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Marginalized Monitoring: Adaptively Managing Urban Stormwater

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Marginalized Monitoring: Adaptively Managing Urban Stormwater

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ABSTRACT

Adaptive management is a theory that encourages environmental managers to engage in a continual learning process and adapt their management choices based on learning about new scientific developments. One such area of scientific development relevant to water management is bacterial genetics, which now allows scientists to identify when human sewage has seeped into unintended places. Source-specific bacterial testing in a variety of cities across the United States indicates there is human sewage in urban stormwater pipes. These pipes are designed to carry runoff from city streets and lots; sending untreated water directly into rivers, streams, and lakes. This scientific breakthrough could be highly useful to urban water managers because it helps identify sewage infrastructure problems that pose significant public health risks. While accepted within the scientific community, this research sought to understand the extent to which urban water managers were using this new monitoring method and, to the degree they were

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not, to identify the barriers. We designed our study to illustrate how municipal stormwater managers understand and adapt to highly relevant scientific developments in monitoring techniques. The research findings and analysis are based on qualitative research interviews with urban stormwater managers and their state and federal agency regulators to identify what encourages and discourages the application of useful scientific discoveries to better manage water systems, with a particular focus on how the law influences adaptive management. This research provides important insights into necessary legal and management reforms that must occur if the theoretical benefits of adaptive management are to be realized. Moreover, it adds to the theoretical research on adaptive management by providing a detailed case study of the barriers in practice to the adoption of adaptive management approaches.

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I. INTRODUCTION

A child returns from playing at the beach and within two days is severely sickened with intestinal illness, fever, and eye infections.[1] She has been unwittingly exposed to microscopic fecal pathogens from human sewage.[2] This is not an isolated story; in the United States, pathogens from fecal contamination are the leading cause of impairments to river, stream, bay and estuary water quality, and one of the top ten causes of impairments to lakes.[3] Images of raw human sewage in waterbodies are often associated with the need to build infrastructure for sanitation projects in developing countries.[4] However, this narrative comes from the United States, and is a story about the aging, crumbling and leaking water infrastructure buried beneath major urban population centers.

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1. Interview with Confidential Interviewee No. 13 (Sept. 5, 2012).

2. *Id.; see also,* Timothy Wade et al., *Rapidly Measured Indicators of Recreational Water Quality and Swimming-Associated Illness at Marine Beaches: A Prospective Cohort Study,* 9 ENVTL. HEALTH 66 (2010); Timothy Wade et al., *Rapidly Measured Indicators of Recreational Water Quality are Predictive of Swimming-Associated Gastrointestinal Illness,* 114 ENVTL. HEALTH PERSP. 24 (2006) [hereinafter Wade, *Swimming-Associated Gastrointestinal Illness*].

3. ENVTL. PROT. AGENCY, NATIONAL WATER QUALITY INVENTORY: REPORT TO CONGRESS 2004 REPORTING CYCLE 14-15, 18, 22 (2009), *available at* http://water.epa.gov/lawsregs/guidance/cwa/305b/upload/2009_01_22_305b_2004 report_2004_305Breport.pdf (showing 72,305 miles of rivers and streams, 528,425 acres of lakes, and 2,845 square miles of bays and estuaries impaired by pathogens). These data likely underrepresent the extent of the problems because 84% of the total U.S. river and stream miles, 61% of the total U.S. lakes and 71% of the total bays and estuaries are unassessed. *Id.* at 13, 17, 20. Further, the Centers for Disease Control reports that between 2007 and 2008, there were 486 cases of disease outbreaks related to recreational waters—oceans, lakes, rivers and streams. Michele C. Hlavsa et al., *Surveillance for Waterborne Disease Outbreaks and Other Health Events Associated with Recreational Water—United States, 2007–2008*, 60 CTRS. FOR DISEASE CONTROL & PREVENTION SURVEILLANCE SUMMARIES 12, 5 (2011).

4. The numbers of health problems related to waterborne illnesses in the U.S. pales by comparison to the two million children who die every year from waterborne illness in the developing world; waterborne diseases are those that are transmitted by drinking fecally contaminated water. BRUCE GORDON ET AL., WORLD HEALTH ORG., INHERITING THE WORLD: THE ATLAS OF CHILDREN'S HEALTH AND THE ENVIRONMENT (2004).

Due to scientific advancements, researchers now have the ability to identify the presence of human sewage in places it should not be. Across the United States, from the California coast to the East Coast and the Great Lakes in between, scientists are finding evidence of human sewage leaking out of cracked and corroded or misconnected pipes. In some situations, this raw sewage is seeping into groundwater supplies; in cities dependent on groundwater for their drinking water, this poses a significant public health problem.[5] In other situations, human sewage is reaching stormwater pipes, which are designed to quickly move rain and melting snow from urban streets and discharge it untreated into rivers and lakes.[6]

The scientific research provides a new window into the world of water infrastructure. Previously, concerns about human sewage contaminating water centered almost exclusively on issues related to the management of wastewater treatment plants and their combined or sanitary sewer overflows.[7] Similarly, academic and professional literature about municipal stormwater presumes stormwater only contains pollutants related to runoff from city streets and lots – things like fertilizers, oil and grease.[8] However, advances by scientists in detection and specificity around sources of bacteria have altered

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5. In the United States, between 2007 and 2008 alone, there were thirty six waterborne disease outbreaks associated with drinking water, with 44% of those outbreaks related to groundwater-supplied drinking water. J. M. Brunkard et al., *Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water—United States, 2007–2008*, 60 CENTERS FOR DISEASE CONTROL & PREVENTION SURVEILLANCE SUMMARIES 38–73 (2011). Such reports are voluntary; thus, the rate of actual illness is expected to be higher. *Id.*; Mark A. Borchardt et al., *Viruses in Nondisinfected Drinking Water from Municipal Wells and Community Incidence of Acute Gastrointestinal Illness*, 120 ENVTL. HEALTH PERSP. 1272, 1272-79 (2012).

6. *See infra* Appendix 1, Summarizing Scientific Research.

7. *E.g.*, ALEXANDRA DAPOLITO DUNN, NPDES ISSUES & THE URBAN ENVIRONMENT, SK037 ALI-ABA 83 (2004).

8. *E.g.*, "Stormwater runoff carries pollutants dislodged from various locations, such as salt, soil, leaves, pesticides, fertilizers, oil, gasoline, antifreeze, trash, animal waste, and any other materials present on the land's surface." *Id.* In contrast, the Clean Water Act and regulations related to municipal stormwater anticipate sewage leakage or direct connections into the stormsewer as evidenced by the prohibition against non-stormwater discharges. Federal Water Pollution Control Act, 33 U.S.C. § 1342(p)(3)(B)(ii) (2012).

our understanding of the problems faced in the built environment and illuminated a looming and costly human health problem with water infrastructure.[9] While this aging infrastructure problem may impact both groundwater-based drinking water supplies and oceans, lakes, rivers and streams via stormwater, this research focuses solely on urban stormwater. Yet, the lessons learned in this research could be beneficially applied to the drinking water aspect of the problem as well.

In the late 1980s and early 1990s, Congress and the Environmental Protection Agency (EPA) created an iterative regulatory structure for detecting and eliminating non-stormwater discharges from untreated municipal stormwater.[10] Unlike traditional wastewater permits issued pursuant to the Clean Water Act (CWA), which contain prescriptive end-of-pipe pollution limits, the permits for municipal stormwater discharges rely heavily on "Best Management Practices" and reducing pollution to the "Maximum Extent Practicable."[11] This regulatory structure, like others that are more iterative than prescriptive, may benefit from carefully incorporating adaptive management theory, which promotes a continuous learning

9. Bram Sercu et al., *Storm Drains are Sources of Human Fecal Pollution during Dry Weather in Three Urban Southern California Watersheds*, 43 ENVTL. & SCI. TECH. 293, 293-98 (2009); W. Ahmed et al., *Evaluation of* Bacteroides *Markers for the Detection of Human Faecal Pollution*, 46 LETTERS IN APPLIED MICROBIOLOGY 237, 237-42 (2008) [hereinafter Ahmed et al., *Evaluation of Bacteroides Markers*]; Elizabeth P. Sauer et al., *Detection of the Human Specific* Bacteroides *Genetic Marker Provides Evidence of Widespread Sewage Contamination of Stormwater in the Urban Environment*, 45 WATER RESOURCES RES. 4081, 4081-91 (2011).

10. 33 U.S.C. § 1342(p) (requiring NPDES permits for MS4s); 33 U.S.C. § 1342(p)(3)(B)(ii) (prohibiting non-stormwater discharges); 40 C.F.R. § 122.26(d)(2)(iv)(B) (2012) (establishing Phase I rules to detect and eliminate illicit discharges); 40 C.F.R. § 122.34(b)(3)(i) (2012) (establishing Phase II rules to detect and eliminate illicit discharges); ROBERT PITT & CTR. FOR WATERSHED PROT., ILLICIT DISCHARGE DETECTION AND ELIMINATION: A GUIDANCE MANUAL FOR PROGRAM DEVELOPMENT AND TECHNICAL ASSESSMENTS 1 (2004).

11. 33 U.S.C. § 1342(p) (requiring NPDES permits for MS4s); 33 U.S.C. § 1342(p)(3)(B)(ii) (prohibiting non-stormwater discharges); 40 C.F.R. § 122.26(d)(2)(iv)(B) (establishing Phase I rules to detect and eliminate illicit discharges); 40 C.F.R. § 122.34(b)(3)(i) (establishing Phase II rules to detect and eliminate illicit discharges); PITT & CTR. FOR WATERSHED PROT., *supra* note 10.

process for resource managers. According to adaptive management theory, agencies are encouraged to learn as they implement their programs; the understanding is that such learning would allow programs to come closer to achieving their goals by routinely incorporating new information. Although Congress gave wide latitude to municipalities to structure their urban stormwater programs, and anticipated the programs would improve over time, it did not carefully structure the program to promote continual learning and incorporate scientific advances. This is particularly problematic in the failure to utilize new monitoring techniques that provide clearer and more accurate information about public health risks from stormwater.

When Congress created this new regulatory structure for urban stormwater, it lacked the tools to appreciate the extent to which human sewage was leaking or plumbed into storm sewers. As scientists develop additional knowledge about stormwater systems, however, water managers' tools should become more sophisticated and fine tuned to more efficiently deliver on the 1972 promise of the Clean Water Act to have fishable and swimmable waters throughout the United States. Applying adaptive management to municipal stormwater, one would expect urban water managers to be aware of and apply new scientific sleuthing to identify, prioritize, and fix leaking sewage and storm water infrastructure problems. And yet, the environmental management theories, laws, and science are plagued by a range of disconnects that result in continuing human health risk related to contaminated waters.

This research weaves together the disconnected strands of science, law, and environmental management through a case study of adaptive management in the context of stormwater contaminated by human sewage. We use qualitative research interviews with urban stormwater managers to identify what encourages and discourages the application of useful scientific discoveries to better manage water systems. From this grounding, we show that the potential for adaptive management to support more efficient spending of public funds for resource management is not being fulfilled. We draw out some of the missing elements in the legal structure that could be fine-tuned to better incorporate scientific advancements.

We start this article by explaining adaptive management theory in Section II. We then describe the federal laws that establish a more iterative, rather than prescriptive, regulatory framework for urban stormwater and illicit discharges of human sewage in Section III. Next we characterize the scientific advancements that allow for identification of human-specific fecal bacteria, which is evidence of human sewage, in Section IV. Then we explore through qualitative research interviews with urban stormwater managers whether and how those charged with identifying and eliminating sources of human sewage from their stormwater systems apply adaptive management in Section V. In conclusion, we offer recommendations aimed at removing obstacles to and encouraging more scientifically-informed water management decisions.

II.
ADAPTIVE MANAGEMENT THEORY AND SHORTFALLS

The theory of adaptive management arose out of an approach developed by C.S. "Buzz" Holling in the 1970s.[12] The crux of this theory was that ecosystems acted as dynamic, rather than static systems; therefore, traditional natural resource management approaches of "attack[ing] environmental stressors in piecemeal fashion, one at a time," and apportioning decisionmaking "among a variety of mission-specific agencies and resource-specific management regimes" were inadequate.[13] Instead, a more effective response to dynamic systems would be one that focused on collecting, testing, and applying information in these dynamic systems[14] to shift from rule-based approaches of management toward strategies that emphasize continuous monitoring of circumstances and adjusting decisions accordingly.[15] Such an

12. *See generally* C.S. HOLLING, ADAPTIVE ENVTL. ASSESSMENT AND MGMT. (C.S. Holling ed., 1978).

13. Bradley C. Karkkainen, *Bottlenecks and Baselines: Tackling Information Deficits in Environmental Regulation*, 86 TEX. L. REV. 1409, 1439 (2008) [hereinafter Karkkainen, *Bottlenecks and Baselines*].

14. *See* J.B. Ruhl, *General Design Principles for Resilience and Adaptive Capacity in Legal Systems—With Applications to Climate Change Adaptation*, 89 N.C. L. REV. 1373, 1391 (2011).

15. *See* J.B. Ruhl. *Regulation by Adaptive Management—Is It Possible?*, 7

approach, according to advocates, would be more reflective of the dynamic and complex character of actual environments.[16]

In particular, adaptive management is an attempt to respond to environmental management problems, where numerous factors and response relationships prevail; where the knowledge about both those factors and the relationships are not fully identified; and where the systems are often dynamic, rather than static.[17] This approach arose out of an ecological management context, where such complex challenges are especially prevalent.[18] "The gist of the adaptive approach is that it proceeds in an iterative fashion, of constant monitoring and reevaluation, to reassess policy decisions as part of the greater evaluation of ecological impact and change."[19]

Definitions of adaptive management are often in dispute.[20] Nevertheless, one scholar has attempted to provide four core principles of adaptive management:

> (1) treating present ecological models, understandings, and the management interventions predicated upon them as provisional; (2) designing interventions as testable hypotheses where possible; (3) carefully and systematically monitoring and evaluating the results; and (4) adjusting our models, understandings, and management interventions in accord with

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MINN. J. L. SCI. & TECH. 21, 28 (2005) [hereinafter Ruhl, *Is It Possible?*].

16. *See* HOLLING, *supra* note 12 (observing the mismatch of the piecemeal approach of traditional ecosystem management methods with the complex dynamics of actual ecosystems); Karkkainen, *Bottlenecks and Baselines, supra* note 13, at 1439 (describing ecosystem management as an area "rife with informational deficits"); Barbara Cosens, *Resilience And Law as a Theoretical Backdrop for Natural Resource Management: Flood Management in the Columbia River Basin*, 42 ENVTL. L. 241, 245-46 (2012).

17. *See* Michael Ig, *Complexity, Environment, and Equitable Competition: A Theory of Adaptive Rule Design*, 41 GEO. J. INT'L L. 647, 656 (2010).

18. *See* HOLLING, *supra* note 12.

19. *Id.*; *supra* note 17, at 656 (citing Bradley C. Karkkainen, *Panarchy and Adaptive Change: Around the Loop and Back Again*, 7 MINN. J.L. SCI. & TECH. 59 (2005)).

20. *See* Holly Doremus, *Adaptive Management, The Endangered Species Act, and the Institutional Challenges of "New Age" Environmental Protection*, 41 WASHBURN L.J. 50, 52 (2001) [hereinafter Doremus, *The Institutional Challenges*] (describing the term as "highly malleable").

what we have learned through experience.[21]

Thus, adaptive management approaches often contemplate that agencies—either alone or in conjunction with stakeholders—actively seek new information and modify their management approaches in light of that new information. Such approaches can range from the narrow—the inclusion of pre-specified contingency measures that apply if initial efforts fail to achieve expected goals[22]—to the broad—the express design of management strategies to test scientific hypotheses[23] or even policy hypotheses.[24]

This approach, in turn, has been applied in areas beyond ecosystem management where these complex challenges arise. Such areas include climate change and drinking water in Ontario,[25] energy development in the western United States,[26] and wetlands restoration in the Everglades.[27] Further, there have been more general calls to incorporate adaptive management in processes of environmental assessment,[28] Superfund decisionmaking,[29] Endangered Species Act decisionmaking,[30] and water management.[31] In all of these

21. *See* Karkkainen, *Bottlenecks and Baselines*, *supra* note 13, at 1443.

22. *See* Bradley C. Karkkainen, *Adaptive Ecosystem Management and Regulatory Defaults: Toward a Bounded Pragmatism*, 87 MINN. L. REV. 943, 953 (2003) [hereinafter Karkkainen, *Adaptive Ecosystem Management*].

23. *See id.* at 948-51.

24. *See id.* at 951-53.

25. Patricia Hania, *Climate Change and the Protection of Drinking Water in Ontario: An Opportunity to Adopt Adaptive Management?*, 22 J. ENVTL. L. & PRAC. 167 (2011); *see also* Kevin E. Regan, *Balancing Public Water Supply and Adverse Environmental Impacts Under Florida Water Law: From Water Wars Towards Adaptive Management*, 19 J. LAND USE & ENVTL. L. 123 (2003).

