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Removing Michigan's Lead Water Service Lines: Economic Savings, Health Benefits, And Improved Health Equity

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ABSTRACT Michigan's recently revised Lead and Copper Rule requires water utilities to inventory existing water service lines by 2025 and replace all lead-containing lines by 2041. This article summarizes a cost-benefit analysis using new inventory data on the number of lead service lines in the state, the projected cost of their replacement, and the estimated lifetime benefits from reduced lead exposure. Replacing 423,479 lead service lines would reduce lead exposure for 420,800 newborns and result in $3.24 billion in future benefits (compared with replacement costs of $1.33 billion). This would generate net savings of $1.91 billion and a societal return on investment of $2.44 per dollar invested. These estimates are conservative and include only quantified benefits for newborn children in Michigan for the period 2020–60. More than 153,100 of the children benefiting would be non-White (of whom 78,400 would be Black or African American), and 106,900 would be in households with incomes below the federal poverty level. Sensitivity analyses show that accelerating the replacement pace would increase the societal return on investment. This primary prevention–driven policy has the potential to reduce childhood lead exposure and improve health equity.

Lead exposure has long-term health, cognitive, and behavioral consequences.[1] Although US policies have made progress in reducing average population lead exposure risks,[2] significant hazards remain. There is no known safe level of exposure for children, and despite reductions in population blood lead levels in the US, recent estimates of the long-term economic impact of lead exposure for newborn children exceed $80 billion per year nationally.[3] This includes harms from decreased overall health;[4] short-term health care costs;[5] increased morbidity and mortality;[6] cognitive, developmental, and educational impacts;[7] and decreased labor productivity.[8] Lead exposure is also a major source of racial and ethnic health disparities and environmental inequality, as historical structural inequities in housing contribute to today's lead risks.[9,10]

Given lead's potent and irreversible neurotoxicity, primary prevention—proactively identifying and eliminating lead in a child's environment—is recommended, including lead paint inspections and abatements, remediation of risks in soil, and removing lead from drinking water. Among all sources of lead for children, exposure from water contributes approximately 20 percent of the total blood lead risk, and for infants specifically, expected contributions from water are even greater.[5] When present, lead service lines are the greatest source of lead in drinking water.[11] Millions of lead service lines were installed in the US primarily from the late

1800s through the 1940s[12] and predominantly in the Midwest and Northeast,[13] chosen for their lower cost and higher durability at the time. Lead also was used in plumbing fixtures, faucets, and solder throughout the country. Restrictions banning new lead service lines were implemented in 1986; however, because they lacked requirements to remove existing lead service lines, an estimated six to ten million lead service lines remained in use across the US as of 2016.[14] Although water utilities can use corrosion control treatment to reduce lead release, this does not eliminate the risk for lead.[15] Everyday baseline exposure is compounded when planned or unintended changes in water quality increase the amount of lead released into drinking water, such as in the water crisis in Flint, Michigan, that began in 2014.[16] Any strategy that maintains lead service lines will continue to unnecessarily and unknowingly expose children and families to this pollutant.

The Bipartisan Infrastructure Law of 2021 allocated $15 billion to states to expedite lead service line replacements, yet that funding remains inadequate to remove all of the nation's lead service lines.[17] Therefore, without a federal mandate, state and local policy makers will need to work with water systems to support the complete removal of these lines. Perhaps the best example of a proactive replacement policy is the 2018 Michigan Lead and Copper Rule. This rule established that water utilities would replace remaining lead service lines at an average rate of 5 percent per year, mandating complete elimination by 2041.[18] All of these replacements must be full lead service line replacements; no partial replacements are allowed per the rule. Michigan was the first state to require the proactive replacement of all lead service lines, followed by New Jersey and Illinois.[19]

