal. Water quality is monitored using indicators such as selected fecal bacteria and dissolved oxygen which are proxies for a wide variety of pollutants, not all of which can be measured. These indicators have been essential in identifying pollution sources and assessing environmental quality. Average water quality across the waterways of New York City has significantly improved since the 1970s. However, conditions are still unacceptable in locations where most untreated sewage is delivered. Most of the city is serviced by a combined sewer system, designed with hundreds of Combined Sewer Overflow (CSO) pipes that discharge to waterways following precipitation. Managers face consent orders to limit these CSOs that bypass treatment plants several dozen times a year when capacity of the delivery system is exceeded. The challenge to restore clean waterways and control CSOs is enormous.

When managers are faced with a challenge of this magnitude, difficult decisions are made to best use public funds for maximizing sustainable environmental improvements. The constraints on decision-making include using approved monitoring approaches (e.g., indicators) to assess environmental conditions, meeting current and evolving (usually stricter) regulatory standards, while also efficiently using limited public funds. Independent scientists and an engaged public have the responsibility to comment on public environmental management projects. Academics sometimes avoid advocacy on regulatory issues in society, but their feedback can positively contribute to management agency actions and decisions. This is not a call for antagonistic interactions with management agencies but instead greater public involvement to support these agencies and policymakers in making more forward-looking decisions that will result in accelerating sustainable environmental gains. Independent scientists can often contribute insight and a broader perspective on management decisions and their unrecognized environmental implications, as well as highlight potential future emerging contaminants that are not yet regulated.

Agency decisions on mitigation strategies often come down to oversimplified cost-benefit analyses, where least-cost options targeting violations based on monitoring data for single indicators are often selected. But managing for

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single indicators can lead to “band-aid” solutions that may be counterproductive. Management actions, where possible, should primarily address the source of environmental degradation rather than just symptoms or individual indicators of contamination. We use New York City to illustrate two examples of these difficult decisions and questionable CSO mitigation strategies.

Example 1—End-of-Pipe CSO Chlorination

As part of a CSO control consent order, New York City has approved multiple plans to install end-of-pipe chlorination on major CSOs in Flushing Creek, the Hutchinson River, and Alley Creek. The CSO control plans have thereby narrowly targeted fecal pathogens, as indicated by the fecal indicator bacteria (FIB) *E. coli* and enterococci, as their primary source of management concern, despite the presence of other pollutants. Large-volume CSOs deliver untreated sewage also containing floatables, nutrient pollution, oxygen-consuming wastes, pharmaceuticals, and other emerging contaminants. Disinfection in the absence of additional treatment would be considered inadequate by modern wastewater standards and does not lend itself to future treatment improvements. End-of-pipe chlorination and subsequent dechlorination of CSOs can be technically difficult, and if poorly managed can have adverse environmental impacts on flora and fauna in the waterway. In addition, assuming that FIB are controlled by chlorination, the primary CSO sewage tracer (FIB) will be eradicated despite the volume of sewage discharge remaining unchanged.

Example 2—Hypoxic Waterway Aeration

New York City has made an even greater investment into artificial aeration of Newtown Creek and the Gowanus Canal to address unacceptably low oxygen conditions in these industrial waterways. These poorly flushed, dead-end waterways experience extensive CSO discharge carrying oxygen-consuming wastes that cause recurrent water column hypoxia. The aeration system in Newtown Creek, consisting of large-volume pumps that circulate air through the water column, also generate potentially hazardous bioaerosols and volatiles from the air-water interface in this densely populated urban area [4, 5]; however, regulations for outdoor bioaerosols are lacking. Rather than investing these resources into broad-based CSO volume reduction, a single indicator (oxygen) is targeted for management.