26. Melinda Harm Benson, *Adaptive Management Approaches by Resource Management Agencies in the United States: Implications for Energy Development in the Interior West*, 29 J. ENERGY & NAT. RESOURCES L. 87 (2010).

27. Alfred R. Light*, Tales Of The Tamiami Trail: Implementing Adaptive Management In Everglades Restoration*, 22 J. LAND USE & ENVTL. L. 59 (2006).

28. Martin Z.P. Olsynzki, *Adaptive Management in Canadian Environmental Assessment Law: Exploring Uses and Limitations*, 21 J. ENVTL. L. PRAC. 1 (2010).

29. Jonathan Z. Cannon*, Adaptive Management In Superfund: Thinking Like A Contaminated Site*, 13 N.Y.U. ENVTL. L.J. 561 (2005).

30. J.B. Ruhl, *Taking Adaptive Management Seriously: A Case Study of the*

areas, scholars have observed similar environmental complexities, interrelationships and uncertainties, and called for the incorporation of adaptive management techniques that would better adjust future management methods to developing information about environmental responses to past management efforts.[32]

The stormwater context we analyze in this paper shares the features of these other systems in which scholars have urged the incorporation of adaptive management techniques. In fact, unlike other water pollution discharge permits under the Clean Water Act, which contain specific numeric limitations based on technology and water quality standards, municipal stormwater permits use an iterative approach focused on management plans and practices. Instead of prescriptive limits, Congress mandated municipal stormwater permits to "require controls to reduce the discharge of pollutants to the maximum extent practicable."[33]

Endangered Species Act, 52 U. KAN. L. REV. 1249, 1250 (2004) [hereinafter Ruhl, *Taking Adaptive Management Seriously*].

31. John H. Davidson & Thomas Earl Geu, *The Missouri River and Adaptive Management: Protecting Ecological Function and Legal Process*, 80 NEB. L. REV. 816 (2001).

32. *See, e.g.,* Hania, *supra* note 25, at 168-69 (describing "climate change [as] a looming complex environmental problem that exhibits multi-source, cross-media and inter-jurisdictional elements") (internal quotation marks omitted); Benson, note 27, at 92-94 (describing the uncertainties involved with managing the Powder River Basin); Light, *supra* note 27, at 65-67 (describing the complexity of the Everglades ecosystem); Olsynzski, *supra* note 28, at 4, 10 (describing adaptive management as "a powerful tool for managing and ultimately reducing the uncertainty associated with specific environmental effects and making better management decisions" and thus sometimes relevant to situations "where there is considerable uncertainty, especially with respect to the effectiveness of a proposed management action"); Cannon, *supra* note 29, at 567-73 (describing Superfund sites as "present[ing] the sorts of uncertainties and opportunities for learning over extended periods for which adaptive management is particularly suited. Decisions require information about (1) the nature, quantity and location of contaminants on site; (2) site characteristics, including ecosystem processes such as ground water flow and microbial activity; (3) costs and effectiveness of remedies; (4) political and economic conditions affecting clean up and reuse; and (5) values affecting the merits of alternative site futures."); Ruhl, *Taking Adaptive Management Seriously*, *supra* note 30, at 1253-62 (describing the "complex adaptive nature of ESA's subject matter"); Davidson & Geu, *supra* note 31, at 820-34 (describing the "diverse" and multifaceted nature of the Missouri River Basin).

33. 33 U.S.C. § 1342(p)(3)(B) (2012).

Stormwater permits also "require implementation of 'best management practices' (BMPs)—engineering, housekeeping, and, sometimes, educational measures designed to reduce pollutant discharges."[34] Additionally, under the EPA's rules, the municipal authority needs to have a plan to detect and address illicit discharges.[35] Then at the end of each year, the municipality needs to submit an Annual Report to the state agency or EPA explaining how it carried out the plan. While some aspects of the illicit discharge program are prescriptive, others are more adaptive in that it allows the municipality wide discretion as to how it finds and eliminates illicit sources. This is a context in which a continual process of learning and adaptively managing the system would be valuable to achieving the statutory and regulatory goals of the Clean Water Act. We explore the regulatory framework for stormwater in greater detail in the following section on the Clean Water Act.

Although conceptually attractive, the practice of adaptive management is hampered by a number of concerns regarding the actual application of adaptive management as well as the suitability of adaptive management for all circumstances. Professor J.B. Ruhl argued that although the U.S. Fish and Wildlife Service (FWS) explored ways to reform the Habitat Conservation Plan (HCP) program under the Endangered Species Act, environmental group dynamics and judicial application of administrative law inhibited the incorporation of more flexible procedures,[36] to the extent that "[t]oday, the HCP

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34. Dave Owen, *Urbanization, Water Quality, and the Regulated Landscape*, 82 U. COLO. L. REV. 431, 446-50 (2011).

35. The EPA's Phase I regulations for large and medium MS4s require as part of the application a description of the MS4s program to "detect and remove" illicit discharges. 40 C.F.R. § 122.26(d)(2)(iv)(B) (2012). The EPA's Phase II regulations for small MS4s require a minimum control of detecting and eliminating illicit discharges. 40 C.F.R. § 122.34(b)(3)(i) (2012). *See also* CTR. FOR WATERSHED PROT., ILLICIT DISCHARGE DETECTION AND TRACKING GUIDE 4 (2011).

36. *See* Ruhl, *Is It Possible?*, *supra* note 15, at 49-53. In particular, Professor Ruhl pointed towards two adaptive-management-oriented developments—an FWS shift toward ecosystems rather than species, and a greater emphasis on landowner collaboration—and discussed ways in which courts struck down these changes as failing to have adequate support to survive arbitrary and capricious review. *Id.*

program increasingly resembles a plain vanilla regulatory program: functional, but increasingly stripped of its once promising adaptive qualities."[37] Professor Alejandro Camacho argued that that stripped-down vision of adaptive management is limited, observing how the FWS both limits the circumstances under which adaptive management is mandated,[38] and fails to include procedures that actually use the monitoring data required under the HCPs to adjust management techniques.[39] Professor Lawrence Susskind made a similar observation in his study of adaptive management in the Glen Canyon, where Congress gave little guidance to the Glen Canyon Dam Adaptive Management Group about how to weigh different resource goals, and the Department of Interior failed to structure the actual management group in ways that would enhance its adaptive management capabilities.[40] Professor Bradley Karkkainen observed that it is unclear whether adaptive management can produce not only better-informed decisions, but superior substantive results.[41] Large-scale adaptive management experiments are underway in the Chesapeake Bay and Florida Everglades, but "they have yet to deliver clearly convincing victories on the ground in the form of substantial advances in

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37. *Id.* at 33; *cf.* J.B. Ruhl, *Adaptive Management in Courts*, 95 MINN. L. REV. 424, 426 (2010) (observing that when courts evaluate agency plans that incorporate adaptive management techniques, "(1) larger-scale plans are more likely to incorporate adaptive management plans that withstand judicial scrutiny than are smaller-scale ones; (2) the practice of tiering site-specific environmental impact analyses to an earlier, overarching, cumulative study is well suited to adaptive management, and adaptive management can reduce the need for supplemental analyses; and (3) adaptive management procedures, no matter how finely crafted, cannot substitute for showing that a plan will meet substantive management criteria required by law.").

38. *See* Alejandro E. Camacho, *Can Regulation Evolve? Lessons From a Study in Maladaptive Management*, 55 UCLA L. REV. 293, 331 (2007) [hereinafter Camacho, *Can Regulation Evolve?*].

39. *See id.* at 333-34; *cf.* Karkkainen, *Adaptive Ecosystem Management*, *supra* note 22, at 953-56 (describing a narrower implementation of adaptive management in HCPs, National Forest Plans, and the Everglades Restoration Plan, than contemplated by most proponents of adaptive management).

40. *See* Lawrence Susskind, *Collaborative Planning and Adaptive Management in Glen Canyon: A Cautionary Tale*, 35 COLUM. J. ENVTL L. J. 1 (2010).

41. Karkkainen, *Bottlenecks and Baselines*, *supra* note 13, at 1444.

environmental protection and ecological restoration."[42]

Other scholars, such as Professors Holly Doremus and Jody Freeman, have expressed concerns about the susceptibility of adaptive management to agency capture by using flexibility as a smokescreen to avoid actual management responsibilities.[43] Moreover, without prescriptive standards, citizens may be less able to hold agencies accountable for derogation of their management duties, as citizen suits may be impracticable without clear rules and timetables.[44] Many in the environmental community are suspicious of adaptive management because they "see it as a step toward greater agency discretion, less accountability, and less certainty that basic environmental-protection standards will be attained."[45] Adaptive management alone may also fail to incorporate sufficient incentives to weigh environmental values against the more economic values that might arise through more open-ended processes, especially when they are structured to involve regulated stakeholders through collaborative processes.[46] Finally, adaptive management may itself involve time and resource costs and may involve a greater degree of stakeholder burden and controversy because of its iterative nature.[47]

Professor Doremus argued that a more structured approach to adaptive management might address some of these concerns. In particular, she suggested that, when determining whether to incorporate adaptive management techniques, managers,

42. *Id.*

43. *See* Doremus, *The Institutional Challenges, supra* note 20, at 52; Jody Freeman, *The Contracting State*, 28 FLA. ST. U. L. REV. 155, 157 (2000); *cf.* Richard B. Stewart, *A New Generation of Environmental Regulation?*, 29 CAP. U. L. REV. 21, 57-58 (2001) (describing adaptive management mechanisms as often having a "shadowy" legal status).

44. Doremus, *The Institutional Challenges*, *supra* note 20, at 84; *cf. id.* at 50 (pointing out that the absence of clarify may also make adaptive management programs more difficult to evaluate in terms of successfulness).

45. Karkkainen, *Bottlenecks and Baselines, supra* note 13, at 1443.

46. *See* Rena I. Steinzor, *Reinventing Environmental Regulation: The Dangerous Journey from Command to Self-Control*, 22 HARV. ENVTL L. REV. 103, 141-43 (1998).

47. *See* Holly Doremus, *Adaptive Management as an Information Problem*, 89 N.C. L. REV. 1455, 1478 (2011) [hereinafter Doremus, *Adaptive Management as an Information Problem*].

"should undertake an explicit, structured analysis of [the] benefits and costs [of applying adaptive management]."[48] Such an analysis would involve examining the extent to which a resource management problem exhibits information gaps,[49] the extent to which those information gaps can be addressed through additional research,[50] and the extent to which the agency can legally engage in actually adjusting their policy choices.[51] Finally, she encouraged agencies to more systematically address contexts in need of adaptive management by more generally developing strategies for facilitating information production regarding managed natural systems;[52] budgeting for learning about natural systems in a manner targeted to improve future management efforts;[53] and improving information diffusion between different agencies, agency offices, and the greater research community.[54] In our qualitative research interviews with stormwater managers we explored some of the issues Professor Doremus identified in order to better understand how a regulatory scheme that allows for more adaptive, rather than prescriptive, approaches implements adaptive management.

Professor Doremus's suggestions, as well as a number of the scholarly studies of adaptive management, focus on the core program of adaptive management: improving the management of a given system through iterative monitoring/adjustment efforts. Thus these studies address whether and how information from monitoring approaches can be used to structure future management practices.[55] But the stormwater context illustrates an additional factor that must be addressed more fully in discussions regarding adaptive management: understanding whether and how natural resource managers incorporate non-agency scientific and technological advancements in the

48. *See id.* at 1482.
49. *See id.* at 1467-70.
50. *See id.* at 1470-77.
51. *See id.* at 1477-78.
52. *See id.* at 1483-88.
53. *See id.* at 1488-89.
54. *See id.* at 1490-96.
55. *See id.* at 1483-96.

monitoring process itself.[56]

In some ways these questions are analogous to those explored in an earlier article by Professor Doremus, where she sharpened discussions of natural resource management data gaps by providing a structured discussion of the "information supply pipeline" (using an analogy of oil pipelines).[57] One of the distinctions she drew was between the "exploration" stage of information gathering, where researchers explore and gather data in different potential areas of study;[58] and "extraction," where the data developed in the "exploration" stage is—often, but not necessarily, by resource managers—evaluated and used when applicable to better enhance management decisions.[59]

The flow of information about monitoring processes also exhibits different stages, much like the "information supply pipeline." Academic researchers "explore" a number of monitoring methods for water contaminants. This can involve exploring different technologies for monitoring as well as different indicators that better match with the goals, such as protecting human health and eliminating raw sewage from untreated stormwater, embedded in the stormwater management program.

Yet this exploratory data is meaningless for actual stormwater management efforts without some form of "extraction," where the exploratory efforts conducted by academics are extracted for their utility to stormwater management efforts. This study, which focuses on how municipal storm water managers incorporate third party research on monitoring methods and metrics, can thus strengthen discussions about adaptive management by highlighting impediments to and incentives for scientific extraction.

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56. *Cf.* Karkkainen, *Bottlenecks and Baselines*, *supra* note 13, at 1443 (describing adaptive management as focusing on adjusting environmental management approaches according to new information about environmental responses, while silent on developments regarding advances in the monitoring processes and technologies).

57. *See* Holly Doremus, *Data Gaps in Natural Resource Management: Sniffing for Leaks Along the Information Pipeline*, 83 IND. L.J. 407 (2008) [hereinafter Doremus, *Data Gaps in Natural Resource Management*].

58. *See id.* at 417-23.

59. *See id.* at 423-29; *see also id.* at 430-43 (describing subsequent stages of "refining," "blending," "distribution," and "consumption" of data).

III. LEGAL FRAMEWORK

Rainfall and melting snow and ice runs along roads, parking lots, and yards and picks up all types of urban pollutants, from oil and grease to pesticides and trash. In urban areas, where many surfaces are paved, any water that does not get absorbed into the ground is known as stormwater runoff.[60] The municipality collects this runoff in a web of infrastructure, which includes drains, ditches, and buried pipes. Cities with combined sewers send stormwater runoff to a sewage treatment plant to get treated along with the sanitary sewage from homes and businesses. Areas without combined sewers collect stormwater in Municipal Separate Storm Sewer Systems (MS4s) and discharge this untreated stormwater directly into rivers, streams and lakes.[61] It is this latter system that we focus on in our research. In this section, we explain the federal regulatory framework in which MS4s operate. Unlike other water pollution programs under the Clean Water Act, Congress chose to have cities use an iterative and discretionary management approach to address urban stormwater pollution. This regulatory approach would benefit from an intentional continual process of learning and adapting management techniques to produce better results. However, while Congress gave broad discretion to cities, it did not give explicit guidelines supportive of a continual learning and adaptation process.

A. *The Federal Framework for Municipal Stormwater*

Stormwater discharges from MS4s are one of the most significant sources of water pollution in the nation.[62] In the EPA's latest report to Congress, urban stormwater is a major

60. Owen, *supra* note 34, at 441-42.

61. 40 C.F.R. § 122.26(a)(7), (b)(8). EPA defines a municipal separate storm sewer system as a conveyance or system of conveyances meant to control stormwater, including roads, curbs, or storm drains, that is owned by a city, town, or other public body, excluding combined sewers or public treatment works. *Id.*

62. Envtl. Def. Ctr. v. U.S. Envtl. Prot. Agency, 344 F.3d 832, 840 (9th Cir. 2003).

cause of impairment of water quality.[63] Yet, for years the EPA attempted to avoid regulating municipal stormwater pollution. Initially, EPA exempted MS4s from the general Clean Water Act requirements of a National Pollutant Discharge Elimination System (NPDES) permit for all "point sources" of pollution.[64] In *Natural Resources Defense Council v. Costle,* the 9th Circuit Court of Appeals rejected that approach and held EPA's exemption was invalid.[65]

Part of the difficulty of establishing a regulatory structure for MS4s is that they do not easily fit into the point and nonpoint regulatory categories Congress established in the Clean Water Act.[66] Although diffuse and diverse, the runoff from urban areas is not a non-point source because MS4s gather the runoff and discharge it from discrete pipes into rivers, streams and lakes. Unlike a typical point source, such as a factory that has a few discrete pipes discharging polluted wastewater, MS4s may include multiple municipalities connected to the storm sewer infrastructure and could include thousands of miles of open channels and storm drains with hundreds of discharge pipes into multiple waterbodies. In Los Angeles County, for instance, the Los Angeles County Flood Control District operates an MS4 that collects stormwater from eighty-four cities and some unincorporated areas of the county through "500 miles of open

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63. According to the most recent National Water Quality Inventory (derived from Section 305(b) of the CWA), approximately 9% (22,559 miles) of impaired rivers and streams; 7% (701,024 acres) of impaired lakes, ponds, and reservoirs; and 12% (867 square miles) of impaired bays and estuaries are polluted by urban runoff/stormwater. This may not seem extremely high but the impact is disproportionately large considering urban areas cover only around 3% of the United States. *See* U.S. ENVTL. PROT. AGENCY, NATIONAL WATER QUALITY INVENTORY: REPORT TO CONGRESS 2004 REPORTING CYCLE 16-23 (2009), *available at* http://water.epa.gov/lawsregs/guidance/cwa/305b/upload/2009_01_22_305b_2004report_2004_305Breport.pdf; *see also* NATIONAL RESEARCH COUNCIL, URBAN STORMWATER MANAGEMENT IN THE UNITED STATES 21 (2008), *available at* http://www.epa.gov/npdes/pubs/nrc_stormwaterreport.pdf.