Although removing lead service lines as a primary prevention strategy to reduce lead exposure is a well-accepted concept,[20] less time has been spent assessing its potential future economic benefits. In this article we detail for key stakeholders the findings of a cost-benefit analysis of Michigan's Lead and Copper Rule and that rule's benefits. This economic work is especially important considering pushback from policy makers and municipalities regarding the cost and urgency of lead service line replacement, including, for example, lawsuits from water utilities.[21] Although some prior work has estimated the total economic burden of childhood lead exposure,[22] and others have determined the expected return on investment of specific lead prevention interventions,[3] our work is different in that it modeled the potential benefits of a real-world lead service line replacement policy. Our models accounted for the gradual replacement of all lead service lines in Michigan (even in homes without a child) and modeled the population affected over a forty-year duration. This sets this work apart from prior analyses that looked only at short-term, targeted interventions to homes that already had children,[3] and it provides greater clarity on the expected economic impacts of an in-progress lead service line replacement policy.

Study Data And Methods

METHODOLOGY We completed this analysis by estimating the number of lead service lines in Michigan as of 2020 and the number of children who would be affected in the absence of the Michigan Lead and Copper Rule; estimating the expected reduction in water lead levels and blood lead levels resulting from proactive lead service line replacement; estimating health, cognitive, and productivity benefits of lower expected childhood blood lead levels; comparing these benefits with the estimated cost of service line replacement; and assessing distributional and equity impacts and completing sensitivity analyses of the pace of replacement under a more aggressive replacement strategy and a more delayed replacement strategy.

We derived the number of lead service lines in Michigan requiring replacement from data reported by 1,337 water utilities on existing water service line materials in the state's Distribution System Materials Inventories in December 2020 (the latest available version at the time of analysis), which included six different categories of lines.[23] For the eleven utilities with more than 4,000 "unknown—no information" lines and fewer than 1,000 lead lines in their initial inventory, we applied an American Community Survey estimate of the share of homes in each system built before 1960 to estimate a revised lead service line count. Remaining lines in other systems classified as "unknown—no information" were apportioned on the basis of the state proportion of known lead service lines.

Expected water lead levels in homes with a lead service line and the reduction in water and blood lead levels after replacement were estimated from data within the Environmental Protection Agency (EPA) Economic Analysis for the final Lead and Copper Rule Revisions.[24]

Our analysis of the EPA's Economic Analysis for the final Lead and Copper Rule Revisions and peer-reviewed research found that replacing a lead service line would be expected to reduce average water lead levels from 5.48 μg/L to 0.82 μg/L, for a 4.66 μg/L reduction. The reduction would persist throughout a child's developmental years because once the lead service line is removed, no new sources of lead in water would be expected to be added to the home.[25] This is similar to previous findings using preliminary 2019 Michigan Lead and Copper Rule compliance data, in which water lead levels in homes with lead service lines were found to be 4.7 parts per billion and in homes without lead service lines, 1.5 parts per billion.[26]

Because of the estimated 4.66 μg/L reduction in water lead levels from proactive lead service line replacement, we assumed that blood lead levels would drop by 0.51 μg/dL throughout childhood, based on data from the same EPA analysis.[25] As a result, we modeled the impacts of this blood lead level difference on changes in IQ, earnings, health care costs, special education costs, and quality-adjusted life-years (QALYs). The decline in IQ per 1 μg/dL increase in a child's blood lead level is estimated to be nonlinear, ranging from a decline of 1.15 IQ points for children in the under 5 μg/dL range to a decline of 0.18 IQ points for those with a blood lead level of more than 10 μg/dL. For each one-point decline in IQ, we estimated a 2.27 percent decrease in average lifetime earnings, based on an average of three studies (details in online appendix A).[27]

For the remaining economic impacts, we estimated the increased risk for hypertension as a function of blood lead levels and higher health care use from greater cardiovascular disease risks.[28] For special education costs, we estimated the share of the population whose IQs would drop below 70 and who would require special education through their primary school years. QALY impacts were based on relationships between lead exposure and life expectancy.[29]

We estimated the number of children benefiting from lead service line replacement under varying policy scenarios using data from the American Community Survey and census projections at the county level. County-level data were used to model the birth populations because they were the lowest geographic level of detail for which water system coverage areas could be identified in the Distribution System Materials Inventories.

