# Measuring the Benefits of Power Plant Effluent Regulation

*The 2020 Steam Electric Reconsideration Rule and Potential Future Methods*

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Dr. David A. Keiser
Bethany A. Davis Noll
Dr. Catherine L. Kling
Dr. Rachel Rothschild

Institute for Policy Integrity
New York University School of Law
Wilf Hall, 139 MacDougal Street
New York, New York 10012

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# About the Authors

**Dr. David A. Keiser** is a Professor in the Department of Resource Economics at the University of Massachusetts Amherst. He is a member of the Editorial Board of Land Economics, and he holds affiliations with Cornell University and Iowa State University. He is currently a chartered member of the U.S. EPA Science Advisory Board and Economic Analysis Committee. Dr. Keiser is an environmental and natural resource economist focusing on the economics of U.S. water quality policy. He has published in top economic and science journals, including *Science, Proceedings of the National Academy of Sciences, Science Advances, Quarterly Journal of Economics, Journal of Economic Perspectives*, and the *Journal of the Association of Environmental and Resource Economists*. His work has been cited in Congressional testimony, incorporated in graduate training at leading universities, and appeared in major news outlets. Dr. Keiser has been a principal investigator or co-principal investigator on over $5 million in federal and state grants.

**Bethany A. Davis Noll** is Executive Director of the State Energy & Environmental Impact Center, an affiliated scholar at the Institute for Policy Integrity, and adjunct professor all at NYU School of Law. She is also the co-chair of the Environmental Law Committee of the New York City Bar Association. Prior to NYU, she worked as Assistant Solicitor General in the New York Attorney General's Office, where she earned the Louis J. Lefkowitz Memorial Award for her work on several environmental appeals. She worked as a litigation associate at Debevoise & Plimpton LLP and an adjunct lecturer in law at Columbia Law School. She also served as a clerk for the Honorable Chester J. Straub in the Second Circuit Court of Appeals and for the Honorable Shira A. Scheindlin in the District Court for the Southern District of New York. Bethany received a J.D. with distinction from Stanford Law School and a B.A., magna cum laude, from Barnard College.

**Dr. Catherine L. Kling** is a Tisch University Professor in the Dyson School of Applied Economics and Management and Faculty Director at the Atkinson Center for a Sustainable Future. She is past Director of the Center for Agricultural and Rural Development at Iowa State University, where she also held the President's Chair in Environmental Economics. She was elected to the National Academy of Sciences in 2015. Kling has published nearly 100 refereed journal articles and has been principal investigator or co-principal investigator on over $15 million in grants. She specializes in the economic valuation of ecosystem services and integrated assessment modeling for water quality modeling. Kling chairs the Water Science and Technology Board of the National Academy of Sciences, serves as editor of the *Review of Environmental Economics and Policy* and is on the editorial board of *PNAS*. She is an elected Fellow of the Association of Environmental and Resources Economists, the Agricultural & Applied Economics Association, the American Association for the Advancement of Science, a Fellow at the Center for Agricultural and Rural Development, and a University Fellow at Resources for the Future. She served for ten years on EPA's Science Advisory Board.

**Dr. Rachel Rothschild** is a legal fellow at the Institute for Policy Integrity and will join the University of Michigan Law School as an Assistant Professor in July 2022. She holds a J.D., cum laude, from N.Y.U. School of Law, where she was a Furman Academic Scholar, and a Ph.D. in history from Yale University, where she was a National Science Foundation Graduate Research Fellow. She earned her B.A., magna cum laude, from Princeton University. From 2015 to 2017, she was an assistant professor and faculty fellow at N.Y.U.'s Gallatin School of Individualized Study. She is the author of *Poisonous Skies: Acid Rain and the Globalization of Pollution* (University of Chicago Press, 2019), and she has written numerous articles and essays on pollution problems for academic journals and media outlets.

# I. Introduction

This report reviews the Economic Analysis (EA) that supported the 2020 Revisions of the Effluent Limitation Guidelines (ELGs) and Standards for the Steam Electric Power Generating Point Source Category ("2020 Rule" or "Rule"). We review the economic framework, literature, and analyses performed to support these revisions. Our report builds on Davis Noll and Rothschild (2021). In that report, Davis Noll and Rothschild detailed numerous impacts of the 2020 Rule that EPA neglected to examine in the EA, such as the health impacts from bromide, lead, and mercury emissions, harms to threatened and endangered species, and forgone climate benefits related to use of the Trump administration's social cost of carbon (SCC) value. For example, the agency left millions of dollars in benefits unquantified by not monetizing the health benefits of fewer incidences of bladder cancer from reductions in bromide levels. Similarly, the Trump-era SCC value dramatically understated the expected harms from climate change to the U.S. by excluding foreign spillover effects on U.S. financial, property, and national security interests, among other methodological flaws. The 2021 report concluded that EPA should reexamine the benefits estimates for any related ELG rulemaking or update to the 2020 Rule.

This review highlights seven key considerations to be addressed along with the considerations in the 2021 report. We outline them here:

1. Economic Framework for Estimating Benefits – The U.S. Environmental Protection Agency (EPA) has invested significant resources to develop a broad economic framework to estimate the benefits of water quality changes in the United States. This framework consists of a new national hydrological model, the Hydrologic and Water Quality System (HAWQS), and a new national economic model, the Benefits Spatial Platform for Aggregating Socioeconomics and H2O (BenSPLASH). Combining these two models serves as a state-of-the-art integrated assessment model for water pollution. It should operate as the framework for estimating benefits associated with any changes to the ELGs.

2. Missing Benefits – EPA noted several categories of economic benefits that were not measured in the 2020 EA. However, recent research related to property values and averting behavior suggests that any new EA should monetize these benefits. For example, numerous studies examine nutrient-related impacts on housing values. Research also links toxic pollutants, including mercury, to housing values. Further, new evidence suggests that the economic damages of averting behavior could comprise a significant share of the economic benefits related to reducing air pollution, which may occur when the power sector changes its operations to respond to an ELG rule, as discussed below. These estimates also indicate a need to consider how well the current cost of illness (COI) approach reflects the full economic value of morbidity impacts.

3. Ecological and Recreational Benefits – This category of benefits represents the largest share of measured economic impacts of changes in water quality. To estimate these benefits, the 2020 EA first measured changes in water quality through a water quality index. Next, the EA linked the index to a meta-analysis of economic studies that estimate the economic benefits of changes to this index. This approach measured the anticipated benefits of the 2020 Rule.

   Given the importance of this category, our review documents several aspects of this process that warrant further analysis. This includes additional sensitivity analyses related to the construction of the water quality index and how this index links to economic value. Further, any future EA should improve the linkages between projected changes in water quality to economic value. One such change includes updating the meta-analysis to include additional published research detailed below. Our review also notes that EPA should prioritize efforts to measure the economic benefits associated with changes in water quality in several excluded bodies of water such as the Great Lakes, estuaries, and enclosed lakes and ponds. Given that these areas experience large numbers of recreational visits and include iconic bodies of water, without estimates related to these water bodies, the 2020 Rule's economic benefit estimates were likely significantly below their true value.

4. The Economic Impacts of Lead – The 2020 EA analyzed the economic impact of exposure to lead through fish ingestion. These estimates focus on earnings impacts tied to anticipated I.Q. loss in children. It is important to recognize that these are a lower bound (they do not incorporate many other values of reducing lead exposure). Furthermore, new research on lead implies that the EPA value of the impact of lead on lifetime earnings is too low. We show that there is compelling evidence to suggest this value should be at least twice as large as EPA's current estimates. Any new EA should update this value and acknowledge that earnings losses are a lower bound estimate that can omit significant additional benefits.

5. Human Health Impacts of Toxic Pollutants – The 2020 Rule affected a host of toxic chemicals that have significant human health consequences. The 2020 EA did not monetize the economic consequences of many of these toxic substances due to perceived data limitations. Our review identifies studies that were overlooked and other research that could shed light on these areas for improved economic monetization. Future EAs should include these benefits.

6. Economic Productivity – The 2020 Rule identified several benefit categories related to economic productivity. The cost to treat drinking water is one important category that was not monetized. Our review highlights new academic research that should be included to monetize these effects.

7. Air Pollution Benefits – Reductions in air pollution play an important role in cost and benefit estimates related to the Rule. This occurs because EPA anticipated that the Rule would impact 1) energy use by steam electric power plants, 2) transportation-related emissions due to waste disposal, and 3) the profile of electricity generation. We identify several aspects of the monetization of air pollution benefits that warrant further attention. First, the EA generally estimated that the 2020 Rule would decrease adverse human health impacts. In turn, these changes in human health typically lead to significant benefits of the Rule. For Option A (the Final Rule), EPA estimated that the value of human health effects outweighs the harm done to Climate Change impacts and Ecological Conditions and Recreational Use. These results are striking in that they suggest that an action that will increase emissions leads to improvements in human health. They also run counter to the 2015 EA that estimated large economic damages associated with human health related changes to emissions. More attention should be given to these estimates given that these results served such a prominent role in the benefit-cost analysis. EPA should explain, in more detail, and justify, the assumptions that lead to these counterintuitive results.

   Second, the 2020 EA did not monetize several categories of air pollution benefits. These include averting behavior damages, coal storage damages, visibility impacts, cognitive impacts, and ozone impacts. Future EAs should monetize these categories. Third, current research suggests that the COI approach used by EPA may significantly understate the economic value of changes in exposure to local air pollutants.

   Finally, the economics literature provides strong justification for using a global rather than domestic social cost of carbon (SCC). The 2021 report by Davis Noll and Rothschild demonstrated that this difference in the SCC played a critical role in the benefit-cost analysis. As their review demonstrated, the lower SCC provided greater weight for less stringent regulatory options. A revised EA should use a global SCC as its default value.

# II. Economic Framework for Estimating Benefits

Many economic analyses of EPA rules and regulations that affect water quality use some form of an integrated assessment model (IAM) to measure the costs and benefits of a proposed regulation (Griffiths et al., 2012; Keiser, Kling, and Shapiro, 2019; Corona et al., 2020). This approach links economic models of the impact of a proposed rule with a model of the pertinent environmental system. In the benefit-cost analysis of the 2020 Rule, EPA used two hydrological models. The Downstream Fate and Transport Equations (D-FATE) model was used to assess the flow of toxic pollutants impacted by the 2020 Rule. A second model, the SPAtially Referenced Regressions On Watershed attributes (SPARROW), modeled the fate and flow of total nitrogen, total phosphorus, and suspended sediment concentrations. SPARROW is a hydrological model developed by the U.S. Geological Survey (USGS). The model is well-regarded and has been used in many applications.

