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Economic Support for Decisions on Source Water Protection

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INTRODUCTION

Source water quantity, quality, and reliability are central to the design and operation of public water systems (PWSs). PWSs regularly modify in-plant operations and upgrade capital equipment following changes in source water conditions to optimize performance and maintain compliance with regulatory standards. PWSs may also adopt upstream source water protection (SWP) strategies to safeguard source waters from adverse impacts before treatment, such as agricultural runoff control and watershed restoration to reduce wildfire risks (Carpenter 2017, Gartner et al. 2017). Around the world there is growing interest in SWP as a means to reduce certain health risks and avoid treatment expenditures; in the U.S., for example, federal and state laws recognize the benefits of watershed services and establish funding for SWP activities (40 C.F.R. §141.2 2016, California Water Code §108.5 2016). In addition, there are numerous on-going and emergent watershed management programs whose stated motivations include securing drinking water supplies (Bennett et al. 2014, Carpe Diem West 2011, Herbert 2007).

When considering SWP options, PWSs need evidence-based information on how SWP interventions affect source water conditions and treatment costs (Gartner et al. 2017). By quantifying relationships between treatment costs and various source water characteristics, economics can equip PWSs with information needed to estimate avoided treatment costs and, in conjunction with cost information on SWP activities and in-plant treatment options, determine whether SWP is likely to be costeffective (i.e., the least-cost alternative for meeting the desired objective). This latter issue is crucial as existing evidence suggests that SWP programs are cost effective only for a fraction of PWSs (Vincent et al. 2016, Heberling et al. 2015, McDonald and Shemie 2014, Hudak et al. 2013, Pyke et al. 2002), except when

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program costs can be sufficiently distributed across multiple stakeholders (Gartner et al. 2017). Where initial estimates for SWP are projected to be cost effective, PWSs can pursue more precise economic and hydrologic modeling specific to their treatment system and watershed to better inform the decision-making process. For municipal and state agencies, modeling efforts and cost effectiveness analyses would most likely consider a broader set of benefits, including those related to recreation, wildfire management, and aesthetics.

What follows is a brief review of the state of knowledge regarding the relationship between treatment costs and source water conditions based primarily on experiences in North American PWSs. Key knowledge gaps are also highlighted. Lastly, a research agenda that will aid PWSs in evaluating the efficacy of potential SWP programs is discussed.

EXISTING RESEARCH AND KNOWLEDGE GAPS

Economists rely on statistically estimated cost functions to quantify relationships between treatment costs and source water conditions, and subsequently to determine potential avoided treatment costs. Cost functions are guided by economic theory wherein, besides source water conditions, treatment costs depend on a PWS's output volume, price of factor inputs (e.g., electricity rates), and in most instances fixed capital inputs. The precise form of a cost function depends on a number of contextual and data-related issues, while input from water treatment engineering is important for refining model specifications and interpreting results. A review of costs functions, and related approaches, as applied to PWSs and source water quality is available in Price and Heberling (2018).

Extant studies find that marginal improvements in source water quality lead to modest reductions in treatment costs. Evidence of this effect is most robust for turbidity, where recent US- and Canada-based studies find that a 1% decline in turbidity leads to a 0.09 – 0.11% reduction in variable costs (Price et al. 2017, Heberling et al. 2015, Mosheim 2006). For example, with a \$1 million annual treatment cost budget, a PWS could save \$1100 per year if a 1% reduction in turbidity leads to a 0.11% change in treatment costs. Slightly larger reductions of 0.19% and 0.30% are found when considering the effect of turbidity on just chemical expenditures (Warziniack et al. 2017, Forster and Murray 2007).

Studies have also evaluated how treatment costs are affected by total organic carbon (TOC), nitrate, and calcium carbonate concentrations, as well as the amount of sediment, phosphorus, and pesticides entering source waters from runoff. Findings for these water quality measures are less robust than for turbidity, being either limited to a single study or exhibiting considerable variation across estimates. Among recent US-based studies, a 1% decline in TOC is associated with a 0.46% and 0.77% reduction in chemical costs (Warziniack et al. 2017, Freeman et al. 2008). However, Heberling et al. (2015) find that TOC has no appreciable effect on variable costs. A 1% decline in nitrate concentrations, sediment loading, and phosphorus loading, is associated with 0.02%, 0.26%, and 0.02 – 0.19% reductions in variable costs, respectively (Mosheim and Ribaud 2017, Heberling et al. 2015, McDonald and Shemie 2014).