64. Natural Res. Def. Council v. Costle, 568 F.2d 1369, 1371-72 (D.C. Cir. 1977).

65. *Id.* at 1371-72 (invalidating EPA's regulations exempting MS4s from NPDES permits).

66. 33 U.S.C. § 1362(14) (2012) (defining point source).

channels and 2,800 miles of storm drains."[67]

Perhaps due to MS4s complexity, ten years passed from the time the 9th Circuit invalidated EPA's exemption of MS4s from NPDES permits[68] before Congress took action. In 1987, Congress directed the EPA to treat municipal storm water more like a factory than farm fields: discharges of municipal stormwater must comply with an NPDES permit for point sources of pollution.[69]

However, the difficulty of neatly fitting into one of the regulatory boxes may have been the reason Congress took a different regulatory approach to urban stormwater. Factories and other typical point sources of water pollution need to meet effluent limitations, water quality standards,[70] and monitoring and reporting requirements, among other things.[71] These NPDES permits are primarily prescriptive and lend themselves to clearly enforceable permit limits. By contrast, in its 1987 amendments to the Clean Water Act (CWA), Congress directed that NPDES permits for municipal stormwater be more iterative and involve best management practices instead of strict end-of-pipe effluent limits based on technology and water quality standards.[72]

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67. Natural Res. Def. Council v. Los Angeles Cnty.,No. 10-56017, 2011 WL 2712963, at *2 (9th Cir. July, 13, 2011).

68. *Costle,* 568 F.2d at 1371-72.

69. Water Quality Act of 1987,Pub.L. No. 100-4, 10 Stat. 7 (1987); 33 U.S.C. § 1362(14) (defining point source); 33 U.S.C. § 1342(p) (2012) (requiring NPDES permits for MS4s). The creation of the MS4 program was part of Congress' 1987 amendments to the Clean Water Act, which were its last major amendments to the CWA. "That legislation culminated six years of congressional efforts to extend and revise the act and were the most comprehensive amendments since 1972." CLAUDIA COPELAND, CONG. RESEARCH SERV., R41594, WATER QUALITY ISSUES IN THE 112TH CONGRESS: OVERSIGHT AND IMPLEMENTATION 2 (2012).

70. "Water quality standards are provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses." 33 U.S.C. § 1313(a), (c)(2)(A) (2012); 40 C.F.R. § 131.3(i) (2012) . For instance, a state may designate a recreational use for a waterbody and then set a particular level of bacteria that cannot be exceeded in order to protect recreation.

71. Clean Water Act, 33 U.S.C. §§ 1311-1312, 1314, 1316-1318, 1342(a), 1343 (2012).

72. *Compare* 33 U.S.C. § 1342(p)(3)(B) (requiring best management practices for MS4s) *with* 33 U.S.C. § 1342(p)(3)(A) (requiring compliance with section

> Section 402(p)(3)(iii) of the CWA mandates that permits for discharges from municipal separate storm sewers shall require controls to reduce the discharge of pollutants to the maximum extent practicable (MEP), including management practices, control techniques and systems, design and engineering methods, and such other provisions as the Director determines appropriate for the control of such pollutants.[73]

Regulators have far less experience with this iterative and more management-oriented approach to municipal stormwater than they do with traditional prescriptive NPDES permits for industries and municipal wastewater treatment plants. Congress adopted phased and tiered NPDES permits for MS4s.[74] Initiated in 1990, Phase I required permits for "the most significant sources of stormwater pollution," which included MS4s serving populations of 100,000 or more.[75] Then, in 1999, Phase II required NPDES permits for the remaining small MS4s.[76] Hence, many cities in the U.S. have only been managing their stormwater under these Clean Water Act requirements for about a decade. When EPA created its regulations for the Phase I permits, it intentionally built in a tremendous amount of discretion and reflected implicitly an adaptive management approach.

> EPA anticipates that storm water management programs will evolve and mature over time. The permits for discharges from municipal separate storm sewer systems will be written to reflect changing conditions that result from program development and implementation and corresponding

1311 water quality standards for industrial stormwater discharges); Defenders of Wildlife v. Browner, 191 F.3d 1159, 1166 (9th Cir. 1999) (holding EPA's decision to not require MS4s to meet Water Quality Standards was not arbitrary and capricious given statute unambiguously expressed Congress' intent that MS4s did not have to strictly comply).

73. National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges, 55 Fed. Reg. 47,990, 48,038 (Nov. 16, 1990) (to be codified at 40 C.F.R. pts. 122-124).

74. 33 U.S.C. § 1342(p)(4).

75. 33 U.S.C. § 1342(p)(2).

76. *Stormwater Discharges from Municipal Separate Storm Sewer Systems*, ENVTL. PROT. AGENCY, http://cfpub.epa.gov/npdes/stormwater/munic.cfm (last visited June 22, 2013). Typically, large and mid-sized MS4s obtain individual permits and the smaller MS4s obtain coverage under a general permit. *Id.*

improvements in water quality.[77]

Professor Dave Owen's review of the legislative history of these Clean Water Act amendments indicates that members of Congress viewed this flexible and time-phased regulatory approach as an "appropriate compromise.[78] In Professor Owen's assessment, these members underestimated the scope and extent of harm urban stormwater causes to public waterways.[79] Furthermore, according to Owen, "some members believed, incorrectly, that many stormwater sources, including drainage from impervious surfaces, were environmentally innocuous."[80]

Breaking from the traditional point source approach was controversial and litigated. Again, the 9th Circuit Court of Appeals was called upon to review the regulation of MS4s. In *Defenders of Wildlife v. Browner*, the court held the Clean Water Act amendments related to MS4s "did not require municipal storm-sewer discharges to comply strictly with [water quality standards]."[81] However, the statute allows the regulatory agency the discretion to include more traditional prescriptive limits, such as requiring compliance with water quality standards or otherwise "determine what [additional] pollution controls are appropriate."[82]

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77. National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges, 55 Fed. Reg. at 48052 (Phase I regulations).

78. Owen, *supra* note 34, at n.120.

79. *Id.* ("We established a mechanism that will require permits only where necessary—rather than in every instance. Without these changes, local, State, and Federal officials would be inundated with an enormous permitting workload even though most of the discharges would not have significant environmental impacts." (quoting 133 Cong. Rec. 985 (1987) (statement of Rep. Hammerschmidt))).

80. *Id.* ("Without any compromise to the environment or reduction in the commitment to clean water we can prevent unnecessary diversion of personnel and other resources to an unproductive paper shuffling exercise by not requiring permits for rainwater runoff from parking lots False" (quoting 131 Cong. Rec. 20,006 (1985) (statement of Rep. Rowland))).

81. Defenders of Wildlife v. Browner, 191 F.3d 1159, 1166 (9th Cir. 1999).

82. *Id.* at 1166. An example of an MS4 permit that included water quality standards is the permit for Los Angeles County and Flood Control District, which contained specific provisions that required the permittees to "assure that storm water discharges from the MS4 shall neither cause nor contribute to the exceedance of water quality standards . . ." and prohibited the "discharge of non-

In the MS4 permit for Los Angeles the regulatory agency exercised that discretion and the permit included a specific requirement to comply with water quality standards.[83] The permit also incorporated a water plan for the Los Angeles Region, which set limits on fecal coliform bacteria and other contaminants for the receiving waters of Southern California.[84] However, even with this more typical point source approach to MS4 pollution, the permit continued to include a strong adaptive management component. Unlike typical end-of-the-pipe effluent limits, this MS4 permit provided that the permittees "shall comply" with the above discharge prohibitions by implementing "control measures and other actions to reduce pollutants . . . in accordance with [the Los Angeles Stormwater Quality Management Program . . ."[85] Further, despite Los Angeles' more traditional prescriptive approach specifying water quality standards, it did not enforce this MS4's NPDES permit the way it would a factory's NPDES permit. For example, the permit stipulated that if the MS4 violated water quality standards, the permittees and the regulator must engage in an iterative and adaptive process to attain compliance.[86]

Although Congress and the EPA created a management-oriented highly discretionary municipal stormwater program, they did not carefully incorporate adaptive management theory into the regulatory structure. Similarly, due to the state of biological and molecular science in the late 1980s,[87] Congress could not have appreciated the problems aging sanitary sewage and stormwater infrastructure would pose to public health and

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storm water to the MS4." Natural Res. Def. Council v. Cnty. of Los Angeles, 673 F.3d 880, 887 (9th Cir. 2011). The permit also incorporated a water plan for the Los Angeles Region, which set limits on fecal coliform bacteria and other contaminants for the receiving waters of Southern California. *Id.*

83. The MS4 permit required permittees to "assure that storm water discharges from the MS4 shall neither cause nor contribute to the exceedance of water quality standards . . ." and prohibited the "discharge of non-storm water to the MS4." *Id.*

84. *Id.*

85. *Id.*

86. *Id.* at 887-88.

87. Scientists developed molecular techniques in the 1980s that allow testing the genetics of bacteria. *See infra* Section IV.

the nation's waters. However, it did anticipate potential problems enough to insert a provision in the Clean Water Act broadly prohibiting non-storm water discharges from MS4s.

B. *The Federal Framework Prohibiting Non-Stormwater Discharges from MS4s*

Pollutants from untreated non-stormwater waste can "significantly degrade" the nation's water quality and threaten human health.[88] EPA studies have shown that non-stormwater waste, also known as illicit discharges, is significant in some MS4s; a study of Sacramento, California, for instance, found "almost one-half of the water discharged from a local MS4 was not directly attributable to precipitation runoff."[89] In its guidance manual EPA highlights that eliminating "illicit discharges is a critical component to restoring urban watersheds."[90] Illicit discharges can cause beach closings due to bacteria contamination, restrict fishing and shellfish harvesting, and prevent the use of waterbodies for drinking water and recreation.[91]

Congress attempted to address this issue in its 1987 amendments requiring NPDES permits for MS4s to require them to "effectively prohibit non-stormwater discharges into the storm sewers."[92] It is this requirement that is particularly relevant to addressing the interplay of emerging science, law and policy as it relates to stormwater pollution, aging infrastructure, and human sewage. MS4s, regardless of size, need to meet this federal statutory requirement.[93] The EPA's regulatory approach to this is essentially adaptive, but would benefit from a more carefully constructed system that actively encouraged learning

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88. U.S. ENVTL. PROT. AGENCY, 833-F-00-007, FACT SHEET 2.5 STORMWATER PHASE II FINAL RULE: ILLICIT DISCHARGE DETECTION AND ELIMINATION MINIMUM CONTROL MEASURE 1 (rev. 2005) [hereinafter STORMWATER PHASE II FINAL RULE], *available at* http://www.epa.gov/ npdes/pubs/fact2-5.pdf.

89. *Id.*

90. PITT & CTR. FOR WATERSHED PROT., *supra* note 10, at 15.

91. *Id.* at 15-16.

92. 33 U.S.C. § 1342(p)(3)(B)(ii) (2012).

93. *Id.*

and adapting management practices in light of that learning. In order to meet the statutory prohibition against non-stormwater discharges, the EPA requires MS4s to have programs to detect and eliminate illicit discharges.[94] For instance, small MS4s need to "develop, implement and enforce a program to detect and eliminate illicit discharges."[95] However, the regulations are light on any required content of such programs. In fact, the EPA requires only four elements in an MS4's illicit discharge program: 1) develop "a storm sewer system map, showing the location of all outfalls and the names and location of all waters of the United States that receive discharges from those outfalls;"[96] 2) pass an ordinance that effectively prohibits non-stormwater discharges "to the extent allowable under State, Tribal or local law;"[97] 3) develop and implement an illicit discharge plan;[98] and 4) inform people about the "hazards" of illicit discharges.[99] All of these requirements provide broad discretion to the MS4 by not establishing timeframes or details. Under the heading "guidance" the EPA provides recommendations primarily aimed at establishing management procedures:

> EPA recommends that the plan to detect and address illicit discharges include the following four components: procedures for locating priority areas likely to have illicit discharges; procedures for tracing the source of an illicit discharge; procedures for removing the source of the discharge; and procedures for program evaluation and assessment. EPA recommends visually screening outfalls during dry weather and conducting field tests of selected pollutants as part of the procedures for locating priority areas. Illicit discharge education actions may include storm drain stenciling, a program to promote, publicize, and facilitate public reporting

94. The EPA's Phase I regulations for large and medium MS4s require as part of the application a description of the MS4s program to "detect and remove" illicit discharges. 40 C.F.R. § 122.26(d)(2)(iv)(B) (2012). The EPA's Phase II regulations for small MS4s require a minimum control of detecting and eliminating illicit discharges. 40 C.F.R. § 122.34(b)(3)(i) (2012).

95. 40 C.F.R. § 122.34(b)(3).

96. *Id.* at § 122.34(b)(3)(ii)(A).

97. *Id.* at § 122.34(b)(3)(ii)(B).

98. *Id.* at § 122.34(b)(3)(ii)(C).

99. *Id.* at § 122.34(b)(3)(ii)(D).

of illicit connections or discharges, and distribution of outreach materials.[100]

The EPA then contracted with the Center for Watershed Protection to produce a guidance manual to assist MS4s charged with developing and carrying out an illicit discharge program. The guidance manual frames the adaptive nature of the program: "Detecting and eliminating these illicit discharges involves complex detective work, which makes it hard to establish a rigid prescription to 'hunt down' and correct all illicit connections."[101] It identifies the program as one that should evolve and show improvements over time.[102] Such an evolving program would benefit from strategies that emphasize regular monitoring of circumstances and adjusting management decisions accordingly. However, as will be explained in the case study below, the adaptive nature of this program is limited by a variety of factors. This is a program that could be strengthened by creating a regulatory structure that carefully supports adaptive management.

While there are a wide variety of types of illicit discharges, ranging from dumping used oil to running car wash water into a storm drain,[103] this research focuses on how water managers address the problem of human sewage entering the storm sewer and being discharged untreated into the nation's waterways. The two primary ways human sewage makes its way into stormwater are: 1) direct connections of sanitary sewage pipes that are erroneously or intentionally cross connected into the storm

100. *Id.* at § 122.34(b)(3)(iv).

101. PITT & CTR. FOR WATERSHED PROT., *supra* note 10, at 1.

102. *Id.*

103. An "illicit discharge" is any discharge to an MS4 "that is not composed entirely of storm water, except allowable discharges pursuant to an NPDES permit . . . and discharges resulting from fire fighting activities." 40 C.F.R. § 122.26(b)(2). In addition to sanitary wastewater, illicit discharges could come from car wash wastewater, improper oil disposal, radiator flushing disposal, laundry wastewaters, spills from roadway accidents, and improper disposal of auto and household toxics. STORMWATER PHASE II FINAL RULE, *supra* note 88, at 1. The Guidance Manual groups these flow types into six categories: sewage and septage, washwater, liquid wastes, tap water, landscape irrigation, and ground or spring waters. PITT & CTR. FOR WATERSHED PROT., *supra* note 10, at 6.

sewer, and 2) outdated infrastructure that is leaking human waste from sanitary sewage pipes that can infiltrate into the storm sewer.[104] Both scenarios pose significant public health concerns and are clearly prohibited as non-stormwater discharges.[105]

The extent of such illicit sewage pollution has more clearly come to light due to scientific developments in both identifying better indicators of human sources of fecal pollution and molecular techniques that allow their detection, which will be explained in the following section. Because MS4s operate under legal requirements to keep non-storm water out of their systems and run programs to detect and eliminate illicit discharges in order to meet this prohibition, MS4s need accurate tools to quickly remedy situations where human sewage is being discharged from storm sewers. In addition to the human health threats of discharging raw sewage into recreational or drinking waters, every day that an MS4 violates any condition of its permit, it may be exposed to significant monetary penalties.[106] This research gathers insights from municipal stormwater managers and analyzes how and to what extent they are employing adaptive management to address illicit discharges. We look at how stormwater managers interpret this iterative management-oriented legal framework, and whether and how they "extract" highly relevant scientific developments to produce better substantive outcomes.

IV.
SCIENTIFIC DEVELOPMENTS

Recent advancements in the study of fecal indicator bacteria have enabled the development of a growing body of work that seeks to understand the many different facets of fecal bacteria pollution in stormwater including its sources and the risk to

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104. STORMWATER PHASE II FINAL RULE, *supra* note 88, at 1; CTR. FOR WATERSHED PROT., *supra* note 35, at 2.

105. Clean Water Act, 33 U.S.C. § 1342(p)(3)(B)(ii) (2012).

106. Clean Water Act, 33 U.S.C. § 1319 (2012). However, this liability threat may not amount to much in this context where enforcement actions against MS4s are rare. *See infra* Section V.

human health at discharge points. These breakthroughs are due, in large part, to the discovery of better water quality indicators and the development and accessibility of molecular techniques such as quantitative polymerase chain reaction (qPCR), the most common method to quantify bacteria without culturing it.[107]

Molecular methods, as opposed to earlier culture-based methods, have become popular with scientists who seek to evaluate alternative indicators and their detection in the environment. Using qPCR, scientists are able to amplify bacterial DNA of a specific species that is associated with humans and not found in other sources.[108] This process allows for identification and quantification of the bacteria, which is indicative of the source. Because the detection is based on amplifying a specific gene, this approach is sometimes referred to as using a genetic marker.