These hydrological models formed the basis for predicting how pollution would travel under various scenarios considered in the EA. EPA then modeled the anticipated physical and economic effects of changes in pollution concentrations. Figure 2-1 from the 2020 EA provides a standard mapping showing how a proposed regulation will likely impact the environment and the anticipated changes in economic value. Academic literature supports this overall framework (Griffiths et al., 2012; Keiser and Muller, 2017; Keiser, Kling, and Shapiro, 2019).

While the organizing framework is solid, there have been several recent advances in the components used to support the EA. EPA has invested heavily in recent years to improve both water quality modeling and the corresponding economic models used to analyze proposed rules and regulations (Corona et al., 2020). EPA should update these aspects of the EA in any related ELG rulemaking. We describe those efforts here:

### *Water Quality Models*

While SPARROW is a defensible model in many settings, it faces limitations in analyzing a national rule. For instance, the EA to support the 2020 Rule used several regional SPARROW models. This means that separate models were developed for different areas of the country, including the Northeast (Ator, 2019), Southeast (Hoos and Roland Ii, 2019), Midwest (Robertson and Saad, 2019), Pacific region (Wise, 2019) and Southwest (Wise, Anning, and Miller, 2019). Each of these models provides predictions of total nitrogen, total phosphorus, and suspended sediment concentrations.

For consistency purposes, and when available, a national rule should use a consistent national hydrological model. Because "…full integration of hydrologic models and economic valuation has developed slowly in water regulations" (Corona et al. 2020), EPA has invested significant resources to develop a new national IAM capable of easily measuring proposed rules and regulations. The water quality component of this IAM is known as the Hydrologic and Water Quality System (HAWQS). It is a national water quality model explicitly built for assessing and measuring the economic benefits of water quality policies (Corona et al., 2020). While some aspects of HAWQS are still under development, an early version of the model is currently available to the general public, suggesting EPA could use it for future rulemaking and that it should at the very least be used for a sensitivity analysis of the benefit estimates here.

Additionally, our review found limited documentation on the D-FATE model. To our knowledge, D-FATE has not been used to analyze other EPA rules and regulations. We suggest that EPA provide additional documentation to support the use of D-FATE and describe the advantages and disadvantages of this model for benefit-cost analysis.

## *Economic Framework*

The 2020 EA discussed several economic models that link to D-FATE and SPARROW. More recently, EPA has developed a new economic framework to model many of the impacts considered in the analysis of the 2020 Rule. This model is the Benefits Spatial Platform for Aggregating Socioeconomics and H2O (BenSPLASH). BenSPLASH links changes in water quality parameters to an impacted population and estimates the resulting economic benefits. Economic benefits are tied to water quality modeling through the use of a water quality index. A valuation function translates changes in the water quality index into changes in economic benefits. EPA estimates this function from a meta-analysis of water quality studies. EPA is building BenSPLASH as the economic companion to HAWQS for national and regional economic benefit assessment.

In a recent paper, Corona et al. (2020) highlight the potential use of HAWQS and BenSPLASH in an application in the Republican River Basin. Several features of this application suggest that HAWQS and BenSPLASH may be available to analyze any updates to the 2020 Rule or related ELG rulemaking. For instance, the meta-data for the valuation function in BenSPLASH are taken from the 2015 Steam Electric EA (EPA, 2015; Corona et al., 2020). Updating these data and the valuation function to assess a new rule should be straightforward. Indeed, EPA highlights the flexibility of BenSPLASH as an attractive feature of the economic framework. The model also allows users to adjust key assumptions that impact the overall benefit estimates, such as the extent of the market and scale of the stream network (Corona et al., 2020). Corona et al. (2020) also note that BenSPLASH "includes an equally weighted seven-parameter version (of a water quality index) used in the EPA's 2015 Steam Electric Effluent Limitation Guideline." This suggests that BenSPLASH has been tailored to measure the benefits of reducing pollutants associated with the 2020 Rule. We encourage EPA to use BenSPLASH and incorporate other comments we note regarding the valuation process throughout this report.

In addition to current efforts to build BenSPLASH, EPA recently funded six large projects to improve estimates of the economic value of water quality and proposed to conduct its own survey to measure the benefits of surface water quality changes.[1] The request for applications for the six externally funded projects noted several vital elements in estimating the benefits of water quality improvements. These elements include 1) potential updates to the Agency's use of a water quality ladder to link changes in water quality to economic benefits,[2] 2) improvements to modeling the spatial connectivity of households and ecosystems, and 3) incorporating the latest economics research into improving the methods used to elicit estimates of households' willingness to pay for improvements in water quality. Addressing each of these components should help improve estimates of the benefits of water quality improvements for any future regulatory action.

A proposed in-house stated preference survey by EPA seeks to improve upon several dimensions that are also explored in the research grants. For instance, EPA seeks to improve estimates of the extent of the market of water quality improvements, the relationship between the amount of water quantity that is improved and the amount of those improvements, and the reasons why individuals value water quality improvements (i.e., recreation vs. ecosystem function). When the findings from these research projects are complete, they should be incorporated into the BenSPLASH framework to the extent feasible.

It is unclear how the use of a national water quality model and new national economics model would impact the overall benefit-cost estimates of the 2020 Rule. However, EPA has invested heavily in these aspects of analyzing water quality rules and regulations, and its products will be state of the art once fully operational. Any related regulatory rulemaking should use the latest science and economics to improve benefit estimates.

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1 A description of these grants, the Request for Applications, and awarded institutions can be found here: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.display/rfa_id/583/records_per_page/ALL. For full disclosure, Keiser and Kling are Principal Investigators funded by this grants program. The notice from EPA regarding its own national survey to measure the benefits of water quality improvements can be found here: https://www.regulations.gov/document/EPA-HQ-OA-2019-0292-0001.

2 A water quality ladder describes how different levels of water quality correspond to uses of water resources. For instance, a common water quality ladder used by EPA links improvements in water quality to the ability to use water resources for boating, then fishing, then swimming, and possibly drinking.

# III. Missing Categories of Benefits

While the 2020 EA considered a range of economic benefits, two key categories of estimated health and environmental benefits were absent, which allowed EPA to claim that a less stringent alternative likely had positive net benefits.[3] These unaccounted for benefits include amenity and local recreation benefits, but those can be captured by hedonic housing price impacts and health damages that can be partially measured by the costs associated with averting behaviors. Hedonic housing price impacts measure the damages to society from changes in pollution as reflected in housing values. Averting behaviors are costly actions that individuals take to reduce harmful or unpleasant effects of exposure to pollution. Both methods to estimate economic damages have featured widely in the economics literature (Phaneuf and Requate, 2017). Still, the EA did not measure them. Corona et al. (2020) note that efforts are underway at EPA to include hedonics in the BenSPLASH model to support future rulemakings. Here, we review the economics literature that should be considered in any related rulemaking in order to assess these categories of benefits.

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## A. Property Value Damages

The hedonic property value model is a commonly used approach in environmental economics to measure the economic benefits of pollution reductions and environmental rules and regulations (Rosen, 1974; Palmquist and Smith, 2002; Phaneuf and Requate, 2017). The intuition of the hedonic approach is that property values reflect the value that individuals place on both structural characteristics of homes (i.e., the number of bathrooms, bedrooms, square footage), as well as non-structural characteristics of homes (i.e., the quality of local schools, crime, local environmental amenities). Through the actions of many buyers and many sellers, resulting home prices reflect the implicit value of environmental amenities. Due to the restrictive assumptions needed to guarantee total capitalization of environmental values in prices, it is important to consider the extent of the benefits captured. It is quite possible, that hedonics lead to underestimates of water quality benefits (Kuwayama et al., 2022). Nonetheless, these methods provide valuable information for use in benefit estimates.

[3] *See* Steam Electric Reconsideration Rule, 85 Fed. Reg. 64,650, 64,652 (Oct. 13, 2020) (to be codified at 40 C.F.R. pt. 423) (hereinafter "2020 Rule") (estimating that the benefits (minus the forgone benefits) would range from –$1.7 million to $43.3 million using a 3 percent discount rate and from $6.5 million to $45.9 million using a 7 percent discount rate).

There have been many economic studies that measure the hedonic home price impacts from several pollutants of concern in the 2020 Rule. We describe some of those studies here:

### *Nutrient Pollution, Water Clarity, and Related Pollutants*

There is a robust literature that estimates the impact of nutrient pollution, water clarity, and related pollutants on home values. Guignet et al. (2021) survey this literature for the express purpose "… of value transfer." A "value transfer" exercise is when a set of estimates of economic value derived in one setting are used to predict how economic value would change with respect to a change in water quality in another setting (this is sometimes referred to as benefits transfer). Value transfers are an important aspect of benefit estimates used in regulatory impact analyses, and are often used by EPA.

Using 36 studies with 656 unique observations, Guignet et al. (2021) estimate average elasticities for 18 measures of water quality. These elasticities are estimates of the percentage change in home values given a 1 percent change in a specific water quality metric. The list of water quality parameters considered includes nitrogen, phosphorus, total suspended solids, turbidity, water clarity, and several others. Using a large number of studies that focus on water clarity (as measured by Secchi disk depth), the authors also estimate a meta-regression for this measure of water quality. Given that EPA anticipated the 2020 Rule would impact many of these pollutants, this meta-analysis or similar analysis should be considered in the estimates of the housing price impacts of any future regulatory rulemaking.

### *Mercury*

Tang, Heintzelman, and Holsen (2018) estimate that homes within one mile of a fish consumption advisory in New York lakes realize a 6 to 10 percent decrease in home values. Mercury is the primary pollutant of concern in the study. Other pollutants that trigger advisories include P.C.B.s, chlordane, and dioxin. Future regulatory rulemaking should use these findings to estimate amenity and local health impacts as measured through housing price changes related to the impact on the flow of mercury.