In both of these cases, the environmental concerns are broader than just fecal bacteria or oxygen-consuming wastes, but the selected management interventions target only one symptom of contamination. Managing for a single water quality indicator is not as effective as managing for a healthy environment. Of additional concern, the management interventions decouple the most common monitoring assessment tools (oxygen level and FIB) from the other less commonly measured pollutants, and potentially aggravate other aspects of environmental quality. Broader ecological benefits from a healthy environment are rarely considered, instead decisions are more commonly made by comparing the cost of intervention vs the reduction in a specific indicator. This makes sense from a manager’s perspective, but may not be the most efficient use of public funds from the end users’, or taxpayers’, perspective. While these interventions provide a nominally cost-effective mechanism to achieve standards based on the most commonly measured water quality indicators, and may meet regulatory requirements, they do not reduce the delivery of untreated sewage. In the end, the public will still be left with waterways severely contaminated by huge volumes of poorly treated sewage, and fewer indicators to track these volumes.

Source Reduction Alternatives

In our view, alternative approaches that focus on broader environmental benefits and work toward the goal of water quality improvement in a more comprehensive manner should be given priority when investing public resources. Specifically, management approaches that focus on CSO source reduction, utilizing either green or gray approaches, have the potential to reduce delivery of both regulated sewage and as-yet unregulated contaminants to local waterways, and provide a more sustainable way to achieve environmental goals. If the investment of funds allocated to single-indicator strategies (hundreds of millions of US dollars) in Flushing Creek and Newtown Creek were directed instead to CSO reduction, both the source of, and the full range of, contaminants of concern would be reduced. CSO source reduction has the crucial advantage of diverting stormwater from urban impervious surfaces out of the combined sewer infrastructure, thereby reducing the total volume delivered to wastewater treatment plants and making CSO discharges less frequent. The many methods of diverting stormwater from sewer infrastructure include green infrastructure (GI) strategies such as bioretention basins, green roofs, stormwater treatment wetlands, and permeable pavement. Compared to traditional “gray” infrastructure for managing stormwater, GI has been shown to be more cost-effective in life-cycle assessments [6, 7], which take a broader perspective than most cost-benefit analyses used in urban water management decision-making. In a portion of New York City, a similar screening analysis [8] demonstrated that aggressive implementation of GI could reduce urban stormwater volumes by 23–42%. New York City is investing in green infrastructure, and we think these efforts, motivated by a more complete value assessment, should be greatly expanded and prioritized over problematic single-indicator strategies.

Water quality monitoring tools, such as fecal indicator bacteria, form the basis for our assessment of pollution and state regulatory decisions, because it is not possible or efficient to measure all forms of pollution. However, when considering alternate management interventions, the broader sources of pollution must be kept in mind rather than managing just to control the specific indicators that signal water quality degradation. For example, it is now well known that untreated urban sewage contains a large number of pharmaceutical compounds and other emerging contaminants of concern (e.g., [9]), most of which remain unregulated but nonetheless are environmental pollutants. Similarly, fecal bacterial levels in water are tightly regulated but similar contamination in air or sediment remains unregulated [10]. If management efforts focus on the sources of contamination via sewage reduction strategies, these broader sources of regulated and unregulated waste will be reduced—and also stimulate the broader improvements in water quality that we should be seeking. Established monitoring indicators have an important role in waterway management but excessive focus on single indicators like *E. coli*, enterococci or dissolved oxygen can be counterproductive unless combined with broader pollutant source reduction.

There are multiple, partial, solutions to this issue, combinations of which can make a difference in water quality improvements. We need to be continuously improving our environmental regulations and bringing improved technological solutions to these major environmental challenges [1]. As new regulations occur (e.g., for pharmaceuticals), investment in prior single-symptom interventions will create a continuous game of "catch-up," requiring additional single-symptom interventions to deal with newly measured or regulated contaminants. However, if we invest in incremental reductions to the source of sewage contamination, rather than band-aid interventions that manage for indicators or treat single symptoms, we will make more sustainable progress toward a healthy urban coastal environment.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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