The current EPA water quality criteria recommends testing for *E. coli* or enterococcus as an indicator of the presence of human sewage;[109] however recent studies document that both *E. coli* and enterococcus come from a variety of human and non-human sources,[110] can persist and grow in the environment,[111]

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107. PCR is a relatively new technology and is slowly replacing culture-based methods. Culture-based methods are easy and inexpensive but can take 18-24 hours to process whereas PCR requires expensive machinery and intensive training but can process samples in just a few hours. *See* SANDRA L. MCLELLAN ET AL., MARINE AND FRESHWATER FECAL INDICATORS AND SOURCE IDENTIFICATION 2, 14 (unpublished draft book chapter).

108. *E.g., id.*

109. U.S. ENVTL. PROT. AGENCY, AMBIENT WATER QUALITY CRITERIA FOR BACTERIA 5 (1986).

110. This factor can make it more difficult both to find the source of the pollution and to evaluate the level of danger to humans. *See e.g.*, Tao Yan & Michael J. Sadowsky, *Determining Sources of Fecal Bacteria in Waterways*, 127 ENVTL. MONITORING & ASSESSMENT 97 (2007); Belinda Barnes & David M. Gordon, *Coliform Dynamics and the Implications for Source Tracking*, 6 ENVTL. MICROBIOLOGY 501 (2004).

111. *E.g.,* Cheryl M. Davies et al., *Survival of Fecal Microorganisms in Marine and Freshwater Sediments,* 61 APPLIED & ENVTL. MICROBIOLOGY 1888, 1893 (1995); Timothy R. Desmarais et al., *Influence of Soil on Fecal Indicator Organisms in a Tidally Influenced Subtropical Environment,* 68 APPLIED & ENVTL. MICROBIOLOGY 1165 (2002); Satoshi Ishii et al., *Presence and Growth of Naturalized* Escherichia Coli *in Temperate Soils from Lake Superior Watersheds,* 72 APPLIED & ENVTL. MICROBIOLOGY 612 (2006); Peter W.

and may show no correlation to the presence of pathogens associated with human illness.[112] When it comes to testing stormwater, this means that *E. coli* and enterococcus levels may be high even if human sewage is not present. The indicators are so general that they do not tell water managers much about the source of the bacteria problem. Understanding the limitations of these bacteria indicators has led to a wealth of new scientific studies to find more specific indicator organisms. Scientists have studied a variety of possible new indicators as well as better methods for testing.[113] Researchers who study this particular link between indicator presence and human sewage presence have evaluated the relationships between actual pathogen appearance and the appearance of both traditional (i.e., *E. coli* and enterococcus) and alternative indicators in stormwater samples.[114] There is a general consensus that neither *E. coli* nor

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Bergholz et al., *Environmental Patterns Are Imposed on the Population Structure of Escherichia Coli After Fecal Deposition*, 77 APPLIED & ENVTL. MICROBIOLOGY 211 (2011).

112. *E.g.,* Rachel T. Noble & Jed A. Fuhrman, *Enteroviruses Detected by Reverse Transcriptase Polymerase Chain Reaction from the Coastal Waters of Santa Monica Bay, California: Low Correlation to Bacterial Indicator Levels,* 460 HYDROBIOLOGIA 175 (2001); Alexandria B. Boehm et al., *A Tiered Approach for Identification of a Human Fecal Pollution Source at a Recreational Beach: A Case Study at Avalon Bay, Catalina Island, California, USA,* 37 ENVTL. SCI. & TECH. 673 (2003); Mary E. Schoen & Nicholas J. Ashbolt, *Assessing Pathogen Risk to Swimmers at Non-Sewage Impacted Recreational Beaches*, 44 ENVTL. SCI. & TECH. 2286 (2010).

113. *E.g.*, W. Ahmed et al., *Sourcing Faecal Pollution: A Combination of Library-Dependent and Library-Independent Methods to Identify Human Faecal Pollution in Non-Sewered Catchments*, 41 WATER RESEARCH 3771 (2007) [hereinafter Ahmed et al, *Sourcing Faecal Pollution*]; J.R. Stewart et al., *The Coastal Environment and Human Health: Microbial Indicators, Pathogens, Sentinels, and Reservoirs*, 7 ENVTL. HEALTH S3 (2008); Reagan R. Converse et al., *Rapid QPCR-based Assay for Fecal Bacteroides spp. as a Tool for Assessing Fecal Contamination in Recreational Waters*, 43 WATER RESEARCH 4828 (2009).

114. *See, e.g.*, V.B. Rajal et al., *Molecular Quantitative Analysis of Human Viruses in California Stormwater*, 41 WATER RESEARCH 4287 (2007); M.L. O'Shea & R. Field, *Detection and Disinfection of Pathogens in Storm-Generated Flows*, 38 CAN. J. MICROBIOL. 267 (1992); R.T. Noble, S.M. Allen et al., *Use of Viral Pathogens and Indicators to Differentiate Between Human and Non-Human Fecal Contamination in a Microbial Source Tracking Comparison Study*, 1 J. WATER HEALTH 195 (2003); S.C. Jiang & W. Chu, *PCR Detection of Pathogenic Viruses in Southern California Urban Rivers*, 97 J. APPLIED MICROBIOLOGY 17 (2004).

enterococcus are the best indicators of human sewage pollution.[115] Some scientists now test for the presence of a human-specific genetic marker found in *Bacteroides*, another type of fecal bacteria. Studies show that a human-specific *Bacteroides* genetic marker provides a much better indicator of the presence of human sewage than either of the EPA recommended tests for bacteria.[116]

Much of the research on alternative fecal indicator bacteria has centered on the need for source specificity.[117] These source studies can be grouped into two different categories: source-type determination and source-location determination. Source-type studies involve the differentiation between human and animal (wild or domestic) sources of fecal contamination. Source-location determination uses information about the types and concentrations of fecal indicator bacteria and attempts to locate and map the origin of contamination. In the case of water quality standards on recreational beaches – where most studies have been completed - epidemiological studies have shown that those pathogens that are most dangerous to human health come from human sources.[118] As this pertains to stormwater, human

115. *See, e.g.,* Noble & Fuhrman, *supra* note 112.

116. *See, e.g.,* Ahmed et al., *Evaluation of Bacteroides Markers*, *supra* note 9, at 237; Anne E. Bernhard & Katharine G. Field, *A PCR Assay to Discriminate Human and Ruminant Feces on the Basis of Host Differences in* Bacteroides-Prevotella *Genes Encoding 16S rRNA*, 66 APPLIED & ENVTL. MICROBIOLOGY 4571 (2000); Laurie C. Van De Werfhorst et al., *Comparison of the Host Specificities of Two Bacteroidales Quantitative PCR Assays Used for Tracking Human Fecal Contamination*, 77 APPLIED & ENVTL. MICROBIOLOGY 6258 (2011); Ryan J. Newton et al., Lachnospiraceae *and* Bacteroidales *Alternative Fecal Indicators Reveal Chronic Human Sewage Contamination in an Urban Harbor*, 77 APPLIED & ENVTL. MICROBIOLOGY 6972 (2011).

117. *E.g.*, Kenneth Schiff & Patrick Kinney, *Tracking Sources of Bacterial Contamination in Stormwater Discharges to Mission Bay, California*, 73 WATER ENV'T RESEARCH 534, 534 (2001) (using total coliforms, fecal coliforms, and enterococcus); J.L. Ram et al., *Identification of Pets and Raccoons as Sources of Bacterial Contamination of Urban Storm Sewers Using a Sequence-Based Bacterial Source Tracking Method*, 41 WATER RESEARCH 3605 (2007) (using *E. coli*); V.B. Rajal et al., *supra* note 114, at 4287 (testing for human pathogens directly).

118. *E.g.*, R.W. Haile & J.S. Witte, *The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff*, 10 EPIDEMIOLOGY 355 (1999); R.T. Noble et al., *Use of Viral Pathogens and Indicators to Differentiate Between*

sources are treated differently than non-human sources under the Clean Water Act.[119] This means that new indicator organisms should be able to differentiate between human and non-human fecal pollution to more correctly identify where human sewage has entered an MS4 system.

Other scientists have taken the alternative indicator research beyond the lab and into the field to seek practical application. These scientists have tested stormwater for a variety of traditional as well as new indicators for the purpose of locating and eliminating the sources of such pollution.[120] Often times, these studies have involved determining indicator concentration at different points along a stormwater pipe system or a river system where stormwater outfalls are located and determining areas where illicit discharges likely exist, as evidenced by high indicator concentrations.[121] By combining source-type and source-location studies, "hot spots" of human fecal indicators can be identified. This will allow for targeted source investigations and therefore would be a more effective use of limited resources to find and abate sources of human sewage entering the nation's waters untreated.

Dr. Sandra McLellan's research lab has been collecting and analyzing bacteria samples in and around the City of Milwaukee.[122] While part of Milwaukee utilizes a combined sewer system, an MS4 collects and discharges untreated stormwater from the uncombined parts of the service area into seven water bodies.[123] Dr. McLellan has analyzed water samples

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Human and Non-Human Fecal Contamination in a Microbial Source Tracking Comparison Study, 1 J. WATER HEALTH 195 (2003).

119. Human sewage in stormwater is clearly prohibited as a non-stormwater discharge. Clean Water Act, 33 U.S.C. § 1342(p)(3)(B)(ii) (2012). *See also* discussion *infra* Section V.

120. Noble et al., *supra* note 118.

121. Schiff & Kinney, *supra* note 117; Julie L. Kinzelman & Sandra L. McLellan, *Success of Science-Based Best Management Practices in Reducing Swimming Bans – A Case Study from Racine, Wisconsin, USA*, 12 AQUATIC ECOSYSTEM HEALTH & MGMT. 187, 187-96 (2009).

122. Elizabeth P. Sauer et al., *supra* note 9, at 4082.

123. MS4 Permit City of Milwaukee, at 1, WI-S049018-3. The seven waterbodies are Milwaukee, Menomonee, Kinnickinnic, and Root Rivers, Oak Creek, Lake Michigan, and Milwaukee Harbor Estuary.

from Milwaukee's MS4 since 2006. She and her research team evaluate the samples using qPCR to detect and quantify new alternative indicators, and use the resulting data to determine whether the samples have been polluted with human sewage.[124]

Dr. McLellan's research documents human *Bacteroides* in numerous stormwater outfalls in the Milwaukee metropolitan area.[125] She and her team took 828 water samples from forty-five different stormwater outfalls over a period of four years (2006-2009).[126] The results were staggering: 476 of the 828 samples (57%) contained the human *Bacteroides* genetic marker and every site examined had intermittent sewage contamination.[127] In some cases, the volume of the sewage contamination was not small. Eight of the outfall locations tested demonstrated a human *Bacteroides* content consistent with 25% or more sanitary sewage composition.[128] Though it was not the primary focus of her study, McLellan and her team conducted up-the-pipe investigations at five outfalls that had high levels of indicator bacteria.[129] Four of the five outfalls had an area upstream with approximately two-fold higher levels of human *Bacteroides*, demonstrating the potential for future surveys to pinpoint the breach in the sanitary system.[130]

Milwaukee is not alone; scientists using similar research methods have found human *Bacteroides* in stormwater discharges in other cities.[131] A high volume of studies have come out of Santa Monica Bay, California, an area that contains some of the most popular beaches in the world. The area is heavily polluted by stormwater runoff from metropolitan Los Angeles. A number of studies have relied on the human *Bacteroides* marker

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124. Elizabeth P. Sauer et al., *supra* note 9, at 4082.

125. *Id.*

126. *Id.*

127. *Id.*

128. *Id.*

129. *Id.*

130. *Id.*

131. *See, e.g.,* Kinzelman & McLellan, *supra* note 121, at 187-96; J.K. Parker et al., *Characterizing Fecal Contamination in Stormwater Runoff in Coastal North Carolina, USA,* 44 WATER RESEARCH 4186 (2010); Sercu et al., *supra* note 9.

to detect widespread human sewage contamination in stormwater systems and provide insight into infrastructure problems.[132] Other studies have examined human-specific fecal pollution in stormwater systems in North Carolina,[133] Florida,[134] and Australia[135] (see Appendix 1 for characterization of scientific research on this topic).

The research of Dr. McLellan and other scientists is crucial to determine source types and locations of fecal pollution, identify health risks, and prioritize action to eliminate the source of human sewage. Given the potential utility of this research for water managers and the extensive database of stormwater outfalls that tested positive for the presence of human sewage in the Milwaukee metropolitan area, we identified this region as one ripe for exploration of how stormwater managers understand and utilize scientific research that bears heavily on their work. As such, our research examines how these scientific developments are understood and used in the management of illicit discharges from MS4.

V.
ADAPTIVE MANAGEMENT APPLIED TO STORMWATER

Congress and the EPA have established a legal framework for municipal management of illicit discharges to stormwater that is more adaptive than prescriptive. While the federal law clearly prohibits non-stormwater discharges from the MS4, it provides wide discretion to the MS4 to create and implement a plan to detect and eliminate these illicit discharges. The regulatory focus is on management actions informed by a system of monitoring discharge pipes instead of specific end of pipe pollution limits. This program seems influenced by the theory of adaptive

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132. *E.g.*, Sercu et al., *supra* note 9; Noble et al., *supra* note 118; Jiang & Chu, *supra* note 114.

133. Parker et al., *supra* note 131.

134. M.J. Brownell et al., *Confirmation of Putative Stormwater Impact on Water Quality at a Florida Beach by Microbial Source Tracking Methods and Structure of Indicator Organism Populations*, 41 WATER RESEARCH 3747 (2007).

135. Ahmed et al., *Evaluation of Bacteroides Markers*, *supra* note 9; Ahmed et al., *Sourcing Faecal Pollution*, *supra* note 113.

management, which focuses on strategies that emphasize continuous monitoring of circumstances and adjusting decisions accordingly.[136] However, the program would benefit from carefully identifying and addressing the architecture needed to support a successful adaptive management program that produces better substantive results.[137]

In this research we build on Professor Holly Doremus' work urging agencies engaged in adaptive management to more systematically address their information needs and understand how information is diffused to resource managers.[138] Professor Doremus outlined an information supply pipeline in her work,[139] and in our research we focused on how scientific information is "extracted" and used for better water management. As explained in section IV, scientists have developed innovations in the monitoring process to more accurately and efficiently identify the existence of human sewage. Thus, in the municipal stormwater context, we explored how highly relevant scientific developments by non-agency scientists are understood, diffused and applied to MS4 management to identify and eliminate illicit discharges of raw human sewage into our nation's waterways. Our research observations highlight impediments and incentives for scientific extraction that may be broadly applicable to other systems.

A. *Research Methodology*

We selected the Milwaukee metropolitan area because it is a study area with an existing body of scientific data on human specific bacteria in stormwater outfalls and ongoing efforts to gather data to characterize the extent of illicit connections in the urban area. Unlike much academic research, Dr. McLellan's

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136. *See* Ruhl, *supra* note 15, at 28.

137. *See generally* Karkkainen, *Bottlenecks and Baselines, supra* note 13, at 1444 (questioning whether adaptive management produces better substantive results).

138. *See* Doremus, *Adaptive Management as an Information Problem, supra* note 47, at 1470-96.

139. *See* Holly Doremus, *Data Gaps in Natural Resource Management: Sniffing for Leaks Along the Information Pipeline*, 83 IND. L.J. 407, 430-43 (2008).

findings of human sewage in stormwater were widely communicated to the public through the paper of record in Wisconsin.[140] Moreover, the study area is large enough to contain a variety of MS4s operating within it, producing a broader pool of potential interviewees.

One needs to understand the MS4 managers' and state and federal regulators' perspectives, the influences on their decisions, and the systems in which they work to assess how and to what extent urban stormwater managers are incorporating scientific developments to better manage urban waterways. Through qualitative research interviews with the water managers, one can discern how they incorporate scientific advancements into their work, and the barriers and incentives to extracting relevant scientific information that could lead to positive substantive outcomes for water resources.[141] With this in mind, we undertook a series of qualitative research interviews with MS4 water managers, and stormwater regulators from the Wisconsin Department of Natural Resources (DNR) and United States Environmental Protection Agency (EPA).[142] In order to maintain the confidentiality of the interviewees, we omit their names and cities they serve and uniformly use the male pronoun when describing their responses.

B. *Research Findings*

All MS4 managers and state and federal regulators interviewed agree that bacteria in Milwaukee's watersheds is a

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140. Don Behm, *Storm Sewers Oozing Human Fecal Bacteria to Beaches, Rivers, Study Finds*, MILWAUKEE J. SENTINEL, Aug. 2, 2009, *available at* www.jsonline.com/news/milwaukee/52319607.html; Don Behm, *Human Fecal Bacteria Detected in Harbor Water Samples*, MILWAUKEE J. SENTINEL, Oct. 13, 2011, *available at* www.jsonline.com/news/milwaukee/human-fecal-bacteria-detected-in-harbor-water-samples-131833298.html.