Besides variable costs, source water quality affects expenditures on capital equipment. McDonald et al. (2016), for instance, find a positive correlation between the amount of sediment and nutrients entering source watersheds and the probability of adopting more sophisticated treatment technology. There are also numerous instances where deteriorating source water quality have been anecdotally linked to capital upgrades (Dunlap et al. 2015, Davenport and Drake 2011, Jones et al. 2007, Oneby and Bollyky 2006). However, since many upgrades are concurrently motivated by a desire to expand treatment capacity or comply with new regulatory standards, it can be difficult to determine what proportion of these costs are attributed to declines in upstream water quality. Evidence from cost functions, which can control for these confounding factors, is limited to a few studies that incorporate capital expenditure into their cost measure (Abildtrup et al. 2013, Figuepron et al. 2013, Horn 2011, Piper 2003, Renzetti 2001). Taken together, these studies show a negative relationship between total costs and source water quality, but it is unclear whether the inclusion of capital expenditures substantially alters the estimated relationships between treatment costs and source water conditions.

Few cost function studies have considered how water treatment costs are affected by the availability of source water independent of its impact on water quality via the dilution of contamination or increased runoff. Existing evidence indicates that water availability, defined as reservoir elevation or streamflow at intake, is negatively correlated with treatment costs (Heberling et al. 2015, Renzetti 2001). Variability in reservoir elevation and streamflow (i.e., the reliability of water supply) is positively correlated with costs; and may, under prevailing conditions, have a markedly greater effect on costs than availability (Renzetti 2001).

There are, as is evident from the preceding overview, several knowledge gaps in the existing literature. First, there is a need to better understand relationships between treatment costs and key source water quality parameters (e.g., TOC, pH, phosphorous, nitrogen, algae, cyanobacteria), water availability, and variation in water quality parameters and water availability. Second, there is a need to use a cost function approach to evaluate the relationship between amortized capital expenditures and source water conditions, and to determine whether this relationship differs from those based on variable cost.

Finally, little is known about how the relationships between treatment costs and source water conditions vary across treatment technologies, production scales, management regimes, and geographic regions. Price et al. (2017) evaluate heterogeneity across treatment technologies and Mosheim (2006) and Mosheim and Ribaud (2017) across production scales—with the latter finding that smaller systems are more adversely affected by marginal changes in water quality than larger systems—but more research is in order. In particular, the effects that source water conditions have on treatment costs in small-scale ground water systems have not been adequately studied.

CONSIDERATIONS FOR FUTURE RESEARCH

Building a knowledge base that can effectively aid PWSs in evaluating the efficacy of SWP programs will require a threefold approach. First, case studies should be used to assess

avoided treatment costs at individual PWSs. Cost functions developed for case studies can be tailored to a particular treatment technology, and these are well-suited to evaluating the intricacies of source water quality, process modifications, and atypical events such as process shutdown or a spike in pollutants. The functions can also, in some instances, account for abrupt changes in treatment that are triggered when source water conditions exceed predefined thresholds (e.g., augmented chemical usage, activation of capital equipment).

Second, multi-system studies should be used to assess average avoided treatment costs over many PWSs. These studies require a different approach to data acquisition and statistical modeling than case studies. Multi-system studies are suited to evaluating linkages between treatment costs, commonly monitored source water parameters, and land use; they can be used to identify heterogeneity in linkages across treatment technologies, production scales, and geographies. Third, an updatable database of relevant cost function studies, including both case studies and multi-system studies, should be developed and maintained to reduce the effort needed by PWSs to find avoided cost information. Organizing selected studies by characteristics of the treatment system, source water, and modeling approach would further enhance the usefulness of the database. A catalog of cost functions related to source water quality, but not source water availability or reliability, is provided through the U.S. EPA's Environmental Dataset Gateway (USEPA, 2018).

Data constraints are the primary obstacles to both case study and multi-system research approaches. For case studies, data must be obtained directly from PWSs, which, in addition to compiling relevant information, need to partner with researchers and consultants to develop cost functions that reflect their system's production technology. Since statistical models that analyze data ordered in sequential time intervals are often appropriate for case studies, a common requirement is daily or weekly observations of water treatment costs, production rates, and source water conditions over several years. As a rule of thumb, at least three years of observations are needed to model seasonal patterns in these types of case studies.

For modeling purposes, treatment cost may be defined as all operation-related expenditures or just those pertaining to a subset of treatment processes (e.g., chemical costs), while source water variables should include all raw water characteristics that are regularly monitored as part of the treatment process (e.g., turbidity, TOC, pH, temperature, reservoir elevation). Information on discrete changes in treatment processes (e.g., shutdowns, activation of auxiliary equipment) may also be incorporated into the models. Although compiling this data can be burdensome, partner PWSs gain valuable site-specific estimates of avoided treatment costs to inform SWP decisions. Findings from this kind of analysis, which could be disseminated through the aforementioned database of cost function studies, would readily benefit non-partner PWSs with similar treatment technologies and source water concerns.