## *Toxic Pollutants*

Several recent studies find negative impacts of toxic pollutants on home values. Austin (2020), in a current working paper, studies the impact of coal ash discharges on water quality, fetal health, and home prices. He finds that coal ash discharges increase surface water levels of heavy metals, including arsenic, lead, and selenium. He also finds that these releases lead to a greater number of violations for downstream drinking water systems. These violations include inorganic compounds, arsenic, and health-based standards. There are significant, negative corresponding health impacts on children. Finally, his results suggest large, negative impacts of contaminated drinking water on homes within 1 mile of a coal ash pond.[4]

In a separate working paper, Cassidy, Meeks, and Moore (2021) study the impact of hazardous water quality on home values as reflected through the Area of Concern (AOC) Program. The authors find that toxic pollutants in the Rust Belt area of the U.S. significantly reduced home prices. The study does not consider specific pollutants but notes that "… persistent chemicals such as PCBs and PBDEs are found in the water, sediment, wildlife, and people who live near the Great lakes" (Cassidy, Meeks, and Moore, 2021). This work is in line with Mendelsohn et al. (1992), which estimates a large, and significant impact of PCB contamination on home values near the harbor in New Bedford, Massachusetts. While these studies do not tie specific pollutants from Steam Electric plants to home prices, they do find an impact from related pollutants and suggest the need to carefully consider how toxic, persistent pollutants may lead to significant housing price impacts.

There is also a substantial literature on air pollution, related toxics, and home prices. Currie et al. (2015) examine the impact of the opening and closing of facilities on EPA's Toxic Release Inventory (TRI) on housing prices and human health. They find that plant openings result in a 11 percent decline in local home values, and their operation significantly impacts the probability of low birth weight within a short distance of the plant. Given the prevalence of Steam Electric facilities on the TRI, this research should inform the analysis of the impacts on air pollution from these facilities of changes to the 2020 Rule or any future regulatory rulemaking.

Incorporating hedonic housing price impacts into future EAs is needed but will require careful consideration and EPA will likely need to highlight the fact that any estimate based on hedonics alone is likely to be an underestimate. The economic theory that supports the hedonic property value model suggests that the model *can theoretically* capture all economic benefits of water quality improvements, except nonuse values. This means that if the hedonic model operates perfectly and one has the data to estimate a hedonic model, the results will reflect all economic benefits of a considered rule. However, the theoretical model that supports this interpretation relies on several strong assumptions that make the full and accurate capitalization of damages unlikely. These include an assumption that individual homeowners are perfectly informed of the environmental quality and impacts of pollution exposure, that all combinations of housing and environmental attributes in housing choices are available, and that movement from one home to another is costless. Empirical evidence suggests that, in practice, full capitalization cannot be assumed.

In air pollution settings, Kuminoff (2018) finds that hedonic approaches to measuring the benefits of the Clean Air Act yield significantly smaller economic benefits than those that rely on alternative models based on dose-response estimates of human health impacts related to air pollution. These findings raise the question as to whether hedonics could play a role in related ELGs and, if so, how? Our view is that hedonic estimates should contribute to, and support, new EAs, particularly when there are no other means by which to estimate appropriate values. A large fraction of the benefits of water quality improvements measured by the 2020 EA focused on the ecological and recreational benefits of changes in

[4] As discussed below, the degree of capitalization of these damages into house prices is unlikely to reflect total damages. Fetal health effects and drinking water violations that are suffered by households outside of this radius are unlikely to be reflected accurately.

water quality. We agree with this emphasis, as tens of millions of U.S. households participate in water quality recreation each year. However, the economics literature also suggests a strong impact of water quality on home values. These impacts are generally concentrated close to water bodies and likely reflect recreational use value, in addition to other values such as the amenities associated with living near and enjoying a body of water. Thus, a future EA should consider hedonic impacts by estimating impacts of changes in water quality on homes very close to waterbodies. Since these hedonic estimates also likely reflect recreational use value, a future EA could subtract the recreational value of these particular homes from the hedonic estimates, so as not to double count benefits. The one exception is nonuse values. Since hedonic estimates do not capture nonuse values, these should not be subtracted from the hedonic estimates. Instead, they should be added to any use value estimates, hedonics or otherwise.

The economics literature provides guidance on how to determine which homes to model for property value benefits versus recreational benefits. Determining how far away the benefits of water quality improvements capitalize into housing markets is the economic concept known as the "extent of the market." Guignet et al. (2021) focus their analysis on home values within 500 meters of a waterway and note that some studies have detected impacts up to approximately one mile away. Thus, a hedonic price analysis for a future rulemaking could consider home prices within a tight distance of impacted waterways, such as one mile. However, this does not imply that the total benefits of the Rule should stop at one mile. Rather, a hedonic property value analysis could use the elasticities and meta-analysis results in Guignet et al. (2021) to estimate the economic benefits of households within one mile of an impacted waterbody. The EA would then add these estimates to recreational and other categories of benefits that accrue to residents greater than one mile away. Given that EPA is developing the capability to include hedonic housing price impacts in future benefit estimates (Corona et al., 2020), this aspect of economic benefits should be considered in any future, related EA.

## B. Averting Behavior

Averting behaviors are actions that individuals take to protect themselves from the harm of exposure to pollution. The economics literature demonstrates that these actions are costly, widespread, and an important component of the health impacts of pollution regulations (Phaneuf and Requate, 2017). Under some circumstances as demonstrated by Bartik (1988), averting behavior expenses reflect the full damages from a pollutant, but these are potentially quite restrictive (i.e., averting behavior costs capture the full benefits only if the good purchased is a perfect substitute for the unpolluted state). Thus, in many circumstances, these averting behavior costs should be added to the health impacts that remain after any mitigating behavior. The EA for the 2020 Rule did not consider or mention this potential approach to estimating damages. Since the 2020 Rule impacts both drinking water sources and air pollution exposure, any future, related ELG should include damage estimates reflecting health effects that can be estimated via averting behavior methods. We outline two possible mechanisms for future work:

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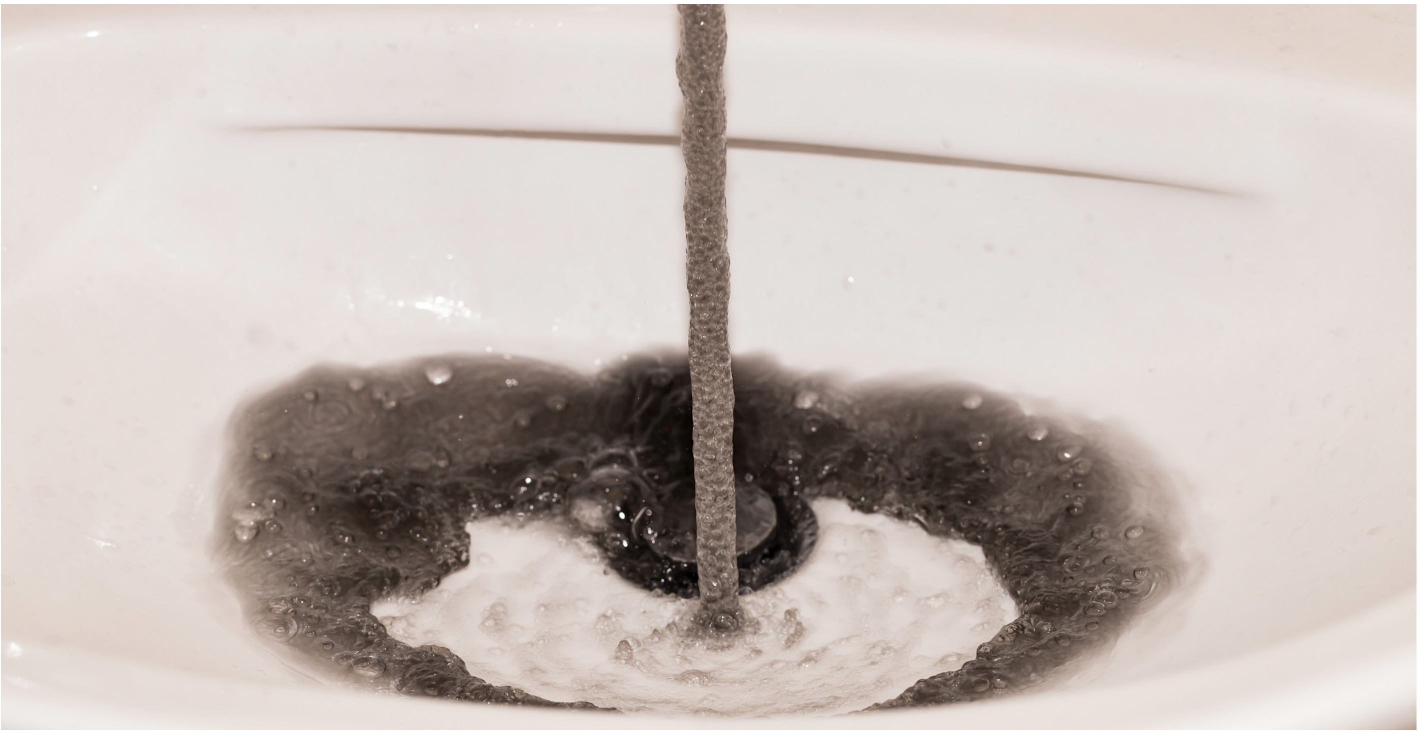

## *Averting Behavior and Drinking Water*

Recent research documents the link between poor water quality, drinking water violations, and averting behavior such as the purchases of bottled water and filters. Allaire et al. (2019) establish a strong relationship between sales of bottled water and violations of the Safe Drinking Water Act. The authors find that health-based Tier 1 violations increase sales of bottled water by 14 percent. These violations have the potential to cause serious health impacts even with short-term exposure. Tier 2 violations of other pollutants increase sales by 5 percent. Tier 2 violations are related to pollutants that have serious health concerns due to exposure over longer time periods. Similar to Allaire et al. (2019), Graff Zivin, Neidell, and Schlenker (2011) find significant averting responses to drinking water violations in Northern California and Nevada. One broad category that they examine, "Elements/chemicals," contain pollutants relevant to the 2020 Rule such as arsenic and disinfection byproducts. Sales of bottled water increase approximately 17 percent in response to a violation within the "Elements/chemicals" category. Their estimates imply that consumers increase spending by $60M annually in response to drinking water violations. Other literature that supports strong averting behavior related to degraded drinking water include applications ranging from lead (Christensen, Keiser, and Lade, 2021) to shale gas development (Wrenn, Klaiber, and Jaenicke, 2016).