141. This type of research aims to describe themes in the interviewee's world. *See* STEINER KVALE, INTERVIEWS: AN INTRODUCTION TO QUALITATIVE RESEARCH INTERVIEWING 54 (1996).

142. We interviewed eight MS4 managers, two Wisconsin Department of Natural Resources stormwater regulators, one U.S. EPA stormwater regulator, and one parent of a child sickened by bacteria-contaminated water.

problem, and that MS4s are a significant conveyor of bacteria.[143] However, some expressed uncertainty about how "bad Milwaukee's watersheds are compared to other urban watersheds"[144] or the extent to which MS4s are contributing to the impairments.[145] Milwaukee's watersheds are, in fact, impaired by bacteria.[146] However, bacteria are diverse and come from a wide variety of sources, with different levels of public health implications. Human source bacteria originating in human sewage has a greater potential to make people sick, for instance, than bacteria from pets or wildlife.[147] Additionally, the follow up for bacteria from wildlife should be different than for human sewage in stormwater.[148] However, our research shows that neither the Clean Water Act regulatory framework nor the people charged with managing urban waters are actively adapting to, or extracting, scientific innovations to detect and eliminate illicit discharges of raw human sewage.

We first identified the regulatory impediments to adaptive management contained in the Clean Water Act and its implementing regulations and then explored the additional non-regulatory obstacles to adaptive management. We focused on how adaptive management theory could be more rigorously applied to aid the transfer or extraction of knowledge from 3rd party scientists to resource managers.

A critical aspect of adaptive management is that managers understand and incorporate evolving scientific knowledge into their management decisions.[149] Adaptive management may be

143. Interview with Confidential Interviewees No. 1 through 12 (May 17 – June 6, 2012). A consultant who contracts with MS4s to screen for illicit discharges was unsure whether bacteria was a problem in these watersheds. Interview with Confidential Interviewee No. 8 (June 6, 2012).

144. Interview with Confidential Interviewee No. 1 (May 29, 2012).

145. Interview with Confidential Interviewee No. 10 (May 29, 2012).

146. Impaired Water Search, WIS. DEP'T OF NATURAL RES., http://dnr.wi.gov/water/impairedSearch.aspx (search "Milwaukee" for "County", search "Recreational Restrictions – Pathogens" for "Impairment", then follow "Search" hyperlink) (identifying 21 waterbody segments impaired by coliform or *E. Coli* bacteria).

147. *See supra* Section IV.

148. Interview with Confidential Interviewee No. 12 (May 23, 2012).

149. *See* Ruhl, *Is It Possible?*, *supra* note 15, at 28.

most useful in environmental management situations where numerous factors and response relationships prevail; the knowledge about those factors and the relationships are not fully identified; and the systems are often dynamic, rather than static.[150] Managing urban stormwater to identify and eliminate illicit discharges of human sewage is theoretically well suited for an adaptive management approach because the discharges are often intermittent and the sewersheds can be large and complex. Further, the program requires regular monitoring of outfalls during dry weather to detect possible illicit sources, and scientists have developed new monitoring techniques that can quickly and accurately identify sources of human sewage that pose significant human health risks. However, adaptive management will not deliver superior management results if water managers fail to actively seek new information and modify their management approaches accordingly.

We first assessed whether MS4 managers clearly understood the goals of their programs, drawing from Lawrence Susskind's work on adaptive management in the Glen Canyon observing problems that arose from the absence of guidance on management goals.[151] Unlike the Glen Canyon case study, most of the MS4 managers reported they had clear goals to eliminate all illicit discharges from their urban storm sewers.[152] This clarity mirrors the prescription from Congress to prohibit all non-stormwater discharges into MS4s.[153]

Since the goals of the program were clearly understood as detecting and eliminating all illicit discharges, we next analyzed how managers incorporated science into accomplishing those goals in order to examine the information flow problems observed by Holly Doremus.[154] We generally assessed how the

150. *See* Ig, *supra* note 17, at 656.

151. *See* Susskind, *supra* note 40.

152. Interview with Confidential Interviewees No. 1 through 12 (May 17 – June 6, 2012). An exception to this was an MS4 manager who hired a consultant to carry out most of the illicit discharge program. Interview with Confidential Interviewee No. 7 (May 25, 2012).

153. 33 U.S.C. § 1342(p)(3)(B)(ii) (2012).

154. *See* Doremus, *Adaptive Management as an Information Problem*, *supra* note 47, at 1478.

interviewees understood and incorporated scientific developments. We also focused more specifically on new monitoring breakthroughs pioneered by Dr. McLellan's research on human sewage in stormwater discharges in their management areas. At the outset, we established that none of the government entities interviewed – from the MS4s to the state and federal regulators – conducted any controlled experiments on illicit discharges.[155] While controlled experiments are not the only form of science, this does underscore the importance of whether and how stormwater managers stay current with scientific advancements by non-agency scientists who are conducting controlled experiments and researching new monitoring methods.

Those MS4 managers and state and federal regulators who were aware of Dr. McLellan's research were enthusiastic about its utility for MS4 management related to identifying and eliminating human sewage from stormwater. Several characteristic responses follow:

> She has unlocked some of the secrets so you can fine tune your efforts to get at the source of the problem. That is so important in times of tight budgets because now more than ever we need to be more efficient with our methods so we can quickly identify the source of a problem that needs to be fixed.[156]
>
> The existence of bacteria with the standard coliform test can mean many sources. When you can pinpoint it is human, that helps focus resources in areas that are more problematic.[157]
>
> This research answers the source question. If it is human sewage, then it is related to infrastructure that we control in part. If it is raccoon poop, we can't control that. If it is dog waste, we can educate, but we can't control individuals picking up after their dogs.[158]

Distinguishing the source of the bacteria is "really important for storm sewer outfalls because we don't want to chase a

155. Interview with Confidential Interviewees No. 1 through 12 (May 17 – June 6, 2012).

156. Interview with Confidential Interviewee No. 6 (May 23, 2012).

157. Interview with Confidential Interviewee No. 3 (May 23, 2012).

158. Interview with Confidential Interviewee No. 1 (May 29, 2012); *see also* Interview with Confidential Interviewee No. 8 (June 6, 2012).

natural background problem."[159] Human specific bacteria testing could go a long way to define where problems are within an area. "If we could take this test up the system and narrow down which line of sewer it is coming from, that would be helpful."[160]

One MS4 manager suggested that this type of research has a widespread utility because identifying the source of bacteria "is a dilemma all over the country."[161] A regional EPA stormwater regulator who works with multiple states similarly recognized the breadth of the problem with sewage contamination.[162] He further stated, "We understand that all bacteria are not equal. They have different health implications and we need to tailor our programs to better address the sources of bacteria."[163] Depending on the type of bacteria you find, it helps fingerprint the source. "Using human specific testing would help us better protect public health, spend time more effectively, and not chase after problems that don't exist."[164]

One interviewee had experience using human *Bacteroides* results from Dr. McLellan's lab. "When we get these results, we know we need to do more work. . . Today we were testing for human *Bacteroides* as we went up the system trying to find the source. The tests are getting more reliable and less expensive. I'm trying to see if this is a good way to identify the source."[165]

Another MS4 manager was familiar with a 2011 article by Dr. McLellan, which analyzed data from testing stormwater outfalls during wet weather. He suggested that, "Wet weather testing . . . indicates the problem is more of a widespread one with leaking laterals."[166] He added, "Leaking private laterals are a much bigger source than cross-connected pipes from what we've seen."[167]

This enthusiasm for human-specific bacteria testing by some

159. Interview with Confidential Interviewee No. 10 (May 29, 2012).
160. Interview with Confidential Interviewee No. 3 (May 23, 2012).
161. Interview with Confidential Interviewee No. 10 (May 29, 2012).
162. Interview with Confidential Interviewee No. 12 (May 23, 2012).
163. *Id.*
164. *Id.*
165. Interview with Confidential Interviewee No. 8 (June 6, 2012).
166. Interview with Confidential Interviewee No. 3 (May 23, 2012).
167. *Id.*

of the interviewees belies the variety of obstacles that prevent the use of what MS4 managers and state and federal regulators described as highly relevant and useful scientific data. Our research interviews uncovered a variety of obstacles to "extracting" science and using it to inform management decisions. The obstacles arose in two forms: regulatory and non-regulatory. In the regulatory category, we highlight the problems inherent in the way Congress, the EPA, and the delegated state in our study area have chosen to structure the laws governing management of this system. In the non-regulatory category, our study highlights the importance of: 1) trusted intermediaries to disseminate science, 2) science translation and communication, 3) dissemination of science to field staff and scale of adaptive management, 4) practical concerns about testing method, 5) budgetary impacts of lacking clear standards, and 6) triage barrier. By identifying these obstacles, we aim to show which barriers need to be removed in order to develop programs that encourage "extracting" scientific advancements to produce better water management results.

1. Clean Water Act Obstacles to Adaptive Management

a. *Water Quality Standards*

A fundamental disconnect between law, science and water management, is imbedded in the federal Clean Water Act and its implementing regulations. "Water quality standards are provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses."[168] For instance, a state may designate a recreational use for a waterbody and then set a particular level of bacteria that cannot be exceeded in order to protect recreation. That state-issued bacteria level should be based on the water quality guidelines the EPA established for recreational water (e.g., lakes, rivers, and oceans). However, a fundamental problem is that the EPA and states base these water quality standards on general bacteria indicators and not human specific indicators.

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168. 33 U.S.C. §§ 1313(a), 1313(c)(2)(A) (2012); 40 C.F.R. § 131.3(i) (2012).

> In 1986, EPA developed recommended bacterial water quality criteria for coastal recreational waters and, in 2004, established federal standards for those states and territories that had not yet adopted water quality criteria that met or exceeded the 1986 criteria. For freshwater, full-body contact beaches (e.g., lakes and rivers), EPA recommends that the monthly geometric mean water quality indicator concentration be <33 CFU/100mL for enterococci or <126 CFU/100mL for *Escherichia coli.* For marine water, full-body contact beaches, EPA recommends that the monthly geometric mean water quality indicator concentration be <35 CFU/100mL for enterococci.[169]

The EPA created these water quality recommendations in 1986, and at that time it was impossible to distinguish wildlife sources from human sources in a scientific manner. The recommendations are not reflective of recent studies that document that both *E. Coli* and enterococcus come from a variety of human and non-human sources[170] and may show no correlation to the presence of pathogens associated with human illness.[171] These recommended standards used to detect fecal contamination do not allow water managers to distinguish between human and non-human sources.[172]

This sets up a domino effect of confounding factors that impede effective water management. These bacteria water quality standards, in turn, drive the 303(d) list of impaired waters, which drive the restoration plans known as Total Maximum Daily Loads (TMDLs).[173] However, as all bacteria are

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169. Hlavsa et al., *supra* note 3, at 3; *see also* U.S. ENVTL. PROT. AGENCY, AMBIENT WATER QUALITY CRITERIA FOR BACTERIA 5 (1986).

170. This factor can make it more difficult both to find the source of the pollution and to evaluate the level of danger to humans. *See e.g.*, Yan &. Sadowsky, *supra* note 110; Barnes & Gordon, *supra* note 110.

171. *See, e.g.*, Noble & Fuhrman, *supra* note 112, at 175; Boehm et al., *supra* note 112, at 673; Schoen & Ashbolt, *supra* note 112.

172. *E.g.*, Ahmed et al., *Sourcing Faecal Pollution*, supra note 113; Stewart et al., *supra* note 113; Converse et al., *supra* note 113.

173. "The goal of the Clean Water Act (CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." 33 U.S.C § 1251(a) (2012). Under section 303(d) of the CWA, states, territories, and authorized tribes, collectively referred to in the act as "states," are required to develop lists of impaired waters. These are waters for which technology-based

not created equally, using a generic instead of source specific bacterial indicator for a water quality standard can lead to management responses that aren't narrowly tailored to remedy the problem.[174]

What seems to have happened with the bacteria water quality standards is that the state of knowledge has been frozen. This is a situation where the EPA could benefit from applying adaptive management in the context of developments in the science of pollution monitoring, learning from the developments that scientists have pioneered in understanding the sources of bacteria, and providing water quality recommendations to states based on this knowledge.[175] As Professor Doremus has observed, "[no] matter how productive exploration [research] is, if the data it makes available are not extracted [for management purposes] it can never play a role in management decisions."[176] The EPA already has an established mechanism, through section 304(a) of the Clean Water Act, to make water quality criteria recommendations[177] and to regularly review state water quality standards every three years in what is known as a triennial

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regulations and other required controls are not stringent enough to meet the water quality standards set by states. The law requires that states establish priority rankings for waters on the lists and develop Total Maximum Daily Loads (TMDLs), for these waters. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards." *Overview of Impaired Waters and Total Maximum Daily Loads Program*, ENVTL. PROT. AGENCY, http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/ intro.cfm (last visited March 6, 2013).

174. Interview with Confidential Interviewee No. 12 (May 23, 2012).

175. Despite EPA carrying out a review of science and producing new draft Recreational Water Quality Criteria for public comment in early 2012, it continues to recommend the use of the same indicators (*E. coli* and enterococci) set at the same levels as it established in 1986. Notice of Availability of Draft Recreational Water Quality Criteria and Request for Scientific Views, 76 Fed. Reg. 79176 (Dec. 21, 2011).

176. Doremus, *Data Gaps in Natural Resource Management*, *supra* note 57, at 456.

177. CWA section 304(a) requires the EPA to establish recommended water quality criteria based on science. States then create their own water quality criteria and submit to the EPA for approval. The EPA's regulations provide that it will approve criteria based on its guidance, but puts the burden of proof on states submitting less protective criteria to prove their criteria are scientifically defensible. 40 C.F.R. § 121.11 (2012).

review.[178] The EPA could establish a human specific bacteria indicator water quality standard recommendation and work with states to incorporate it during the triennial review.[179]

b. *Regulations of MS4s' Illicit Discharge Program Are Barriers to Addressing Human Sewage Problems*

Similarly, in the specific application to MS4s managing stormwater, the stormwater program has not evolved to reflect the state of scientific developments related to bacteria and has not shifted its attention towards the emerging problems with aging sewage and stormwater infrastructure. An EPA stormwater regulator stated, "People used to not think of bacteria as a problem in MS4s, but we're finding most of the time there are high loadings of bacteria from MS4s."[180] He explained the original focus of the illicit discharge program:

> Historically we've tested for chemicals that would indicate if industry had wrongly hooked up to the storm sewer. We have not placed a huge emphasis on bacteria because we assumed if there was [*sic*] bacteria, it was [*sic*] coming from dumpsters, pets, or wildlife. Now we've observed and suspect bacteria is coming from illicit connections. So the illicit discharge program has to place more emphasis on bacteria than we did before.[181]

The MS4 program is one that would benefit from incorporating requirements for source-specific bacterial indicators, without which MS4s have a limited ability to implement targeted management approaches to effectively detect and eliminate illicit discharges of sewage. This is an area that is overdue for improvement.

While the Clean Water Act and the EPA's implementing

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178. 33 U.S.C. § 1313(c)(1) (2012). For example, for information on Wisconsin's triennial review see WIS. DEP'T OF NATURAL RES., TRIENNIAL STANDARDS REVIEW, http://dnr.wi.gov/topic/SurfaceWater/TSR.html (last visited Sept. 3, 2012).

179. *Cf.* Doremus, *Data Gaps in Natural Resource Management*, *supra* note 57, at 457 ("Targeted funding, free from annual appropriations struggles, ought to be provided both for general indicator tracking and for specific high-priority extration efforts.").

180. Interview with Confidential Interviewee No. 12 (May 23, 2012).

181. *Id.*

regulations require all NPDES permits for MS4s to prohibit non-stormwater discharges and for the MS4s to develop programs to detect and eliminate illicit discharges, our analysis found that the MS4 permits in our study area did not reflect the current state of science related to identifying human sources of bacteria. The EPA could take a more active role in extracting relevant scientific developments, particularly in monitoring pollutants, and providing a regulatory framework that directs incorporation of scientific innovations.[182]

The EPA's federal regulations for the illicit discharge program are sparse and provide wide discretion to agencies issuing NPDES permits for MS4s. In its Phase I regulations for large and medium sized MS4s, the EPA required, as part of the permit application, field screening for illicit discharges that limited the chemical analysis to testing for "pH, total chlorine, total copper, total phenol, and detergents (or surfactants) False."[183] It also required an illicit discharge program description that includes investigative procedures an MS4 will follow when the field screening indicates a "reasonable potential of containing illicit discharges . . ."[184] Here, the EPA indicates the procures "may" include generic bacteria testing for fecal coliform or fecal streptococcus.[185]

In its Phase II regulations for small MS4s, the EPA provides even less content. EPA recommends visually screening outfalls during dry weather and "conducting field tests of selected pollutants" to prioritize management efforts.[186] The regulations do not identify the pollutants to test. The closest indication of pollutants EPA thinks an MS4 should test comes from an EPA-contracted guidance manual on illicit discharges. The guidance

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182. Doremus, *Data Gaps in Natural Resource Management*, *supra* note 57, at 457.