Multi-system studies require cross-sectional or panel data obtained from surveys. Cross-sectional data observes many subjects at the same point in time, while panel data observes multiple subjects at several different time periods. The ensuing cost functions, which reflect sample averages, are coarser than those obtained from case studies since they typically employ annual or monthly observations and are unable to control for many site-specific

characteristics. Nonetheless, results from these analyses offer insight on the potential magnitude of avoided treatment costs that PWSs can use in the initial stages of SWP planning. Findings are also useful for policy makers considering the broader effects of water quality changes.

To the author's knowledge, a 1996 American Water Works Association (AWWA) questionnaire is the last publicly available survey to simultaneously elicit information on treatment costs and source water conditions for a large number of U.S. PWSs (AWWA 1996). Mosheim (2006), Mosheim and Ribaudo (2017), and Piper (2003) each used the survey to quantify the effects of water quality on costs. More recently, AWWA's Water Quality and Treatment Cost Survey (AWWA 2015), Statistics Canada's Biennial Drinking Water Plants Survey (Statistics Canada 2017), and several small-sample surveys (Warziniack et al. 2017, Freeman et al. 2008, Ernst et al. 2004) collected cost and source water information—but data are not readily available. Surveys like these are necessary to understanding SWP benefits, particularly when there is a desire to evaluate source water characteristics over a greater range of values than can be obtained with a case study. Sound design and sampling methods, as well as the ability to verify results, are important to the credibility of survey-based studies. As much as possible, survey administrators should aspire to collect data that are representative of target PWSs, elicit information on all variables relevant to cost function analyses as dictated by economic theory, and, while balancing privacy concerns, make data available to researchers.

Additional economic analyses, like benefit-cost analyses (BCA) or cost effectiveness analyses (CEA), are needed to help identify when SWP is cost effective relative to in-plant treatment. These studies should compare avoided treatment costs obtained from cost function studies to SWP program costs (e.g., Heberling et al. 2015). BCA and CEA should account for the inherent uncertainty in watershed and economic modeling by using the distribution of estimated costs and benefits and estimating the likelihood that SWP options will be cost effective. Accounting for uncertainty is important because the cost of reducing pollutants via SWP is likely more variable, and that variability less well understood, than the cost of in-plant treatment. In some instances, BCA and CEA will also need to include a probabilistic component accounting for potential landscape disruptions (e.g., wildfire, flooding, and chemical spill) that could drastically alter source water conditions. Gartner et al. (2017) found that flooding events are a major motivating factor among PWSs considering SWP.

An interdisciplinary approach is essential to conducting cost function studies, BCAs, and CEAs. Source water quality, for instance, is a function of the ecology of the water body (i.e., river, lake, reservoir) or ecosystem (i.e., groundwater) that represents the source, which, in turn, responds in a dynamic manner to physiochemical drivers in watershed loads. These loads are the product of ecological interactions between natural and engineered systems situated on the landscapes draining to the source. Consequently, understanding the impact of SWP activities on water quality will require interdisciplinary efforts (e.g., hydrologists, ecologists) to develop spatially explicit watershed models linking land use and management practices to water quality parameters (e.g., Elias et al. 2016). Access to geographic information system (GIS) data on land use and land management data, and the expertise to

integrate this information into modeling tools, will be essential to these efforts, as will advances in access to source water information like that being developed for the cloud-based WaterSuite (Benjamin et al., In Press).

The centrality of watershed and waterbody ecology in these models underscores the importance of an ecological perspective in linking SWP to changes in treatment costs. Moreover, engineering principles associated with water treatment and watershed management activities are needed to fully appreciate these links and ensuing policy implications. Development of economic analyses thus depends on effective collaboration with ecologists and engineers to adequately account for the changing dynamics from SWP measures.

It is often difficult for PWSs to know if a proposed SWP program will be cost effective. Indeed, several PWS have initiated programs without a formal or complete analysis of the benefits (Gartner et al. 2017). As the types of research outlined here are conducted and made available, possibly through an updatable database, they should help PWSs decide when SWP is likely to be cost effective and whether to pursue detailed site-specific assessments. While this work is necessarily interdisciplinary, substantial knowledge gaps regarding avoided treatment costs suggest the need for further economic research. To move forward with these efforts, it will be necessary to consider partnerships between PWSs, or survey developers in the case of multi-system studies, and economists that can help address the general lack of data and studies needed to support SWP decisions.

Biography

James I. Price is a postdoctoral researcher at the U.S. Environmental Protection (USEPA) Agency in Cincinnati, OH. He holds a Ph.D. in economics from The University of New Mexico, with concentrations in environmental economics and econometrics. Price's recent research centers on estimating the economic benefits of improved water quality.

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