Given that the 2020 Rule does not require limits on bromide, which impacts drinking water systems, the 2020 Rule should have documented how the Rule may increase the prevalence of violations at drinking water treatment plants and subsequent averting behavior. In recent years, disinfection byproducts comprise one of the largest categories of drinking water violations (Allaire, Wu, and Lall, 2018). Since disinfection byproducts are an important consequence of the 2020 Rule, this suggests that averting behavior may play a significant role in measuring benefits.[5] These averting behavior costs are in addition to those related to drinking water treatment costs. Further, as discussed above, Austin (2020) finds that coal ash discharges are associated with higher levels of drinking water violations.

[5] In the EA for the 2020 Rule, EPA discussed how halogens such as bromide and iodine result in increased disinfection byproducts. These halogens are discharged by steam electric power plants and serve as precursors to disinfection byproducts.

### *Averting Behavior and Air Pollution Exposure*

EPA admitted that the air pollution related benefits are underestimated because they "did not analyze all benefits of changes in $NO_x$, $SO_2$, and other pollutants emitted by EGUs" (p. 8-24). The EA included two categories of health benefits: mortality and morbidity. As stated in the EPA Guidelines for Preparing Economics Analyses (EPA, 2010), morbidity effects consist of four main components: 1) Averting expenditures, 2) Mitigating costs for treating illness such as the cost of medical care and medication, 3) Indirect costs such as lost time from work and leisure, and 4) Pain and suffering. EPA measures a *portion* of morbidity costs using a COI approach. As EPA notes, "…cost-of-illness (COI) estimates generally capture only mitigating and indirect costs, and omit averting expenditures and lost utility associated with pain and suffering" (EPA, 2010).

In recent research, Deschênes, Greenstone, and Shapiro (2017) use new data on pharmaceutical expenditures to study averting behavior related to the $NO_x$ Budget Program. The authors find that defensive expenditures related to air pollution exposure represent over one-third of the estimated benefits of the program. This research is directly related to the pollutants and electric generating units impacted by the 2020 Rule. Prior EPA estimates suggest that over 90 percent of the human health impacts of air pollution benefits are attributable to mortality (EPA 2019, p. 4-23). The 2020 EA did not provide a breakdown of the fraction of benefits by mortality or morbidity. However, the results of Deschênes, Greenstone, and Shapiro (2017) call into question how well prior COI estimates capture the full extent of morbidity estimates. Deschênes, Greenstone, and Shapiro's (2017) results suggest that standard COI estimates may significantly undervalue morbidity estimates, which implies that the 2020 EA may have significantly undervalued these benefits.

# IV. Ecological and Recreational Benefits

The 2020 EA included estimates of the ecological and recreational benefits associated with the 2020 Rule. Including ecological and recreational benefits is important, as this category of benefits often represents the largest share of estimated benefits of changes in water quality (Olmstead, 2009). To estimate these benefits, EPA first assessed the impacts of the Rule on an aggregate measure of water quality, a Water Quality Index (WQI). EPA then used a benefits transfer exercise that takes advantage of a meta-analysis used to value changes in the WQI. Thus, EPA estimated benefits by simulating changes in water quality from the 2020 Rule, translating these changes into changes in the WQI, and then valued these changes using a benefits function from a recent meta-analysis. The overall procedure for estimating these benefits is common and has been used previously by EPA to estimate benefits of water quality rules and regulations (Griffiths et al., 2012). While the procedures for estimating these benefits are standard, a number of important aspects of the analysis should be reconsidered or expanded in subsequent EAs:

### *Water Quality Index*

As discussed previously, the water quality models used to estimate the WQI should be replaced with EPA's HAWQS model; it has been developed specifically for benefit estimate purposes.

Further, in analyses of future rulemaking, EPA should consider how the aggregation function used to construct the WQI impacts benefit estimates. Since the WQI is a function of many underlying measures of water quality, some discretion is left to the analyst as to how to combine these distinct parameters into one composite measure of water quality. Walsh and Wheeler (2015) find that the procedure for combining these separate measures of water quality can have a significant impact on the benefit estimates of water quality rules. They study how the aggregation procedure impacts the benefit-cost analysis of the 2003 EPA CAFO rule. In particular, they explore the sensitivity of estimates to four different aggregation functions: the geometric, arithmetic, and harmonic means, and a minimum operator. They find that, "…the aggregation function can have a profound impact on the estimated benefits of the Rule, yielding a range of $82 million to $504 million dollars. In fact, the choice of indicator determines whether the net monetized benefits of the CAFO Rule are negative or positive."

While Walsh and Wheeler (2015) find support for, "…the continued use of the geometric mean…", they note that, "…several steps in the construction the WQI need to be updated."[6] They recommend updating the WQI given that its current construction dates back to the 1970s. There have been significant improvements in our understanding of the supporting sciences since that time, as well as changes in priorities regarding particular pollutants. They also recommend improving the link between valuation and the aggregation function itself and to study how variation in constructing the WQI may correspond to different valuation of water quality. At a minimum, in evaluating any future, related rule, it would be prudent for the agency to report the sensitivity of benefit estimates with respect to the method used to construct the index. The 2020 EA used the geometric mean. While Walsh and Wheeler (2015) find that the geometric mean yields a middle of the road estimate of benefits for the 2003 CAFO rule ($287M), it is difficult to know a priori how different weighting schemes will behave in any other rule.

[6] Walsh and Wheeler (2015) note that their, "sensitivity analysis did not support a switch from the geometric mean. With the geometric WQI, the importance of individual parameters to estimated benefits is a good reflection of the weights provided by a panel of hydrology experts. Also the geometric mean does not inflate high valued indicators or eclipse the most impaired indicator as much as the other aggregation functions."

### Studies Used in the Meta-analysis

The studies used to construct the benefits transfer function were based on studies from 1985 to 2017. Any future, related EA should include new publications. We found at least one new published paper (Choi and Ready, 2021) and one new working paper (Sandstrom et al., 2021) that employ similar methods as other studies included in the meta-analysis. As discussed in Section II, EPA has also funded several new projects to improve estimates of the economic value of water quality. Once the results of these valuation studies become available, they should be incorporated into an updated meta-analysis.

### Model Assumptions and Sensitivity Analysis

Two different versions of the meta-analysis were presented in the EA. However, the results of this meta-analysis call into question the robustness of the results and the sensitivity of the benefit estimates. For instance, across the four models that were published in 2015 (EPA, 2015) and then again in 2020 (EPA, 2020a), there are four variables where the coefficient estimates change signs entirely across the four specifications. These variables include "wtp_median," "River," "swim_use," and "gamefish." This fact suggests that the model may be mis-specified or suffer from issues related to endogeneity, which would suggest that further work is needed to improve the meta-analysis. It is not clear how changes to the meta-analysis would impact overall benefit estimates, but given that the parameters on some variables change sign, the sensitivity of the benefit estimates to different model specifications needs to be tested and analyzed.

### Omission of Great Lakes, Estuaries, and Enclosed Lakes and Ponds

EPA recognized several limitations of its analysis. One that was particularly important is the omission of the economic benefits associated with water quality changes in the Great Lakes and estuaries. The agency noted that six of the 112 steam electric power plants in their analysis discharge to these waterbodies. Five of these plants discharge to the Great Lakes and one discharges to Hillsborough Bay in Tampa, FL. The agency also noted that omitting these power plants, "likely underestimates benefits of water quality changes from the regulatory options" (EPA, 2020a). Given that the Great Lakes and many estuaries support significant recreational activities for large population centers, more focus on this omission is necessary. Its omission could have a significant impact on recreational benefit estimates. To move forward on this issue, the agency could model how nutrient pollution impacts outcomes of interest including recreation and housing values. These impacts could then be tied to economic value by appealing to valuation studies of the Great Lakes (Palm-Forster et al., 2016; Wolf et al., 2017, 2019; Wolf and Klaiber, 2017; Zhang and Sohngen, 2018) and Tampa Bay (Kuwayama, Olmstead, and Zheng, 2022).

Further, this analysis excluded economic benefits of enclosed lakes and ponds. Their exclusion in the analysis likely significantly decreased overall benefit estimates. To the extent possible, these resources should be a priority area in terms of understanding and incorporating their benefits. One possibility is to include hedonic and recreational benefit estimates associated with lakes and ponds consistent with the approach described above, while including recreational and ecological benefits of other water resources.

# V. The Economic Impacts of Lead

The EA for the 2020 Rule listed a number of adverse impacts of lead exposure. These effects include "decline in cognitive function, conduct disorders, attentional difficulties, internalizing behavior, and motor skill deficits…", as well as "adverse health outcomes related to the immune system…" and "…lower birth weight in newborns…" (EPA, 2020a). EPA stated that due to data limitations, it estimated only the economic damages from lead as reflected through changes in I.Q. and subsequent decreases in lifetime earnings. But a substantial economics literature exists and continues to show significant economic damages associated with lead exposure beyond that. For example, research by Lanphear et. Al (2018), cited by EPA in the EA, provides a dose-response function linking blood lead levels to increased mortality rates in exposed populations, even at very low doses (Lanphear et al., 2018). These damages are even larger in comparison to the cognitive impacts associated with lifetime earnings. Although many of these studies focus on lead exposure through air, others focus on ingestion through other media. Future, related EAs should reconsider the range of important, unmeasured economic benefits of lead reduction. Where appropriate, these estimates should supplement those previously measured.

Here, we highlight two broad areas for the agency to consider. First, we show that the impacts of lead on lifetime earnings are too low. Next, we discuss several new studies of the economic impacts of lead that further show the agency's estimates of the damages from lead exposure are too low.

### *Impacts of Lead on Lifetime Earnings*

Several new published studies and working papers mark important advancements in identifying the causal impact of lead on human health and long-run economic outcomes. Grønqvist, Nilsson, and Robling et al. (2020) use a detailed dataset of approximately 800,000 children in Sweden to understand the impact of lead exposure on long-run outcomes including crime and lifetime earnings. The authors write, "The pattern is clear: higher levels of exposure in early childhood are linked to lower GPA, a reduced likelihood of high school completion, and a greater risk of crime." Their results suggest that lifetime earnings decrease by 0.88 percent per 1 μg/dl increase in blood lead levels.[7] Given a median lifetime earnings in the United States of $1.7M, this translates into a lifetime earnings impact of approximately $15,000 per 1 μg/dl change in blood lead levels.[8] By comparison, the 2020 EA used a much smaller estimate of the impact of lead on lifetime earnings. The EA for the 2020 Rule estimated that a value of 1 I.Q. point is $20,832 (2018$). EPA also used an estimate that for every change in 1 μg/dl in blood lead levels, I.Q. falls by approximately 0.31595 points.[9] In other words, EPA's estimate implied an average lifetime income reduction of $6,581.87 per 1 μg/dl increase in blood lead levels, which is less than half of that implied by Grønqvist, Nilsson, and Robling (2020). While estimates of lifetime earnings losses are critical, they omit the value of all of the other reasons people are willing to pay to avoid lead damages. However, they do provide a very valuable lower bound estimate.