183. National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges, 55 Fed. Reg. 47,990, 48,068 (Nov. 16, 1990) (to be codified at 40 C.F.R. pts. 122-124) (Phase I regulations).

184. National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges, 55 Fed. Reg. at 48,071 (Phase I regulations).

185. *Id.*

186. 40 C.F.R. § 122.34(b)(3)(iv) (2012) (Phase II regulations).

manual provides a table of potential pollutants for field tests, and lists *E.coli*, enterococci, and total coliform, as "sometimes (>50% of samples)" indicative of an illicit sewage discharge.[187] Consistent with the reflections by the EPA regulator in our study that the program has not historically focused on bacteria, the guidance manual lists bacteria tests as just one of many possible indicators, and does not include bacteria in the primary group recommended to "fingerprint" an illicit source.[188] Noteworthy, the guidance manual is almost a decade old, therefore it does not reflect scientific developments in source specific bacterial indicators.

The lack of requirements in MS4 permits for testing for source-specific bacterial indicators can lead to a mismatch between problem identification and management response, and result in a waste of scarce public funds.[189] For instance, if an MS4 permit holder knows there are bacteria in its stormwater discharges or in the river into which it discharges, but does not know the source of the bacteria, it may craft a pet waste program to correct the perceived problem, while missing that the actual source is a broken sanitary sewage pipe.[190] Similarly, using a non-human-specific bacteria test leads to water managers wasting time and resources on eliminating or remediating potential sources of illicit discharges that may neither be illicit (i.e., instead they are caused by birds or raccoons) nor human health priorities. In contrast, new studies using human

187. CTR. FOR WATERSHED PROT., *supra* note 35, at tbl. 39.

188. *Id.* at tbl. 1.

189. This has been similarly identified as a problem in other regulatory programs. *See* Alejandro E. Camacho, *Transforming the Means and Ends of Natural Resources Management*, 89 N.C. L. REV. 1405, 1417 (2011) ("A number of adaptive management programs have failed to provide clear objectives for experiments to be assessed against, or specific criteria or triggers for when strategies must be adjusted to reflect new information or changed circumstances."); *see also* Ruhl, *Taking Adaptive Management Seriously, supra* note 30, at 1236-84 (evaluating the legal constraints that the Endangered Species Act creates for the Fish and Wildlife Service actually implementing adpative management).

190. In our study area, this situation exists because Milwaukee Metropolitan Sewerage District monitors ambient water quality and sends reports to MS4s on the coliform and *E. coli* bacteria levels in the waterbodies into which the MS4s discharge. Interview with Confidential Interviewee No. 5 (May 22, 2012).

Bacteroides or other human-specific targets have significant potential for water managers to quickly and accurately identify when they have a human health problem caused by sewage being discharged untreated into public recreational waters.[191] With this specificity, an MS4 could target its limited resources towards fixing the infrastructure problems that pose the greatest heath risks.

Regardless of awareness level by field staff or supervisors of human-specific bacterial indicator testing, if the permits are written in a way that does not direct incorporation of scientific advancements, or worse – prohibits adapting to monitoring innovation by the managers – MS4 engineers will not incorporate the new monitoring method or data. As explained above, the EPA's federal regulations for the illicit discharge program are sparse and provide wide discretion to the agencies issuing MS4 permits. For large MS4s, the EPA does not specifically recommend bacteria testing.[192] For small MS4s, the EPA merely recommends visually screening outfalls during dry weather and "conducting field tests of selected pollutants" to prioritize management efforts, but does not identify the pollutants to test.[193] Hence, each agency with delegated authority to issue NPDES permits determines the testing parameters for the illicit discharge programs within its jurisdiction. Some states issue MS4 permits that require bacteria testing, while others do not. We are not aware of any that require human indicator bacteria testing.

For MS4s in our study area, Wisconsin's regulations prescribe the types of testing required. Similar to the EPA, the state DNR has not updated the list of testing parameters to reflect current scientific knowledge of illicit discharges despite recognition by federal and state water managers in our study area of the utility of targeted source-specific bacteria testing.

Currently, Wisconsin's MS4 regulations specify that MS4

191. *See infra* Appendix 1.

192. National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges, 55 Fed. Reg. 47,990, 48,068 (Nov. 16, 1990) (to be codified at 40 C.F.R. pts. 122-124).

193. 40 C.F.R. § 122.34(b)(3)(iv) (2012).

permits require testing of dry weather flows at major stormwater outfalls.[194] The regulations list a variety of chemical parameters to test in the field. This list does not include bacteria, much less human-specific bacteria. Instead the regulations require special additional approval from DNR to test for bacteria.[195] This regulation is a barrier to effective extraction of scientific innovation; the DNR interprets this regulation as preventing it from issuing an MS4 permit that allows for testing bacteria at outfalls.[196] Hence, even in a study area where the regulators and the EPA are aware of advances in human-specific bacteria testing methods and understand its utility for more efficient source identification, the regulations and permit language continues to lag behind and impede incorporation of new scientific advancements.

Because the MS4 permits specify the field testing methods to use and require an additional approval to test for bacteria, the MS4 managers, who are trained as engineers, carry out the protocol in the permit and feel constrained from independently adopting a new monitoring method.[197] This helps explain why they do not test for human *Bactericides* despite the close

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194. WIS. ADMIN. CODE NR 216.07(3)(i) (2012). A major outfall is defined as "a municipal separate storm sewer system outfall that meets one of the following criteria:

> (a)A single pipe with an inside diameter of 36 inches or more, or from an equivalent conveyance (cross sectional area of 1,018 inch^2) which is associated with a drainage area of more than 50 acres.
>
> (b) A municipal separate storm sewer system that receives storm water runoff from lands zoned for industrial activity that is associated with a drainage area of more than 2 acres or from other lands with 2 or more acres of industrial activity, but not land zoned for industrial activity that does not have any industrial activity present is not classified as a major outfall under this paragraph."

WIS. ADMIN. CODE NR 216.002(16).

195. If there is any flow, an illicit discharge field analysis needs to include sampling for "pH, total chlorine, total copper, total phenol and detergents unless the permittee obtains concurrence from the department to perform alternative sampling that is more effective to detect illicit discharges such as with ammonia, potassium or bacteria." WIS. ADMIN. CODE NR 216.07(3)(i).

196. *Summary Notes of the June 12, 2012 Meeting of the Menomonee River Watershed-Based Permit Framework Group*, at 5 (on file with author).

197. *E.g.*, Interview with Confidential Interviewee No. 5 (May 22, 2012); Interview with Confidential Interviewee No. 6 (May 23, 2012).

proximity to a well-known scientist and lab that has pioneered the use of this method. According to a DNR regulator, "MS4s are just following the code or permit and not thinking about how to be more effective at detecting discharges."[198] This DNR regulator, who oversees twenty MS4s, observed that most of the municipalities never find illicit discharges because the required dry weather screening is not very effective at detecting problems.[199] He expressed frustration with trying to encourage MS4s to take ownership of their systems and be innovative in finding and eliminating illicit discharges.[200] This regulatory system is part adaptive in that it places a lot of discretion in the hands of the MS4 managers to formulate and carry out an illicit discharge program, and part prescriptive in that it specifies the test methods to use at the outfalls. The adaptive aspect of the program is not able to fully realize its promise because the engineers carrying out the program are used to following specific protocols, and do not have the authority to change those protocols because they are specifically enumerated in the statute. Moreover, it is debatable whether a sound program should allow individual MS4 managers to determine the testing methods to use or the detection level that triggers a responsive investigation. The appropriate scale at which adaptive management occurs will be discussed below, but in a budget limited world, it is probably not at the field engineer level.[201]

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198. Interview with Confidential Interviewee No. 10 (May 29, 2012).

199. *Id.*

200. *Id.*

201. This tension between flexibility and uniformly clear standards is apparent, for instance, in what test result triggers a response action by the MS4. While the permit says test for x chemical, it does not specify what level of that chemical would require a follow up investigation to find an illicit discharge. Unlike typical NPDES permits for point sources that specify effluent limits, the lack of specificity in the MS4 permits makes them less enforceable and more malleable to pressures that detract from achieving clean water. One engineer explained how this works for illicit discharges:

> If Bob Pitt's [referring to the EPA-contracted guidance manual] benchmark value is 3.1 for a particular chemical and we see 4, 5, 6 and 7 often, then I'll say 'well we can't chase everything at 4. There are only so many resources. Municipalities can only spend so much money to fix these things.' And we only follow up on the ones that have a value of 6. . . . We have discretion to chase the ones that I identify as the level that triggers a response and I apply that

Regardless, the prescriptive part of the program is outdated and has not incorporated new testing methods that would more clearly identify when there is a human sewage problem that needs immediate attention. This highlights the need for greater clarity in standards and to include a mechanism that requires regulators to regularly update standards based on scientific advances, particularly advances in monitoring methods.

An EPA stormwater regulator in our study area recognized that the permits need to be updated to reflect scientific developments that have shed light on the nature and extent of water pollution caused by human sewage infrastructure problems.[202] At the EPA level, there is an awareness that the historic focus of the program on problems related to industry illegally hooking up to the storm sewer are not as important as sewage contamination.[203] Based on new data showing that human-source bacteria is a widespread problem in storm sewers in our study area and elsewhere, he recognized that the illicit discharge program needs to evolve.[204] He explained that the EPA's focus is to tailor the illicit discharge program to incorporate bacteria testing on a permit-by-permit basis rather than seek a regulatory change.[205]

One option for accomplishing this tailoring of the permit to incorporate new testing methods is to include a tiered testing recommendation. The EPA regulator suggested that MS4s should first test for fecal coliform or *E. Coli* and if that returns positive, to then test for human-specific bacterial indicators.[206] The ability of the EPA to utilize adaptive management by incorporating scientific developments on a permit-by-permit basis, however, is constrained by the legal framework established by each state's regulations of MS4s. In Wisconsin, for instance, the state DNR interprets its regulations in such a way

consistently. DNR doesn't dictate this.
Interview with Confidential Interviewee No. 8 (June 6, 2012).

202. Interview with Confidential Interviewee No. 12 (May 23, 2012).

203. *Id.*

204. *Id.*

205. *Id.*

206. *Id.*

that prevents them from requiring testing for bacteria or human *Bacteroides* in an MS4 permit.[207] This underscores the need to consider a more comprehensive federal approach. As Professor Camacho has observed in the context of adaptive management with respect to climate change, "agencies must be given not only the permission to monitor and assess performance with such goals, but also the responsibility to do so."[208] Such reasoning applies not only to management responses, but also to the developments in monitoring methods examined in this research.

c. *MS4 Permits Lack Clear Standards for 3rd Party Data*

Wisconsin's MS4 permits lack clear requirements for how to respond to non-agency or 3rd party data.[209] In our study area, MS4 managers identified the Milwaukee Metropolitan Sewerage District as a trusted intermediary to diffuse science. This entity maintains a database with human-specific bacteria test results from stormwater outfalls throughout the study area. Part of the data in that database appeared in Dr. McLellan's recent published work that analyzed data from 828 storm sewer samples.[210] Of those samples, 57% contained the human *Bacteroides* genetic marker and every site examined had intermittent sewage contamination.[211] Although the published data in this article is up to date through 2009, Dr. McLellan's testing for human-specific indicators in stormwater continues to

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207. *Summary Notes of the June 12, 2012 Meeting of the Menomonee River Watershed-Based Permit Framework Group*, at 5 (on file with author).

208. *Cf.* Alejandro E. Camacho, *Adapting Governance To Climate Change: Managing Uncertainty Through A Learning Infrastructure*. 49 EMORY L. J. 1, 73 (2009).

209. *Cf.* Doremus, Data Gaps in Natural Resources Management, *supra* note 57, at 458 (observing that "[i]f the government cannot or will not fund extraction, the conservation community can, and to some extent already does, help take up the slack."). In our study area, the Milwaukee Riverkeeper, a community conservation group, has been actively engaged in monitoring water quality at stormwater outfalls and obtaining source specific bacterial testing from Dr. McLellan's lab. SANDRA L. MCLELLAN & ELIZABETH P. SAUER, GREAT LAKES WATER INST., UNIV. OF WIS.-MILWAUKEE, GREATER MILWAUKEE WATERSHEDS PATHOGEN SOURCE IDENTIFICATION, REPORT: MARCH 1, 2006 TO JULY 28, 2009, MMSD CONTRACT NO. M03016P02 at ES-7, 41 (2009).

210. Sauer et al., *supra* note 9.

211. *Id.*

add to this database. Milwaukee Metropolitan Sewerage District, in turn, sends reports of the data collected from stormwater outfalls to the MS4s. Once every three years, Dr. McLellan's lab also publishes a technical report compiling the cumulative data for outfalls tested repeatedly along with an interpretation of the data and a list of priority sites to be investigated based on levels of sewage contamination. This report is available on the research lab's website. However, as recognized by an EPA regulator, there is a "gulf between existing data gathered by 3rd parties and management actions."[212]

According to a DNR regulator, the MS4 permits place a legal obligation on municipalities "to implement response procedures when there is a known or suspected illicit discharge reported."[213] Despite this, most of the MS4 managers were unclear or thought there was no legal requirement to use non-agency data such as Dr. McLellan's, which shows human-source bacteria in specific MS4 outfalls.[214] An MS4 manager who confirmed that he has data produced by Dr. McLellan's lab showing human *Bacteroides* in his MS4s' stormwater outfalls was "unsure if there are legal requirements about using this data."[215]

Another MS4 manager stated that he followed up on every report of human *Bacteroides* in his stormwater outfalls.[216] Yet, there is no clear way for the regulators from the DNR or EPA to verify that because he does not include this data or his response to it in the required Annual Report, explaining, "We only report on what we test."[217] He is not alone. No MS4s in our study area include in their Annual Reports this 3rd party data showing human *Bacteroides* in their storm sewer outfalls. A DNR regulator said they had never enforced or made an issue of the fact that MS4s have failed to include this known and credible data in their Annual Reports.[218]

212. Interview with Confidential Interviewee No. 12 (May 23, 2012).
213. Interview with Confidential Interviewee No. 10 (May 29, 2012).
214. *E.g.,* Interview with Confidential Interviewee No. 6 (May 23, 2012).
215. Interview with Confidential Interviewee No. 1 (May 29, 2012).
216. Interview with Confidential Interviewee No. 3 (May 23, 2012).
217. *Id.*
218. Interview with Confidential Interviewee No. 9 (May 18, 2012).

An EPA regulator assessed that the EPA would have "a hard time" holding MS4s accountable for failing to follow up and fix these identified sources of human sewage.[219] He attributed this to the lack of "wording in the permit that requires use of this data."[220] The DNR regulators similarly see little in the permit language that provides substantive enforceable standards. One DNR regulator, who has worked in the stormwater program since its inception, reported never being involved in any enforcement actions against MS4s on any topic.[221] He thought this was due to the fact that the "code is so grey it doesn't have any details to enforce."[222] He noted that the permits lack any discharge limits and just require programs to be in place and implemented.[223] "If I received an Annual Report that said they refused to do anything, then there would be a clear violation, but that doesn't happen."[224]

The DNR and EPA regulators all identified this as an area that requires greater clarity in the MS4s permits. "DNR should clarify the expectations for the municipalities."[225] Similarly, an EPA regulator said in a future permit in the study area "we want to make it abundantly clear . . . that 3rd party data must be used by MS4s."[226] A DNR regulator recognized that "municipalities will only do what is specifically required" in their permit. He reported that the DNR just produced a guidance document on illicit discharges, but it did not consider the problem of lack of response to 3rd party data and in retrospect they "probably should be more explicit about what MS4s are required to do when they receive 3rd party data like this."[227]

These observations from an experienced stormwater regulator call into question the appropriate level at which adaptive management can realistically occur. It will probably be most

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219. Interview with Confidential Interviewee No. 12 (May 23, 2012).
220. *Id.*
221. Interview with Confidential Interviewee No. 10 (May 29, 2012).
222. *Id.*
223. *Id.*
224. *Id.*
225. *Id.*
226. Interview with Confidential Interviewee No. 12 (May 23, 2012).
227. Interview with Confidential Interviewee No. 10 (May 29, 2012).

effective for EPA, state agencies, and regional intermediaries to engage in adaptive management and set clear regulatory standards based upon it. Freezing standards in time or allowing so much discretion that the MS4 managers do not need to respond to credible 3rd party data are pitfalls the regulations should be redesigned to avoid.

2. Non-Regulatory Obstacles to Adaptive Management

a. *Dissemination of Science Through Trusted Intermediaries*

In addition to our finding that none of the MS4 managers or Wisconsin DNR or EPA regulators conduct controlled experiments, we found that none of the MS4 managers or Wisconsin DNR regulator interviewees reviewed scientific journals.[228] These water managers are not engaged in the exploration phase of science. Instead, MS4 managers obtain information on scientific developments from trusted intermediaries.[229] This highlights the importance of intermediaries in the diffusion of scientific advancements and shows how critical it is to extract and convey information in ways that can be utilized for management purposes. In our study area of the Milwaukee watersheds, the interviewees identified a variety of trusted intermediaries, but the primary one for scientific dissemination is the Milwaukee Metropolitan Sewerage

228. Interview with Confidential Interviewees No. 1 through 12 (May 17 – June 6, 2012). The EPA regulator interviewed did review scientific studies, and assessed their rigor of methods and whether others had replicated it. Interview with Confidential Interviewee No. 12 (May 23, 2012).

229. *See* Doremus, *Adaptive Management as an Information Problem, supra* note 47, at 1492 (describing "trusted intermediaries" as "information diffiusion agents"). In some literatures, such intermediaries are also referred to as "knowledge brokers." *See* S. Michaels, *Matching Knowledge Brokering Strategies to Environmental Problems and Settings,* 12 ENVTL. SCI. & POL'Y 994 (2009) ("Due to their ability to structure and interpret scientific knowledge, knowledge brokers are particularly influential where there is considerable scientific uncertainty, as is often true for environmental problems."). The focus of scholarly analysis of knowledge brokers, however, is on their capacities to extract knowledge from exploratory science. Because we also focus on the issue of trust relationships through repeated regional interactions, we use instead the term "trusted intermediaries."

District, followed by the Wisconsin DNR.[230] The Milwaukee Metropolitan Sewerage District convenes monthly meetings for upper level municipal water managers. The agency also maintains a robust water monitoring program throughout its service area, including a database of Dr. McLellan's human-specific bacterial indicator testing at MS4s' outfalls.

Rather than relying on the proper vetting by other scientists via peer-reviewed published research, the way MS4 managers determine which science is relevant and credible is a function of who is selected to present at the Milwaukee Metropolitan Sewerage District's monthly meetings for upper level managers.[231] If the science is presented to MS4 managers and readily available, they will be more likely to use it.[232] This is possible because of the degree of trust this regional intermediary is able to garner, partly based on regular interactions focused on professional development and information sharing.[233] While the particular trusted intermediary will vary by community, it is important to understand the critical role of a trusted intermediary for science diffusion and identify which agency or entity serves that purpose.

This sheds light on the appropriate scale at which adaptive management occurs. Given the expense and time of implementing a continual learning process for resource managers, it is more efficient and realistic to identify and support an intermediary agency to diffuse scientific learning. When the intermediary is close enough to a cluster of resource managers, it facilitates regular interactions, like the Sewerage District's monthly meetings, focused on continual learning. The federal regulatory structure could leverage societal resources by

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230. Interview with Confidential Interviewees No. 1 through 12 (May 17 – June 6, 2012). Other trusted intermediaries are SEWRPC, DNR, and University of Wisconsin scientists.

231. *E.g.*, Interview with Confidential Interviewee No. 1 (May 29, 2012).

232. *Id.*; One MS4 engineer said he, "follows scientific studies by Sandra McLellan and Robert Pitt because those are the scientists whose work is presented to him and readily available." Interview with Confidential Interviewee No. 8 (June 6, 2012).

233. For an exploration of the role of trust in the legitimacy of regulatory agencies, see Rebecca Bratspies, *Regulatory Trust*, 51 ARIZ. L. REV. 575 (2012).

creating the scaffolding to support intermediaries as they diffuse science or other management learning. In part, this could be accomplished closest to the impacted resources, by creating grants to fund intermediaries providing this critical function.

b. *Science Interpretation and Communication to Non-Scientists*

Another related component to promoting adaptive management is how scientific innovations are interpreted and communicated to non-scientists responsible for management decisions. If the trusted intermediary or any other entity is to make science accessible to resource managers who are not specialists in the particular field of innovation, there must be a careful focus on translating scientific research into management uses and communicating that to non-specialists. The trusted intermediary would be the logical locus of an intentional focus on translating and communicating scientific developments in a way that reaches resource managers.

An obstacle to adaptive management by municipal stormwater managers in our study area is the need for science interpretation and communication. All MS4 and Wisconsin DNR interviewees were engineers without advanced degrees.[234] There is a science communication gap that prevents full understanding of the importance and utility of Dr. McLellan's and other scientists' research on human-source bacteria indicators. One interviewee summed up his confusion interpreting the data succinctly: "I don't speak graduate student."[235] This communication gap means that even those aware of Dr. McLellan's research do not necessarily understand how to use it for specific management actions related to detecting and eliminating illicit discharges. In reflecting on his ability to interpret data from Dr. McLellan's lab, another MS4 upper manager observed, "We're not scientists and

234. Interview with Confidential Interviewees No. 1 through 12 (May 17 – June 6, 2012). One exception to this is an MS4 interviewee who is in charge of the MS4 program, however, his community contracts the work out to a consulting engineer. He was trained in business. Interview with Confidential Interviewee No. 7 (May 25, 2012).

235. Interview with Confidential Interviewee No. 9 (May 18, 2012).

it was written from a scientists' standpoint."[236] The spreadsheets showed varying levels of human *Bacteroides* in this MS4s' outfalls, but the MS4 manager said he was "not really clear what level was a bad level to have in outfalls."[237]

This is not to say that communication efforts are not present in the study area. In fact, Dr. McLellan's lab spends considerable effort communicating their findings. However, this communication effort is specifically targeted to the general public and not to MS4 managers.[238] The public's need for general information is distinctly different from an MS4 manager's need to have research translated into a defined management application in the field. Although Dr. McLellan has even presented her research findings four or five times at the Milwaukee Metropolitan Sewerage District's monthly meetings for upper level MS4 managers, these communications were not geared towards a management application of the academic research.[239] In order to facilitate the transfer of science to improve management decisions, a translational expert needs to be involved in the process - that is, someone with expertise in communicating from one knowledge realm to another.[240]

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236. Interview with Confidential Interviewee No. 1 (May 29, 2012). *See also* Doremus, *Adaptive Management as an Information Problem, supra* note 47, at 1491-92 (describing agency staff "which is often heavy on bachelors- and masters-level expertise, may not have the background or training to make those judgments effectively or with confidence. Resource management agencies may, therefore, fall behind on awareness of both data and new techniques that could be helpful in achieving their goals.").

237. Interview with Confidential Interviewee No. 1 (May 29, 2012).

238. MCLELLAN & SAUER, *supra* note 209, at ES-5, 27, 30. The McLellan Lab focuses on educating the public and working with nonprofit groups on citizen monitoring efforts. *Id.*

239. Interview with Dr. Sandra McLellan, Associate Professor and Senior Scientist, UWM School of Freshwater Sciences (Aug. 29, 2012).

240. *See* H.M. Collins & Robert Evans, *The Third Wave of Science Studies: Studies of Expertise and Experience*, *in* THE PHILOSOPHY OF EXPERTISE 62 (Evan Selinger & Robert P. Crease eds., 2006) (pointing out that for "groups of experts to talk to each other, translation may be necessary" and for a category of expertise that focuses on the ability to do that translation).

c. *Awareness of Science Not Disseminated to Field Staff – Appropriate Scale of Adaptive Management*

In addition to a need for science translation into management usages and communication through a trusted intermediary, there is a need to disseminate understanding from the upper levels of management to the field staff carrying out the programs. Awareness of Dr. McLellan's research was clustered at the EPA, DNR, and top MS4 management levels, while engineers who conducted the stormwater outfall screening to detect illicit discharges were not aware of the human-specific bacteria research.[241] This is not unexpected given the prior responses about scientific developments being diffused through the Milwaukee Metropolitan Sewerage District's meetings for upper level supervisors. The field staff who conduct outfall screening to detect illicit discharges follow the permit terms, which ties into the earlier highlighted obstacle related to required testing methods.

Again, this touches on the appropriate scale or level where adaptive management occurs. Some scholars argue for nested levels of governance to manage complex large-scale environmental problems.[242] Given the time and expense of engaging in a continual process of learning,[243] it may be most efficient to focus effort and funding to support adaptive management at the trusted intermediary agency and top manager level, and then regularly update prescriptive standards based on that cycle of learning, for field staff to carry out in their

241. *E.g.*, Interview with Confidential Interviewee No. 1 (May 29, 2012); Interview with Confidential Interviewee No. 2 (May 22, 2012); Interview with Confidential Interviewee No. 4 (May 17, 2012); Interview with Confidential Interviewee No. 5 (May 22, 2012).

242. *See, e.g.*, Bradley Karkkainen, *Managing Transboundary Ecosystems: Lessons from the Great Lakes*, 19 PAC. MCGEORGE GLOBAL BUS. & DEV. L.J. 209, 235 (2006) ("[W]hile one set of basin-wide governance institutions may be needed to address systemwide problems and processes, and to coordinate the efforts of spatially differentiated parts, another level of more localized institutional arrangements may be necessary to address locally varying conditions.").

243. Doremus, *Adaptive Management as an Information Problem*, *supra* note 47, at 1459 (describing adaptive management as "costly, requiring added modeling, monitoring, and data evaluation").

day to day management. However, attention to the diffusion of science, without simultaneously structuring the laws to support an adaptive framework, will fall short of effective implementation of adaptive management.

d. *Practical Concerns About Testing Methods*

Some MS4 managers and DNR regulators raised practical concerns about using human *Bacteriodes* or even coliform bacteria tests for their illicit discharge program. Their field staffs use an easy to administer rapid field test when they find dry weather flows indicative of an illicit discharge; currently, there are no similar field tests for bacteria.[244] However, some recognized that it would be beneficial to use human indicator bacteria testing as a second stage of testing, after a rapid field test indicates a potential problem.

Several factors need to be addressed in order for MS4s managers to incorporate this new testing method into their management tools: field expertise for sample collection, lab availability to conduct the testing for human specific bacterial indicators, time lag between sample and results, and cost.[245] "The cost of the test and how quickly you can get results influence how useful this testing can be because of the intermittent nature of problems."[246] Another engineer thought if he could get test results within a week or two, the data would be

244. The field tests produce quick results while at the testing site in the field. Interview with Confidential Interviewee No. 3 (May 23, 2012). By contrast, current bacteria tests take 24 hours to produce results, which do not allow for immediate feedback in the field when going manhole to manhole to find the source of contamination. However, qPCR methods produce results in about two hours. Wade et al., *Swimming-Associated Gastrointestinal Illness*, *supra* note 2. Yet, these results must currently be obtained through a lab, which points to the need for scientists to develop a rapid field test for bacteria and source-specific bacteria that could be used by water managers.

245. Interview with Confidential Interviewee No. 10 (May 29, 2012).

246. Interview with Confidential Interviewee No. 3 (May 23, 2012). No one interviewed knew the cost of human specific bacteria testing, but most assumed or were concerned that it was expensive. One MS4 manager said he respects Dr. McLellan's research, but assumes that it is so expensive that he would opt to use sewage sniffing dogs from Michigan before using her genetic testing if they ever detected a problem. Interview with Confidential Interviewee No. 6 (May 23, 2012).

useful to identify the source of the problem. He reasoned that unlike a truly intermittent problem such as someone illegally dumping chemicals into the storm sewer, a sanitary sewer connection or leakage into the storm sewer would still exist weeks and months after the sample was taken.[247] If policy makers choose an adaptive management approach, this research highlights the importance of identifying the practical aspects of how advances in monitoring methods will get incorporated into resource management in the field. Another science translation and communication role of an identified trusted intermediary is to develop information responsive to the practical concerns of resource managers. In the particular situation in our study area, that may mean working with the local lab that provides source-specific bacterial indicator tests to package the lab services in a way that is responsive to MS4 field engineers' needs.

e. *Lack of Clear Standards Impacts Budgeting for Stormwater*

In the grouping of regulatory barriers to adaptive management, we highlighted the problem with unclear or outdated standards.[248] Another consequence of this lack of clarity in MS4 regulations and permits is that it does not send a direct message to elected officials about budgeting.[249] One MS4 manager urged that he wants more prescriptive standards in the MS4 permit. "It would be helpful if regulators could provide clearer and stronger standards for policy makers (our common council) to understand when they're making budget and resource allocation decisions."[250] He works for an MS4 that no longer has any engineers on staff to carry out the illicit discharge program,

247. Interview with Confidential Interviewee No. 8 (June 6, 2012).

248. Professor Susskind observed a similar problem in the Glen Canyon context. Susskind et al., *supra* note 40, at 1 (criticizing adaptive management experiment's lack of clear goals and directives for translating assessments into management adjustments).

249. *Cf.* Doremus, *Data Gaps in Natural Resource Management*, *supra* note 57, at 447-51 (urging for more explicit priority setting so that agencies can better budget for extraction research).

250. Interview with Confidential Interviewee No. 7 (May 25, 2012).

and the department has "almost no training budget."[251] Unless the case is clearly made for what this program should deliver to the public, it makes it hard to budget for protecting water quality, which lacks a vocal constituency in local governments. Given the lack of clear standards, in a competition for stormwater funds, it is not surprising that the first priority is to fix the "squeaky wheel" of private home or business owners to prevent sewage from backing up into basements.[252]

f. *Triage Barrier*

Tied to these budget constraints, some MS4 managers face a triage barrier, or inability to prioritize fixing illicit discharges of human sewage when also facing problems with sewage backing up into homeowner's basements.[253] It is unclear from our research how big a factor the triage barrier is to impeding the incorporation of useful science into MS4s illicit discharge tools. Yet, for the MS4 manager who had a large number of outfalls known to have tested positive for human-source bacteria, it was the fundamental obstacle. He thought the problems with leaking sewage were so widespread and expensive to fix that he did not even want to understand the data because he felt powerless to take action.[254] Although he had Dr. McLellan's data, he responded that he does not have the money and time to do anything with it.[255] He explained that although he "didn't really understand the spreadsheets" showing test results for human source bacteria, he "was not investing the time or effort" to understand them because his MS4 has such widespread infrastructure problems that it "may be 10-30 years" before he would be able to address this.[256] He frankly contrasted the legal goal of eliminating illicit discharges with the political and practical realities. While his city is investing infrastructure

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251. *Id.*

252. *Id.*; *see also* Interview with Confidential Interviewee No. 1 (May 29, 2012).

253. *Cf.* Doremus, *Adaptive Management as an Information Problem*, *supra* note 47, at 447-51.

254. Interview with Confidential Interviewee No. 1 (May 29, 2012).

255. *Id.*

256. *Id.*

money in new sewers, the focus is on preventing sewage from backing up into homes. "Fixing the stormwater outfalls is secondary to fixing backups of human sewage into people's basements."[257]

He is managing a storm and sanitary sewage system that was built in phases around World Wars I and II, and by his assessment the problems with old, leaking infrastructure are system-wide and not easily corrected by identifying and fixing misconnected pipes.[258]

> I think there is a public misunderstanding. . . that there is just a pipe to fix, but in an one hundred year old system such as ours, that's not our problem. We have more of a systemic problem. There is no single smoking gun. Every three feet there is a sanitary sewer joint and we have 150 miles of pipe. Then we have another 150 miles of privately owned laterals with joints every three feet. Every joint could be leaking. Completely replacing our infrastructure would be prohibitive.[259]

He concluded by suggesting an approach that is more aligned with traditional regulation of point sources. "Maybe the answer is putting in an end of pipe UV treatment for bacteria similar to what is being tried in California."[260] Given the indications of widespread and costly water infrastructure problems, coupled with the multiple barriers to effectively employing adaptive management in this context, policy makers should rethink the current approach. There is a need for greater financing for infrastructure, clearer standards to guide water managers and to establish budget priorities that protect public health and clean waterways, and more attention to the communication and dissemination of scientific advancements.

C. *Analysis and Lessons Learned*

The primary emphasis of adaptive management is to shift from rule-based approaches of management towards strategies

257. *Id.*
258. *Id.*
259. *Id.*
260. *Id.*

that emphasize continuous monitoring of circumstances and adjusting decisions accordingly.[261] The successful use of an adaptive process for natural resource management depends on the ability of agency staff to actively seek new information and modify their management approaches in light of that new information. This research identifies a variety of barriers that prevent this management theory from providing substantive improvements in the protection of natural resources. While grounded in the specific context of municipal stormwater, this analysis applies to other natural resource management dilemmas. If adaptive management is to be employed effectively, policy makers should address and remove the barriers that impede the "extraction" of important scientific advancements.

In other research, scholars have produced four primary critiques of adaptive management relevant to our study:

1. Adaptive management needs specified procedures to use monitoring data to adjust management techniques.[262]
2. Due to agency discretion and flexibility, adaptive management may allow agencies to avoid actual management responsibilities.[263]
3. Without prescriptive standards, the public may be less able to hold agencies accountable for derogation of their management duties, as citizen suits may be impracticable without clear rules and timetables.[264]
4. Adaptive management involves time and resource costs and may involve a greater degree of stakeholder burden and controversy because of its iterative nature.[265]

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261. *See* Ruhl. *Is It Possible?*, *supra* note 15, at 28.