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7 This calculation uses the authors' estimate of 4.4% higher lifetime earnings (among males) when early-childhood blood lead levels decrease from 10 to 5 μg/dl.

8 The value of $1.7M median lifetime earnings is from Carnevale, Rose, and Cheah (n.d.), which is based on the 2007-2009 American Community Survey.

9 We evaluate this change between 10 and 9 μg/dl to be consistent with Hollingsworth and Rudik's (2021) calculation of changes in blood lead levels due to deleading. We use Equation 5-5 on page 5-7 (EPA, 2020a). Given that this function is non-linear, these expected changes in income depend on the baseline lead levels. If instead, we evaluated the change based on the average impact between 10 and 5 μg/dl, this would imply a lifetime loss of $8,371.

Recent work by Hollingsworth and Rudik (2021) and Hollingsworth et al. (2021) similarly suggests much larger lifetime earnings impacts than that used by EPA. The two studies use a prior regulatory exemption for leaded gasoline in automotive racing in the U.S. to estimate the causal impact of lead exposure on elderly mortality (Hollingsworth and Rudik, 2021) and student test scores (Hollingsworth et al., 2021). Hollingsworth and Rudik (2021) provide a conservative estimate that the deleading of NASCAR and ARCA races resulted in a 0.17 μg/dl decrease in blood lead levels in children. In a separate analysis, Hollingsworth et al. (2021) estimate lost earnings for an average third grader in Florida within a 50 mile radius of a relevant racetrack. The authors estimate an average lifetime income reduction of $2,659.80 to $4,058.06 in 2020 dollars using a 3 percent discount rate. Using a back of the envelope calculation, this implies an average income reduction of $15,645.88 to $23,870.94 per 1 μg/dl increase in blood lead levels. These impacts are similar, though higher than Gronqvist, Nilsson, and Robling (2020).

### *Recent Research on Fertility and Housing Values*

A set of recent studies find impacts of lead on fertility. While there has not yet been a systemic review of these outcomes, EPA should consider quantifying these effects when there is at least one study of high quality relevant to the to the regulatory analysis so as not to underestimate benefits. For example, Grossman and Slusky (2019) estimate that the drinking water crisis in Flint caused a 12 percent decrease in fertility rates and resulted in a 5.4 percent decrease in birth weight. Another recently published study, Clay, Portnykh, and Severnini (2021), find similarly large impacts of lead on fertility. While Clay, Portnykh, and Severnini (2021) focus on lead in air, they find that the observed decrease in airborne lead from 1978 to 1988 in the U.S. caused a 6 percent increase in mean fertility. The corresponding economic benefits of this reduction are large. The authors write, "If the fertility benefits were counted as social benefits, the phasedown of lead in gasoline would pass a cost-benefit analysis based on these benefits alone" (Clay, Portnykh, and Severnini, 2021).

Other recent studies use the housing market to estimate a willingness to pay to reduce lead exposure. Theising (2019) estimates that remediation of lead service lines increases a property's value by approximately 3 to 4 percent. Christensen, Keiser, and Lade (2021) estimate that the Flint drinking water crisis reduced property values in Flint by 25 to 44 percent. In both settings, lead is ingested through water.

Taken together, these new studies, and others, suggest that EPA's estimate of the economic damages of lead were too low. At a minimum, EPA should revise the economic damages associated with lifetime earnings and recognize that these are lower bounds on the total value. It should seek approaches to estimate the other health and social impacts of lead exposure.

**Taken together, these new studies, and others, suggest that EPA's estimate of the economic damages of lead were too low. At a minimum, EPA should revise the economic damages associated with lifetime earnings and recognize that these are lower bounds on the total value. It should seek approaches to estimate the other health and social impacts of lead exposure.**

# VI. Human Health Impacts of Toxic Pollutants

The EA for the 2020 Rule acknowledged that there are numerous toxic pollutants released from steam electric power plants (EPA, 2020a). In addition to lead discussed supra Section V, these pollutants include aluminum, boron, cadmium, hexavalent chromium, manganese, mercury, selenium, thallium, and zinc. Once discharged, they can become concentrated in fish that are exposed to contaminated water and subsequently harm human health when these fish are consumed for food. EPA did not quantify or monetize any changes in health effects from exposure to these pollutants through fish consumption, instead claiming that data limitations and uncertainty in the dose-response relationship for numerous health endpoints prevented the agency from better quantifying these harms (EPA, 2020a).

However, as EPA itself acknowledged, "dose-response functions are available" for a subset of health endpoints for these contaminants (EPA, 2020a). The agency did not sufficiently explain why it opted not to quantify the impact of various regulatory options on these health effects for which a dose-response relationship exists. In analyses of future ELGs, the agency should instead provide as much information about these impacts as possible. For instance, as EPA noted in its environmental impact assessment accompanying the 2020 Rule, increased exposure to cadmium can lead to chronic kidney disease (EPA, 2020c). Epidemiological studies have found relationships between cadmium exposures and kidney function damage at levels below the reference dose set by EPA's Integrated Risk Information System (IRIS) program (Ginsberg, 2012). Furthermore, researchers have published a method to quantitatively connect cadmium exposure levels to health effects on specific kidney markers, notably loss in glomerular filtration rate (Ginsberg, 2012). As the authors of this recent study explain, their methodology and findings provide a method for quantification and monetization of the health harms from chronic kidney disease, such as the "costs of disability and medical care" (Ginsberg, 2012). Other toxic chemicals, such as boron (EPA, 2004), selenium (EPA, 1991), thallium (EPA, 2009), and zinc (EPA, 2005), have oral reference doses listed in EPA's IRIS database that could be used to quantify the potential health impacts of exposures by modeling the underlying data that serves as the basis for the reference dose. Given these research findings, EPA should reexamine its determination that there is insufficient data to properly quantify and monetize the health effects of toxic pollutants in these wastewater streams.

Recent methodological advances in quantifying health effects could also allow the agency to better assess the harms from these toxic pollutants, particularly given the large number of non-cancer health harms associated with these chemicals. The World Health Organization (WHO) has pioneered a probabilistic approach to assessing non-cancer health effects from toxic chemicals that accounts for differences in individual susceptibility to adverse health outcomes, data uncertainty, and harms at low doses of exposure (WHO International Programme on Chemical Safety, 2018; Chiu et al., 2018). EPA should carefully consider how the methodologies presented in Ginsberg (2012) and Chiu et al. (2018) can be applied to the non-cancer health effects literature for all toxic pollutants released from steam electric power plants to quantify and monetize the benefits of reduced exposure.

**EPA should reexamine its determination that there is insufficient data to properly quantify and monetize the health effects of toxic pollutants in these wastewater streams.**

EPA should also model these relationships without the assumption of a zero risk level as recommended by the National Academy of Sciences in the report *Science and Decisions* (National Academy of Sciences, 2009). Following this report, the agency issued new guidance instructing risk assessors to account for populations that may be particularly susceptible to toxic chemicals because of intrinsic or extrinsic factors (EPA, 2014). These include life stage and genetics as well as co-exposure to other toxic chemicals and pre-existing health conditions exacerbated by systemic inequalities such as poverty (Koman et al., 2019). By making these changes to the agency's assessment of toxic chemicals risks to vulnerable populations, EPA will better account for the additional health benefits they receive from more stringent controls.

Finally, EPA's Office of Water should consider coordinating with the Agency for Toxic Substances and Disease Registry (ATSDR) to gather additional data that are needed to assess the health effects of the toxic pollutants in these wastewater streams. Congress created the ATSDR through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in order to better investigate the health effects of toxic pollutants where such research is otherwise unavailable (42 U.S.C. § 9604(i)(1)(B)). The ATSDR requests nominations for new chemicals to review each year through its program on toxicological profiles and has particular expertise in assessing cumulative exposures to multiple pollutants (ATSDR, 2004). The agency has recently listed several toxic chemicals that are present in these wastewater streams on the agency's "Substance Priority List" for updates to their toxicological profiles, notably lead, cadmium, hexavalent chromium, zinc, manganese, selenium, and aluminum (ATSDR, 2019). Any new information, data, or studies developed through the ATSDR process should be assessed as part of EPA's future ELG analyses in order to better quantify and monetize the human health effects of these numerous toxic chemicals if additional information is needed on dose-response relationships.

# VII. Economic Productivity

EPA described several categories of impacts under the umbrella of economic productivity. This included the marketability of coal ash for beneficial use, water supply and use, reservoir capacity, sedimentation changes in waterways, commercial fisheries, tourism, and property values. Davis Noll and Rothschild (2021) highlight potential issues with benefit estimates related to the marketability of coal ash. We discuss property value impacts in Section III of this report. Here, we focus on a potential improvement to the approach used to address benefits related to water supply.

In Section 2.3.2.1, EPA noted "The regulatory options have the potential to affect costs of drinking water treatment (*e.g.*, filtration and chemical treatment) by changing eutrophication levels and pollutant concentrations in source waters." EPA determined that these effects were "…likely to be negligible." But that assumption is not supported. There is research that would allow a more robust examination at the very least of the relationship. For example, recent work by Mosheim and Ribaudo (2017) and Price and Heberling (2018) links changes in a number of relevant pollutants with drinking water treatment costs. Mosheim and Ribaudo (2017) develop a cost function for linking changes in nitrogen in source water with drinking water treatment costs. In addition, Price and Heberling (2018) review the academic literature and describe forty-six elasticities related to water quality parameters. These elasticities represent the percentage change in drinking water treatment costs associated with a one percent change in the water quality parameter. These estimates span a large set of water quality parameters including turbidity, total organic carbon, nitrogen, sediments, phosphorus, among others. Any new analysis of related ELGs should consider the feasibility of using these cost studies to evaluate different regulatory options and impacts.

# VIII. Air Quality Related Benefits

The EA for the 2020 Rule estimated two main categories of benefits related to air quality changes. The first is the economic benefits related to human health impacts. The second is the economic benefits associated with climate change. These two categories of benefits accrue through three main mechanisms. First, EPA examined the changes in energy associated with treating and handling changes in waste associated with the 2020 Rule. Second, the 2020 EA considered transportation-related damages associated with transporting waste to landfills. Third, the Agency considered changes in air pollution related to changes in the electricity generation profile. Here, we describe several features of this analysis that warrant further attention. We also discuss how updates to the SCC could have large impacts to the underlying benefit-cost analysis.

## A. Local Air Pollution Benefits

One of the more puzzling aspects of the 2020 EA is that the regulatory options explored by EPA suggest a general improvement in human health, despite a decrease in regulatory stringency. As detailed in Chapter 5 of the 2020 Rule's regulatory impact analysis (EPA, 2020b)—and as reflected in the 2020 EA's Table 8-5 (EPA, 2020a)—the 2020 Rule is expected to result in greater local-pollutant emissions within the electricity sector through changes in generation mix (e.g., coal versus natural gas versus renewables), electric generation capacity, and plant retirements.[10] Other things being equal, that would presumably lead to worse, not better, health outcomes. Yet, despite this, EPA found that the rule reduced expected premature deaths (see Tables 8-10 and 8-11 from EPA, 2020a). While the 2020 EA's Table 8-2 demonstrates modest decreases in local pollutants owing to effects on power requirements and trucking needs at steam electric power plants,[11] those decreases are too small to justify the estimate of strong overall health benefits. Indeed, Table 8-2 does not even report those changes having any impacts on PM2.5 emissions, which are often the most pronounced impacts on health of any local pollutant.

**One of the more puzzling aspects of the 2020 EA is that the regulatory options explored by EPA suggest a general improvement in human health, despite a decrease in regulatory stringency.**

This counterintuitive finding warrants further explanation and examination by EPA, especially because the above factors fail to explain it. Further, these findings are significant. They suggest large economic values related to the general improvement in human health. For instance, in Table 11-1 and 11-2 of the 2020 EA, the category "Human health effects from changes in NOx, SO2, and PM2.5 emissions" are the overwhelming reason why the 2020 EA passes a benefit-cost analysis. The value related to the improvement in human health offsets the damages to "Ecological Conditions and Recreational Use Changes", which is the largest category of non-air related damages. The human health impacts of these local air pollutants further offset the significant category of climate damages. This finding is also a departure from the 2015 EA which generally found significant *negative* human health consequences of less stringent regulatory options.

[10] *See* EPA (2020b) at 5-10 to 5-14 tbl.5-4 (reporting greater greenhouse gas and local pollutant emissions in representative year 2030); EPA (2020a) at 8-6 to 8-6 tbl.8-5 (reporting higher emissions of most pollutants in most years, with the possible slight exception of sulfur dioxide).

[11] *See* EPA (2020a) at 8-4 tbl.8-2.

Further, the analysis by EPA undercounted economic benefits of reductions in local air pollutants in several ways. These benefits should be addressed in future ELG analyses:

### 1. Morbidity Damage Estimates

As discussed in Section III.B., the 2020 EA did not consider averting behaviors as a subset of morbidity impacts. Economic research suggests the importance of these actions (Mansfield, Johnson, and Van Houtven, 2006; Graff Zivin and Neidell, 2009). Further, research by Deschênes, Greenstone, and Shapiro (2017) suggests that COI estimates may significantly undercount overall morbidity estimates. This category of air pollution damages could represent a sizable portion of overall air pollution impacts.

### 2. Coal Storage Damages

Recent research by Jha and Muller (2018) estimates that coal stockpiles at U.S. power plants increase local concentrations of $PM_{2.5}$. For every one ton increase in these stockpiles, Jha and Muller (2018) estimate economic damages of $197. Future rulemaking should consider these additional costs associated with coal production.

### 3. Visibility and Recreation

Visibility impairments due to increases in local air pollution are not measured or counted in the EA. There are a number of studies that measure the economic benefits of improved visibility (Chestnut and Rowe, 1990; Smith et al., 2005; Boyle et al., 2016). While these studies focus on Class I areas, including National Parks and wilderness areas, they could inform the economic consequences of changes in visibility due to changes in local air pollutants from the Rule. Other recent research by Keiser, Lade, and Rudik. (2018) links changes in ozone concentrations to changes in visitation at U.S. National parks. Any future analyses should consider a benefits transfer approach that applies a value of a recreational day to the relationship between ozone and visitation estimated by Keiser, Lade, and Rudik. (2018).

### 4. Cognitive Impacts

A robust literature now exists that links the impact of air pollution to a host of other, important health impacts. Among U.S. studies, Bishop, Ketcham, and Kuminoff (2018) find a strong and economically significant impact of $PM_{2.5}$ on dementia. Austin, Huetel, and Kreisman (2019) find a significant impact of air pollution on academic performance. In Israel, similar research by Ebenstein, Lavy, and Roth (2016) finds a strong link between $PM_{2.5}$ and student performance on high-stakes exams and future educational attainment and earnings. EPA should incorporate these impacts to the extent possible.

### 5. Ozone Impacts

The 2020 EA noted that EPA's prior analyses of ozone's health impacts concluded that ozone contributes to premature mortality through at least cardiovascular and respiratory pathways. But the agency claimed that "the currently available evidence for cardiovascular effects and total mortality is suggestive of, but not sufficient to infer, a causal relationship with short-term (as well as long-term) ozone exposures" (EPA, 2020a). While the agency works out how to isolate ozone-induced premature mortality through respiratory pathways, it "remov[ed] the estimate of the impact of reduced ozone exposure on premature mortality from its benefits estimates from subsequent rulemakings" altogether (EPA, 2020a). In future ELG analyses, as the EA noted, the agency should include respiratory benefit estimates.

## B. Climate Change Benefits

In a prior analysis of the 2020 EA, Davis Noll and Rothschild (2021) highlight the critical role of the SCC in determining the outcome of the benefit-cost analysis. The SCC is an estimate of the economic damages that result from emitting an additional ton of $CO_2$ into the atmosphere. It played an important role in the EA for the 2020 Rule because the various options considered by EPA yielded different anticipated mixes of sources of electricity generation. The choice to use a lower SCC in the 2020 EA yielded a benefit-cost analysis that was more favorable to a less-stringent ELG option. The

category of climate-related benefits is important. In the 2020 EA, climate change impacts were one of the top three largest categories of benefit estimates. In the prior 2015 EA, they were one of the top two largest categories of estimated benefits across various options considered by EPA.

Given the significance of this aspect of the analysis, we review how the choice of the SCC affects the overall benefit-cost analysis. The 2020 EA used a SCC that ranged between $7 to $11 (2018$ / metric ton of $CO_2$) for a 3 percent discount rate and $1 to $2 for a 7 percent discount rate over the period 2020 to 2050. These estimates reflected the revised SCC set during the Trump Administration. However, these values were significantly lower than those used by EPA just a few years prior in the 2015 EA. Those values ranged from $67 to $92 (2013$) for a 2.5 percent discount rate, $45 to $66 for a 3 percent discount rate, and $13 to $23 for a 5 percent discount rate. A key reason for these large differences in magnitude is that the 2015 EA used a SCC that reflected the Interagency Working Group's (IWG) estimates of damages, while the 2020 EA used a Trump-era estimate that purported to reflect only domestic damages.

Davis Noll and Rothschild (2021) show the impact that using the Trump-era SCC number versus the IWG's number has on the bottom line for the benefit-cost analysis. As they note, using the Trump-era SCC "…decreases the social cost of carbon by more than 85 percent. Without that severe reduction, the analysis would likely have shown clear net harms, as indicated by EPA's own analysis provided in an Appendix."

In January 2021, the Biden administration established a new IWG to analyze and update the SCC and methane metrics. The new IWG published a new "interim" estimate in 2021, which reinstates the Obama-era estimates, updated only for inflation (IWG 2021). The agency will need to use these estimates (or updated estimates if available) in future rulemaking. Here, we provide a few additional considerations for the agency's analysis of the carbon emissions in any new rulemaking.

The IWG's new "interim" estimate relies on an estimate of the damages that occur globally from each additional ton of carbon emissions in order to accurately capture the true costs of climate change to U.S. interests, including how global climate damages will directly affect U.S. economic, public health, and national security interests.

Kotchen (2018) outlines the general economic arguments in favor of and against using a more robust SCC based on global damages. He notes that those in favor of using a global SCC argue that economic efficiency, where societal economic welfare is maximized, requires the use of a global SCC. Further, he notes that climate change is a global pollutant, where a solution requires global cooperation. On this point, Greenstone, Kopits, and Wolverton (2013) explain that "Even if the United States were to reduce its GHG emissions to zero, it would be insufficient to avoid substantial damages from climate change." But the use of a global SCC could aid in strategic international negotiations (Pizer et al. 2014). Finally, important "…moral, ethical, and security issues…" (Pizer et al. 2014) arise from the unique nature of the fact that a large fraction of the damages from U.S. emissions occur outside of the United States.

Kotchen (2018) also addresses two of the arguments that have been made to support using a domestic, rather than global SCC. The first is that some previous U.S. benefit-costs analyses have considered only domestic impacts. This is not a valid reason for using the domestic value in the future, but rather suggests a potential need to revise other older analyses. Second, some argue that under certain assumptions, it is individually rational for countries to consider only the domestic impacts of their actions, rather than global damages. Kotchen's (2018) work addresses this issue directly by providing a formal economic argument for using a global SCC in benefit-cost analyses. Taking into consideration the fact that climate policy and negotiations are dynamic in nature, Kotchen (2018) shows that "…a country's choice to internalize the global SCC can be individually rational. The results provide…the first formally derived microeconomic justification for countries to internalize the global S.C.C…"

The Trump-era "domestic" SCC figure was invalid even before the Biden administration promulgated its updated "interim" numbers. The U.S. District Court for the Northern District of California recognized as much when it struck down as arbitrary the Bureau of Land Management's (BLM) repeal of the Waste Prevention Rule in part because the agency had abandoned the peer-reviewed, global estimates of the social cost of greenhouse gases in favor of the flawed Trump-era estimates.[12] The court noted that "focusing solely on domestic effects has been soundly rejected by economists as improper and unsupported by science," explaining that the model relied upon by BLM "ignores impacts on 8 million United States citizens living abroad, including thousands of United States military personnel; billions of dollars of physical assets owned by United States companies abroad; United States companies impacted by their trading partners and suppliers abroad; and global migration and geopolitical security."[13]

As that court explained, even on its own terms, the domestic model ignores many climate damages that accrue to Americans in the United States in at least two ways. First, EPA's valuation of the social costs of greenhouse gases ignores significant, indirect costs to trade, human health, and security likely to "spill over" to the United States as other regions experience climate change damages.[14] This is "because emissions of most greenhouse gases contribute to damages around the world and the world's economies are now highly interconnected."[15] Second, an indirect consequence of the United States using a global social cost of greenhouse gas to justify actions that protect against climate damages is that foreign countries take reciprocal actions that benefit the United States (Revesz et al., 2017). Yet EPA arbitrarily failed to account for this likely significant impact.