262. Fish and Wildlife Service fail to include procedures that actually use the monitoring data required under the Habitat Conservation Plans to adjust management techniques. Camacho, *Can Regulation Evolve?*, *supra* note 38, at 333-34.

263. *See* Doremus, *The Institutional Challenges*, *supra* note 20, at 52; Freeman, *supra* note 44; *cf.* Stewart, *supra* note 43, at 57-58 (describing adaptive management mechanisms as often having a "shadowy" legal status).

264. Doremus, *The Institutional Challenges*, *supra* note 20, at 84; *cf. id.* at 50 (pointing out that the absence of clarify may also make adaptive management programs more difficult to evaluate in terms of successfulness).

265. *See* Doremus, *Adaptive Management as an Information Problem*, *supra* note 47, at 1478.

Our study sheds light on these critiques and adds several new layers of understanding, such as the need for procedures to update monitoring methods, procedures to incorporate 3rd party or non-agency data, potential cost-savings from incorporating scientific developments, and the need to identify and fund trusted intermediaries for science translation, communication and diffusion.

1. Clear Procedures Are Needed for the Use of Monitoring Data Generated by 3rd Party or Non-Agency Scientists

Similar to the Fish and Wildlife Service study by Professor Camacho, we found that there is a need for procedures to use monitoring data to inform management actions. However, we highlight the need more specifically for the incorporation of 3rd party or non-agency data. Understanding how managers address non-agency generated science is essential to whether scientific advancements will be understood and incorporated into better management actions. In the MS4 case study, neither the EPA, state natural resources agency, nor MS4s conducted controlled experiments on illicit discharges, or reviewed scientific journals to keep abreast of developments in their fields. So the primary source of scientific advancement is from 3rd party or non-agency scientists. In order to facilitate the extraction of scientific developments, one must first recognize that agencies treat 3rd party data differently from internally generated data. In the MS4 case study, despite the existence of credible 3rd party data indicating the presence of human sewage in stormwater outfalls for a variety of MS4s, none of the MS4s reported that data or their follow up to it on their Annual Report to the state DNR. And neither the DNR nor the EPA thought the data could be used to show a clear violation of the MS4 permit.[266] This lack of clarity around the use of 3rd party data results in multiple unaddressed discharges of raw human sewage into public waterways, exposing the public to risks from human pathogen contamination. For adaptive management to function, policy makers need to place greater attention on developing clear legal

266. Interview with Confidential Interviewee No. 9 (May 18, 2012); Interview with Confidential Interviewee No. 12 (May 23, 2012).

standards for incorporating 3rd party data into management actions. Any legal standards should include explicit processes for assessing and using data generated by non-agency sources.

2. Clear Standards Are Needed to Update Monitoring Methods

In addition to procedures to incorporate monitoring data, we uncovered a critique that is missing from the current literature: the importance of understanding whether and how natural resource managers incorporate non-agency scientific and technological advancements in the monitoring process itself.[267] This study shows the need for the law to incorporate regular updating of monitoring requirements based on new scientific developments, many of which will come from non-agency scientists engaged in rigorous research programs. Without a mechanism to update monitoring methods, the law becomes an impediment for innovation, and knowledge is frozen at the time of the law's creation.

In the MS4 case study, there are legal barriers to adaptive management that need to be removed if adaptive management is to be employed effectively.[268] The EPA has given delegated states the discretion to identify monitoring methods for the illicit discharge program. The state regulations in our study area require using specific monitoring methods, and the state has not updated the regulations to reflect scientific advancements in these methods. In this specific case study, neither source specific bacterial indicators nor generic bacteria tests were included in the testing methods and special additional approval was required to utilize these methods. The legal framework should be designed to facilitate the incorporation of scientific developments by requiring regular updates of the monitoring methods and precise detection limits that warrant response actions. Without building in a way to update monitoring methods, the regulations

267. *Cf.* Karkkainen, *Bottlenecks and Baselines*, *supra* note 13, at 1443 (describing adaptive management as focusing on adjusting environmental management approaches according to new information about environmental responses, while silent on developments regarding advances in the monitoring processes and technologies).

268. *See* Ruhl, *Taking Adaptive Management Seriously, supra* note 30, at 1236-84.

quickly become outdated and ill suited to an adaptive management approach.

3. Discretion May Allow Avoidance of Management Responsibilities and Regulators and Citizens Will Find Enforcement Impracticable

Our study underscored how a lack of clear standards and procedures tends to allow managers to avoid accountability for meeting management responsibilities. This is tied to the inability of regulators or citizens to use enforcement as a tool to achieve compliance when a program lacks clear rules and timetables. In our study, the regulators discussed how the greyness of the regulatory requirements (i.e., to produce and carry out illicit discharge plans) made it virtually impossible to enforce. Accordingly, there have been no enforcement actions brought against MS4s for failure to remove illicit discharges despite a rich database showing human-specific bacteria indicators in multiple MS4s discharge pipes.

4. Lack of Clear Standards May Undermine Agency Budgets and Make it Difficult to Prioritize Actions to Produce Cleaner Water

Moreover, attention should be paid to the budgetary and triage impact of choosing a regulatory approach that is light on standards and heavy on management discretion.[269] This choice of focus can undermine agencies' ability to garner budgets sufficient to manage the target resources. There is a relationship between the availability of clear standards and the "message" it sends to elected officials who set overall budgets, and supervisors who must operate within those budgets. In the MS4 case study, we found one MS4 lacked the budget to have anyone on staff to carry out the illicit discharge program.[270] In another municipality with significant levels of human *Bacteroides* in its stormwater outfalls, the supervisor reported that he was spending the stormwater budget to fix backups of sewage in

269. Lawrence Susskind et al., *supra* note 40, at 1.
270. Interview with Confidential Interviewee No. 7 (May 25, 2012).

residential basements, while not budgeting additional money to address human sewage discharging into a major publicly-used river.[271] Part of the explanation in both instances was the lack of clear and enforceable legal requirements around illicit discharges, which indicate it is less of an urgent priority for budgeting limited public funds.

5. Time and Resource Costs of Adaptive Management May be Balanced by Cost Savings from Scientific Accuracy

Our study recognizes the critique that adaptive management increases costs and time, but counters that by incorporating scientific advances, such as the source-specific bacterial monitoring featured in our study, managers will be able to move more swiftly and efficiently to eliminate illicit discharges. Rather than chasing after illusive and unknown sources of contamination, incorporating more specific monitoring techniques can help to prioritize problems with the greatest public health risk.

6. Trusted Intermediaries Are Essential for Science Extraction and Communication to Resource Managers

Professor Doremus argued that a more structured approach to adaptive management might address some of the critiques of adaptive management.[272] She explored how scientific knowledge is developed and is then extracted and diffused to resource managers. Our study provides greater details about scientific extraction and the importance of trusted intermediaries in the communication and diffusion of science to managers.

If adaptive management is to be successful, one needs to recognize that scientific capacity of agency staff is a factor that needs to be studied and addressed.[273] In the MS4 case study, the stormwater managers at the municipal and state agency level were primarily trained as engineers. They expressed a lack of understanding of the science related to detecting human sewage

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271. Interview with Confidential Interviewee No. 1 (May 29, 2012).

272. *See* Doremus, *Adaptive Management as an Information Problem*, *supra* note 47, at 1482.

273. *Cf. id.* at 1491-92.

in stormwater. This research identifies a need for relevant science to be clearly communicated in terms that are more accessible to resource managers. Further, in order for the science to be applied to resource management, attention must be paid to practical considerations such as field training, availability of labs to process tests, cost of adopting new monitoring methods, and the response time required to receive results.

Professor Doremus identified the need for "budgeting for learning" if agencies undertake an adaptive management approach.[274] In the MS4 case study, the lack of budgeting for learning was an obstacle to incorporating more accurate monitoring methods. Budgeting for time to review scientific literature and develop better science communication tools could be most efficient if conducted by a trusted intermediary. In the MS4 case study the interviewees identified the Milwaukee Metropolitan Sewerage District as a trusted intermediary to interpret scientific developments. Hence, targeted federal grants to allow the intermediary to monitor, translate, and disseminate scientific innovations is essential.[275] While the intermediary will change with the circumstances, the lesson for other applications of adaptive management is to identify a trusted intermediary for the diffusion of scientific information, and then to clearly budget for the intermediary to engage in science communication and dissemination with the target natural resource managers. Additionally, at the natural resource manager and field staff levels, there is a need to budget for learning so the people making and carrying out management decisions have time allocated to receive and incorporate the information imparted by the trusted intermediary. In situations where resources are so limited that a budget for learning is not possible, the regulatory approach should rely more heavily on prescriptive standards rather than set up local managers for excessive difficulties.

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274. *Id.* at 1488.

275. *See* Doremus, *Data Gaps in Natural Resources Management*, *supra* note 57, at 456-59.

7. The Clean Water Act and its Implementing Regulations Need to Be More Adaptive to Science

In addition to the lessons learned about adaptive management, this research also points toward key reforms necessary for the Clean Water Act to effectively adapt scientific developments that could result in cleaner oceans, lakes, rivers, and streams. Currently, the EPA recommends basing Water Quality Standards for bacteria on generic indicators that come from a wide variety of animal sources. The Water Quality Standards for bacteria have not been updated to reflect scientific advancements in more accurately identifying the source of bacteria. Water Quality Standards should include a subset of human-specific bacteria indicators. This would result in more effectively targeting situations that pose greater human health threats, such as exposure to pathogens in human sewage. The use of human-specific bacteria indicators would allow for more accurate identification of impairments and fine-tuned restoration efforts rather than wasting resources and time on projects that fail to recognize or address the actual source of the bacteria impairment.

Focusing more specifically on problems posed by urban stormwater, policy makers need to be more aware that stormwater is not just carrying runoff from land surfaces; human sewage in stormwater is a prevalent problem. Human source bacteria testing of stormwater outfalls across the country provides the "smoking gun" indicating widespread problems with buried water infrastructure and historic as well as present plumbing mistakes. This not only points toward the need for greater federal attention to shoring up the nation's water infrastructure, but also for the EPA and state agencies to fine tune the MS4s illicit discharge programs to more accurately and rapidly detect and fix problems with raw sewage discharges.

VI.
CONCLUSION

In the late 1980s, Congress and the Environmental Protection Agency created a highly discretionary regulatory structure for detecting and eliminating non-stormwater discharges from untreated municipal stormwater.[276] While more adaptive than prescriptive, the program lacks a rigorous and intentional system to promote adaptive management. In order for adaptive management to result in better environmental results, managers need to actively engage in an iterative and searching process where they are aware of and incorporating advances in scientific discoveries. Through a case study of municipal stormwater management, this research adds to the literature on adaptive management by focusing on an aspect of adaptive management often ignored in theoretical approaches—the adoption of new monitoring technologies. Moreover, this research identifies and articulates key regulatory and non-regulatory barriers to adaptive management and urges policy makers to be cognizant of these barriers in order to provide a legal and regulatory structure that facilitates the incorporation of scientific advancements into natural resource management.

276. 33 U.S.C. § 1342(p) (2012) (requiring NPDES permits for MS4s); 33 U.S.C. § 1342(p)(3)(B)(ii) (prohibiting non-stormwater discharges); 40 C.F.R. § 122.26(d)(2)(iv)(B) (2012) (establishing Phase I rules to detect and eliminate illicit discharges); 40 C.F.R. § 122.34(b)(3)(i) (2012) (establishing Phase II rules to detect and eliminate illicit discharges); PITT & CTR. FOR WATERSHED PROT., *supra* note 10, at 1.

APPENDIX 1. RESEARCH SHOWING HUMAN SEWAGE IN STORMWATER DISCHARGES

Authors	Article	Locations Studied	Type of Testing Conducted
J.K. Parker et al.	Characterizing Fecal Contamination in Stormwater Runoff in Coastal North Carolina, USA - 44 WATER RESEARCH 4186-94 (2010)	3 beaches in coastal Carteret County, North Carolina - two impacted by stormwater outfalls, one impacted by ditch system that funnels runoff.	*E. coli*, *Enteroccus* sp., human-specific *Bacteroides*, and fecal *Bacteroides* spp.
Elizabeth P. Sauer et al.	Detection of the Human Specific *Bacteroides* Genetic Marker Provides Evidence of Widespread Sewage Contamination of Stormwater in the Urban Environment - 45 WATER RESEARCH 4081-91 (2011)	45 stormwater outfalls in 4 watersheds in metropolitan Milwaukee, Wisconsin.	*E. coli*, *Enteroccus* sp., human-specific *Bacteroides*, total *Bacteroides* spp., human-derived viruses (in one instance)
W. Ahmed et al.	Evaluation of *Bacteroides* Markers for the Detection of Human Faecal Pollution - 46 LETTERS APPLIED MICROBIOLOGY 237-42 (2008)	3 stormwater catchments in Queensland, Australia and a number of non-environmental sources (to test host-specificity).	Human specific *Bacteroides*
V.B. Rajal et al.	Molecular Quantitative Analysis of human Viruses in California Stormwater - 41 WATER RESEARCH 4287-98 (2007)	25 storm drains and ditches in California (6 highway runoff, 6 mixed urban runoff, 2 tidally influenced urban, 2 agricultural runoff, 2 natural loading).	Human viruses (adenoviruses and enterovirus), total and fecal coliforms, *E. coli*
Bram Sercu et al.	Storm Drains are Sources of Human Fecal Pollution During Dry Weather in Three Urban Southern California Watersheds - 43 ENVTL. SCI. & TECH. 293-98 (2009)	Creeks and storm drain networks in Santa Barbara, CA.	Total coliform, *E. coli*, enterococci, human-specifc *Bacteroides*

R.W. Haile et al.	The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff - 10 EPIDEMIOLOGY 355-63 (1999)	Number of beach samples taken various distances from storm drain outfalls, Santa Monica Bay, CA.	Total and fecal coliforms, enterococcus, *E. coli*, enteric viruses
C.Q. Surbeck et al.	Flow Fingerprinting Fecal Pollution and Suspended Solids in Stormwater Runoff from an Urban Coastal Watershed - 40 ENVTL. SCI. & TECH. 4435-41 (2006)	Santa Ana River watershed.	*E. coli*, (F+ coliphages) viruses
M.J. Brownell et al.	Confirmation of Putative Stormwater Impact on Water Quality at a Florida Beach by Microbial Source Tracking Methods and Structure of Indicator Organism Populations - 41 WATER RESEARCH 3747-57 (2007)	Samples taken from various points along a stormwater conveyance on Siesta Key Beach, Sarasota County, Florida.	Fecal coliforms, enterococci, polyomavirus
J.H. Ahn et al.	Coastal Water Quality Impact of Stormwater Runoff from an Urban Watershed in Southern California - 39 ENVTL. SCI. & TECH. 5940-53 (2005)	More general and summarizing study - focus on application.	
S. Bay et al.	Water Quality Impacts of Stormwater Discharges to Santa Monica Bay - 56 MARINE ENVTL. RESEARCH 205-23 (2003)	More general and summarizing study - focus on application.	
S.J. Gaffield et al.	Public Health Effects of Inadequately Managed Stormwater Runoff - 93 AM. J. PUB. HEALTH 1527-33 (2003)	More general and summarizing study - focus on application.	
W. Ahmed et al.	Sourcing Faecal Pollution: A Combination of Library-Dependent Methods to Identify Human Faecal Pollution in Non-Sewered Cathments - 41 WATER RESEARCH 3771-79 (2007)	3 non-sewered catchments in southeastern Queensland, Australia.	*E. coli*, Enterococcus, *Bacteroides*

Rachel T. Noble et al.	Multitiered Approach Using Quantitative PCR to Track Sources of Fecal Pollution Affecting Santa Monica Bay, California - 72 APPLIED ENVTL. MICROBIOLOGY 1604-12 (2006)	6 main-stem sites and 4 main tributaries of Ballona Creek (Santa Monica Bay), California.	*E. coli*, Enterococcus, human-specific *Bacteroides*, enteroviruses
Ryan J. Newton et al.	Lachnospiraceae and Bacteroidales Alternative Fecal Indicators Reveal Chronic Human Sewage Contamination in an Urban Harbor - 77 APPLIED ENVTL. MICROBIOLOGY 6972 -81 (2011)	Samples from WWTP and harbor - Milwaukee, Wisconsin.	*E. coli*, Enterococcus, human-specific *Bacteroides*, Lachnospiraceae
W. Ahmed et al.	Evaluating Sewage-Associated JCV and BKV Polyomaviruses for Sourcing Human Fecal Pollution in a Coastal River in Southeast Queensland, Australia – 39 J. ENVTL. QUALITY 1743-50 (2010)	Primarily tested primary and secondary wastewater effluent but also 20 samples from the Maroochy River, many near stormwater pipes.	Human-specific *Bacteroides*, 2 polyomaviruses
Julie L. Kinzelman & Sandra L. McLellan	Success of Science-Based Best Management Practices in Reducing Swimming Bans - A Case Study from Racine, Wisconsin, USA – 12 AQUATIC ECOSYSTEM HEALTH & MGMT. 187-96 (2009)	Storm and surface water in Racine, Wisconsin.	Human-specific *Bacteroides*, *E. coli*