Indeed, the Trump-era domestic estimates were based on numbers that were not considered conclusive or strongly theoretically grounded. Using the results of one economic model (FUND) as well as the U.S. share of global gross domestic product ("GDP"), they were generated by the IWG as an "approximate, provisional, and *highly speculative*" range of 7–23 percent of the global SCC as an estimate of the purely direct climate effects to the United States.[16] Yet, as the IWG acknowledged, this range was almost certainly an underestimate because it ignored significant, indirect costs to trade, human health, and security that are likely to spill over into the United States as other regions experience climate change damages, among other effects.[17]

The IWG's current "interim" estimates are based on a methodology that "reflects rational, evidence-based decisions that incorporate the best available evidence" (Revesz and Sarinsky, 2021). The resulting numbers therefore "offer the best method to measure incremental climate effects from a particular amount of greenhouse gas emissions" (Revesz and Sarinsky, 2021).

The IWG is currently performing a full assessment of its social cost valuations to reflect the latest scientific and economic research.[18] The resulting updates to its SCC estimates will incorporate the most up-to-date thinking available regarding critical methodological decisions like what discount rates to use. Those updated estimates will reflect state-of-the-art thinking in the literature even more closely and will provide EPA an even more solid foundation on which to base its analysis of a policy's climate impacts, including any future rulemaking related to ELGs.

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12 *See California v. Bernhardt*, 472 F. Supp. 3d 573 (N.D. Cal. 2020).

13 *See id.* at 613.

14 Indeed, the integrated assessment models used to develop the global SCC estimates largely ignore inter-regional costs entirely. *See* Howard (2014). Though some positive spillover effects are also possible, such as technology spillovers that reduce the cost of mitigation or adaptation, *see* S. Rao, Keppo, and Riahi (2006), overall spillovers likely mean that the U.S. share of the global SCC is underestimated, *see* Freeman and Guzman (2009).

15 *California*, 2020 WL 4001480, at *23.

16 IWG (2010) (emphasis added).

17 *Id.* (explaining that the IAMs, like FUND, do "not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization")).

18 Exec. Order No. 13,990 § 5(b)(ii)(B), 86 Fed. Reg. 7037, 7040 (Jan. 25, 2021).

# IX. Summary

For a number of important reasons, EPA should reconsider several aspects of the 2020 EA that accompanied the 2020 Steam Electric Rule. Most of all, EPA is currently engaged in significant efforts to improve how water quality benefits are estimated for proposed rules and regulations. This work should serve as an organizing framework for analyzing any update to the 2020 Rule or related, future rulemaking. In addition, assumptions related to the economic impacts of local air pollution and climate change were crucial in determining the bottom line of the benefit-cost analysis. In particular, it is highly suspect that the rule would increase air pollution, but decrease overall human health impacts. This aspect of the analysis deserves much greater attention. Further, several assumptions in these analyses, including using the domestic versus global SCC, are highly questionable. We encourage EPA to consider the arguments made here to inform an update to the estimated net benefits of any future regulatory action. We also urge the agency to monetize several categories of missing benefits using the relevant literature that we suggest here.

**EPA should reconsider several aspects of the 2020 EA that accompanied the 2020 Steam Electric Rule. Most of all, EPA is currently engaged in significant efforts to improve how water quality benefits are estimated for proposed rules and regulations. This work should serve as an organizing framework for analyzing any update to the 2020 Rule or related, future rulemaking.**

# References


Allaire, M., H. Wu, and U. Lall. 2018. “National Trends in Drinking Water Quality Violations.” *Proceedings of the National Academy of Sciences of the United States of America*, 115(9): 2078-2083.

Allaire, M., T. Mackay, S. Zheng, and U. Lall. 2019. “Detecting Community Response to Water Quality Violations using Bottled Water Sales.” *Proceedings of the National Academy of Sciences of the United States of America*, 116(42): 20917-20922.

Ator, S.W. 2019. “Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the northeastern United States.” (2019-5118).

ATSDR. 2004. “Interaction Profile For: Arsenic, Cadmium, Chromium, And Lead.”

ATSDR. 2019. “The ATSDR 2019 Substance Priority List.” https://www.atsdr.cdc.gov/spl/index.html.

Austin, W. 2020. “Throwing the Baby out With the Ashwater? Coal Combustion Residuals, Water Quality, and Fetal Health.” *Working Paper*, https://wes-austin.com/research/.

Austin, W., G. Heutel, and D. Kreisman. 2019. “School Bus Emissions, Student Health, and Academic Performance.” *Economics of Education Review*, 70: 109-206.

Bartik, T.J. 1988. “Evaluating the Benefits of Non-Marginal Reductions in Pollution Using Information on Defensive Expenditures.” *Journal of Environmental Economics and Management*, 15(1): 111-127.

Bishop, K.C., J.D. Ketcham, and N.V. Kuminoff. 2018. “Hazed and Confused: The Effect of Air Pollution on Dementia.” *NBER Working paper*, https://www.nber.org/system/files/working_papers/w24970/w24970.pdf.

Boyle, K.J., R. Paterson, R. Carson, C. Leggett, B. Kanninen, J. Molenar, J. Neumann. 2016. “Valuing Shifts in the Distribution of Visibility in National Parks and Wilderness Areas in the United States.” *Journal of Environmental Management*, 173: 10-22.

Carnevale, A.P. S.J. Rose, and B. Cheah. n.d. “The College Payoff: Education, Occupations, Liftetime Earnings.” The Georgetown University Center on Education and the Workforce, https://cew.georgetown.edu/wp-content/uploads/2014/11/collegepayoff-complete.pdf.

Cassidy, A., R. Meeks, and M.R. Moore. 2021. “Cleaning Up the Rust Belt: Housing Market Impacts of Removing Legacy Pollutants.” *Working Paper*, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3695140.

Chestnut, L.G. and R.D. Rowe. 1990. “Preservation Values for Visibility Protection at the National Parks.” Cooperative Agreement# CR-813-686. Research Triangle Park, NC: U.S. Environmental Protection Agency.

Chiu, W.A., D.A. Axelrad, C. Dalaijamts, C. Dockins, K. Shao, A.J. Shapiro, and G. Paoli. 2018. “Beyond the RfD: Broad Application of a Probabilistic Approach to Improve Chemical Dose–Response Assessments for Noncancer Effects.” *Environmental Health Perspectives*, 126 (6): 067009-1- 067009-14.

Choi, D.S., and R. Ready. 2021. “Measuring Benefits from Spatially-Explicit Surface Water Quality Improvements: The Roles of Distance, Scope, Scale, and Size.” *Resource and Energy Economics*, 63: 101108.

Christensen, P., D.A. Keiser, and G.E. Lade. 2021. “Economic Effects of Environmental Crises: Evidence from Flint, Michigan.” Working paper, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3420526.

Clay, K., M. Portnykh, E. Severnini. 2021. “Toxic Truth: Lead and Fertility.” *Journal of the Association of Environmental and Resource Economists*, 8(5): 975-1012.

Corona, J., T. Doley, C. Griffiths, M. Massey, C. Moore, S. Muela, B. Rashleigh, W. Wheeler, S.D. Whitlock, J. Hewitt. 2020. “An Integrated Assessment Model for Valuing Water Quality Changes in the United States.” *Land Economics*, 96(4): 478-492.

Currie, J.L. Davis, M. Greenstone, and R. Walker. 2015. “Environmental Health Risks and Housing Values: Evidence from 1,600 Toxic Plant Openings and Closings.” *American Economic Review*, 105(2): 678-709.

Davis Noll, B.A. and R. Rothschild. 2021. "An Evaluation of the Benefit Cost Analysis in the 2020 Steam Electric Reconsideration Rule, 85 Fed. Reg. 64,650." *Institute for Policy Integrity*. *Available at* https://policyintegrity.org/publications/detail/an-evaluation-of-the-benefit-cost-analysis-in-the-2020-steam-electric-reconsideration-rule.

Ebenstein, A., V. Lavy, and S. Roth. 2016. "The Long-Run Economic Consequences of High-Stakes Examinations: Evidence from Transitory Variation in Pollution." *American Economic Journal: Applied Economics*, 8 (4): 36-65.

EPA. 1991. "Selenium and Compounds; CASRN 7782-49-2." *Integrated Risk Information System (IRIS)*.

EPA. 2004. "Boron and Compounds; CASRN 7440-42-8." *Integrated Risk Information System (IRIS)*.

EPA. 2005. "Zinc and Compounds; CASRN 7440-66-6." *Integrated Risk Information System (IRIS)*.

EPA. 2009. "Thallium (I), soluble salts; CASRN Various." *Integrated Risk Information System (IRIS)*.

EPA. 2010. "Guidelines for Preparing Economic Analyses."

EPA. 2014. "Guidance for Applying Quantitative Data to Develop Data-Derived Extrapolation Factors for Interspecies and Intraspecies Extrapolation."

EPA. 2015. "Benefit and Cost Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category."

EPA. 2019. "Regulatory Impact Analysis for the Repeal of the Clean Power Plan, and the Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units."

EPA. 2020a. "Benefit and Cost Analysis for the Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category."

EPA. 2020b. "Regulatory Impact Analysis for Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category."

EPA. 2020c. "Supplemental Environmental Assessment for Revisions to the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category."

Freeman, J., and A. Guzman. 2009. "Climate Change and US Interests." *Columbia Law Review*, 109: 1531.

Ginsberg, G.L. 2012. "Cadmium Risk Assessment in Relation to Background Risk of Chronic Kidney Disease." *Journal of Toxicology and Environmental Health*, Part A, 75(7): 374-390.

Griffiths, C.H. Klemick, M. Massey, C. Moore, S. Newbold, D. Simpson, P. Walsh, and W. Wheeler. 2012. "U.S. Environmental Protection Agency Valuation of Surface Water Quality Improvements." *Review of Environmental Economics and Policy*, 6(1): 130-146.

Graff Zivin, J. and M. Neidell. 2009. "Days of Haze: Environmental Information Disclosure and Intertemporal Avoidance Behavior." *Journal of Environmental Economics and Management*, 58(2): 119-128.

Graff Zivin, J. M. Neidell, and W. Schlenker. 2011. "Water Quality Violations and Avoidance Behavior: Evidence from Bottled Water Consumption." *American Economic Review: Papers and Proceedings*, 101(3): 448-453.

Greenstone, M., E. Kopits, and A. Wolverton. 2013. "Developing a Social Cost of Carbon for U.S. Regulatory Analysis: A Methodology and Interpretation." *Review of Environmental Economics and Policy*, 7(1): 23-46.

Guignet, D., M.T. Heberling, M. Papenfus, and O. Griot. 2021. "Property values, water quality, and benefit transfer: A nationwide meta-analysis." *Land Economics*, 050120-0062R1.

Gronqvist, H., J.P. Nilsson, and P-O. Robling. 2020. "Understanding How Low Levels of Early Lead Exposure Affect Children's Life Trajectories." *Journal of Political Economy*, 128(9): 3376-3433.

Grossman, D.S., and D.J. Slusky. 2019. "The Impact of the Flint Water Crisis on Fertility." *Demography*, 56: 2005-2031.

Hollingsworth, A., and I. Rudik. "The Effect of Leaded Gasoline on Elderly Mortality: Evidence from Regulatory Exemptions." *American Economic Journal: Economic Policy*, 13(3): 345-373.

Hollingsworth, A., M. Huang, I.J. Rudik, and N.J. Sanders. 2021. "Lead Exposure Reduces Academic Performance: Intensity, Duration, and Nutrition Matter." *NBER Working Paper Series*, No. 28250.

Hoos, A.B. and V.L. Roland Ii. 2019. "Spatially Referenced Models of Streamflow and Nitrogen, Phosphorus, and Suspended-sediment Loads in the Southeastern United States." (2019-5135).

Howard, P. 2014. "Omitted Damages: What's Missing from the Social Cost of Carbon." *The Cost of Carbon Project Report, Institute for Policy Integrity*.

Interagency Working Group on Social Cost of Greenhouse Gases (IWG). 2010. "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis." February 2010.

IWG. 2021. "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide." February 2021.

Jha, A. and N.Z. Muller. 2018. "The Local Air Pollution Cost of Coal Storage and Handling: Evidence from U.S. Power Plants." *Journal of Environmental Economics and Management*, 92: 360-396.

Keiser, D.A. and N.Z. Muller. 2017. "Air and Water: Integrated Assessment Models for Multiple Media." *Annual Review of Resource Economics*, 9: 165-184.

Keiser, D.A., C.L. Kling, and J.S. Shapiro. 2019. "The Low but Uncertain Measured Benefits of U.S. Water Quality Policy" *Proceedings of the National Academy of Sciences*, 116(12): 5262-5269.

Keiser, D.A., G.E. Lade, and I. Rudik. "Air Pollution and Visitation at U.S. National Parks." *Science Advances*, 4(7): eaat1613.

Koman, P.D., V. Singla, J. Lam, and T.J. Woodruff. 2019. "Population susceptibility: A vital consideration in chemical risk evaluation under the Lautenberg Toxic Substances Control Act." *PLoS Biology*, 17(8):e3000372.

Kotchen, M.J. 2018. "Which Social Cost of Carbon? A Theoretical Perspective." *Journal of the Association of Environmental and Resource Economists*, 5(3): 673-694.

Kuminoff, N.V. 2018. "Can Understanding Spatial Equilibria Enhance Benefit Transfers for Environmental Policy Evaluation?" *Environmental and Resource Economics*, 69: 591-608.

Kuwayama, Y., S. Olmstead, and J. Zheng. 2022. "A More Comprehensive Estimate of the Value of Water Quality." *Journal of Public Economics*, 207: 104600.

Lanphear, B.P., S. Rauch, P. Auinger, R.W. Allen, and R.W. Hornung. 2018. "Low-level Lead Exposure and Mortality in U.S. adults: A Population-Based Cohort Study." *The Lancet Public Health*, 3: e177-e184.

Mansfield, C., F.R. Johnson, and G. Van Houtven. 2006. "The Missing Piece: Valuing Averting Behavior for Children's Ozone Exposure." *Resource and Energy Economics*, 28(3): 215-228.

Mendelsohn, R., D. Hellerstein, M. Huguenin, R. Unsworth, and R. Brazee. 1992. "Measuring Hazardous Waste Damages with Panel Models." *Journal of Environmental Economics and Management*, 22: 259-271.

Mosheim, R., and M. Ribaudo. "Costs of Nitrogen Runoff for Rural Water Utilities: A Shadow Cost Approach." *Land Economics*, 93(1): 12-39.

National Academy of Sciences. 2009. "Science and Decisions: Advancing Risk Assessment." Washington, DC: The National Academies Press.

Olmstead, S.M. 2009. "The Economics of Water Quality." *Review of Environmental Economics and Policy*, 4(1): 44-62.

Palm-Forster, L.H., F. Lupi, and M. Chen. 2016. "Valuing Lake Erie Beaches Using Value and Function Transfers." Agricultural and Resource Economics Review 45(2): 270–292.

Palmquist, R.B., and V.K. Smith. 2002. "The Use of Hedonic Property Value Techniques for Policy and Litigation." In: Tietenberg, T. and H. Folmer (Eds.), <u>The International Yearbook of Environmental and Resource Economics</u>, 2002/2003. Edward Elgar, Cheltenham, U.K., 115-164.

Phaneuf, D., and T. Requate. 2017. <u>A Course in Environmental Economics: Theory, Policy, and Practice</u>. Cambridge University Press: Cambridge, United Kingdom.

Pizer, W., M. Adler, J. Aldy, D. Anthoff, M. Cropper, K. Gillingham, M. Greenstone, B. Murray, R. Newell, R. Richels, A. Rowell, S. Waldhoff, and J. Wiener. “Using and Improving the Social Cost of Carbon: Regular, Institutionalized Updating and Review are Essential.” *Science*, 346(6214): 1189-1190.

Price, J.I., and M.T. Heberling. 2018. “The Effects of Source Water Quality on Drinking Water Treatment Costs: A Review and Synthesis of Empirical Literature.” *Ecological Economics*, 151: 195-209.

Rao, S., I. Keppo, and K. Riahi. 2006. “Importance of Technological Change and Spillovers in Long-Term Climate Policy.” *The Energy Journal*, Special Issue 1: 2006

Revesz, R.L., and M. Sarinsky. 2021. “The Social Cost of Greenhouse Gases: Legal, Economic, and Institutional Perspective.” *Yale Journal of Regulation, Forthcoming*.

Revesz, R.L., J.A. Schwartz, P.H. Howard, K. Arrow, M.A. Livermore, M. Oppenheimer, and T. Sterner. 2017. “The Social Cost of Carbon: A Global Imperative.” *Review of Environmental Economics and Policy*, 11(1): 172-173.

Robertson, D.M., and D.A. Saad. 2019. “Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the midwestern United States.” (2019-5114).

Rosen, S. 1974. “Prices and implicit markets: Product Differentiation in Pure Competition.” *Journal of Political Economy*, 82(1): 34-55.

Sandstrom, K., and F. Lupi. 2021. “Comparing Water Quality Valuation Across Probability and Non-Probability Samples.” Working Paper, Michigan State University.

Smith, A.E., M.A. Kemp, T.H. Savage, and C.L. Taylor. 2005. “Methods and Results from a New Survey of Values for Eastern Regional Haze Improvements.” *Journal of the Air & Waste Management Association*, 55(11): 1767-1779.

Tang, C., M.D. Heintzelman, and T.M. Holsen. 2018. “Mercury Pollution, Information, and Property Values.” *Journal of Environmental Economics and Management*, 92: 418-32.

Theising, A. 2019. “Lead Pipes, Prescriptive Policy and Property Values.” *Environmental and Resource Economics*, 74: 1355-1382.

Wagner, G., D. Anthoff, M. Cropper, S. Dietz, K.T. Gillingham, B. Groom, P. Kelleher, F.C. Moore, and J.H. Stock. “Eight Priorities for Calculating the Social Cost of Carbon.” *Nature*, 548-550.

Walsh, P.J., and W.J. Wheeler. 2013. “Water Quality Indices and Benefit-Cost Analysis.” *Journal of Benefit-Cost Analysis*, 4(1): 81-105.

WHO, International Chemical Safety Programme. 2018. “Guidance Document on Evaluating and Expressing Uncertainty in Hazard Characterization.”

Wise, D.R. 2019. “Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Pacific region of the United States.” (2019-5112).

Wise, D.R., D.W. Anning, and O.L. Miller. 2019. “Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment transport in streams of the southwestern United States.” (2019-5106).

Wolf, D., W. Chen, S. Gopalakrishnan, T. Haab, H.A. Klaiber. 2019. “The Impacts of Harmful Algal Blooms and *E. coli* on Recreational Behavior in Lake Erie.” *Land Economics*. 95(4): 455–472.

Wolf, D., W. Georgic, H.A. Klaiber. 2017. “Reeling in the Damages: Harmful Algal Blooms’ Impact on Lake Erie’s Recreational Fishing Industry.” *Journal of Environmental Management*. 199: 148–157.

Wolf, D. and H.A. Klaiber. 2017. “Bloom and Bust: Toxic Algae’s Impact on Nearby Property Values.” *Ecological Economics*, 135, 209–221.

Wrenn, D.H., H.A. Klaiber, and E.C. Jaenicke. 2016. “Unconventional Shale Gas Development, Risk Perceptions, and Averting Behavior: Evidence from Bottled Water Purchases.” *Journal of the Association of Environmental and Resource Economists*, 3(4): 779-817.

Institute *for* Policy Integrity
NEW YORK UNIVERSITY SCHOOL OF LAW

Institute for Policy Integrity
New York University School of Law
Wilf Hall, 139 MacDougal Street, New York, New York 10012
policyintegrity.org