Baseline population blood lead level distributions and means model inputs were derived from the 2018 National Health and Nutrition Examination Survey. Baseline earnings trajectories for future Michigan children were based on analyses of American Community Survey microdata for Michigan, and baseline health care costs were estimated from Medical Expenditure Panel Survey data, both adjusted to 2020 dollars. Baseline mortality data were based on the Centers for Disease Control and Prevention Wide-ranging Online Data for Epidemiologic Research Causes of Death data from 2019 for Michigan.

Proactive lead service line replacement is likely to protect hundreds of thousands of children, generating large net societal gains.

These data, alongside other inputs, were incorporated in cost-benefit analyses performed by leveraging the Value of Health tool, an Altarum economic model that computes the aggregate, long-term societal benefits of improvements in health, earnings, and longevity. In this analysis the tool did not include general equilibrium impacts of cohort-level changes in population IQ and earnings, but rather contrasted expected outcomes for individual children with and without a lead service line replacement. Sources, methods, and economic assumptions used in the Value of Health analyses are detailed in appendix A.[27] All future costs and benefits in this report were discounted using a 3 percent discount rate; results are shown in 2020 dollars.

LIMITATIONS We acknowledge several limitations of this cost-benefit analysis. One is that it quantified only a subset of known benefits and populations likely to be affected by reduced lead levels after lead service line replacement. The models followed previous research that only quantified the impact of reductions in blood lead levels for newborns (primary prevention),[3] leaving out benefits for other children and adults already exposed to lead. This is because the relative benefit from reducing lead for those already exposed is not well established in existing literature, even though the impacts of chronically elevated blood lead levels have been seen in health outcomes such as cardiovascular disease.[28]

The benefits model also only included a subset of known long-term health and health spending components, limited to those for which prevalence and cost data were readily available (see appendix A).[27] To estimate impacts on long-term productivity, the benefits model only predicted outcomes through changes in IQ and future earnings without incorporating additional impacts from behavioral[9] or health improvements.[1] Other lead impacts known to exist, but not mon-

Line replacement policies are likely to provide meaningful health equity benefits above and beyond the net societal returns.

etized in this analysis, were impacts on fertility,[1] in utero impacts,[1] and effects on crime and incarceration.[3] These impacts were expected to be small relative to the earnings and health benefits used in the model because they have only been found at higher blood lead level thresholds or generally have a smaller overall effect on outcomes. These exclusions resulted in a conservative estimate of the Michigan Lead and Copper Rule's total societal benefits and cost-benefit ratio.

Another limitation of this work was that the smallest geographic region available in the Michigan Distribution System Materials Inventories was the county. It is possible that looking at smaller areas (for example, ZIP codes or census tracts) could yield different results on the number of children benefiting and the economic return from lead service line replacements. Estimating the number of lead service lines in systems with a large share of "unknown—no information" lines in the Distribution System Materials Inventories using the share of homes built before 1960 also introduced some uncertainty and could have resulted in either an over- or underestimate of the true number of lead service lines remaining. The use of these lines was banned nationally in 1986, although some communities began to phase out their use before then.

To estimate the number of newborn children benefiting from proactive replacements relative to the status quo, we assumed that current lead service lines would otherwise not be replaced until 2060. We also assumed that the relationship between water and blood lead levels found in prior EPA work was not different from the levels for Michigan's children and that bottled water consumption does not substantially reduce the relationship between the two. In practice, some lead service lines may be replaced alongside normal infrastructure work before 2060, and bottled water consumption may mediate blood lead level increases in the absence of lead service line replacements. However, even in these instances, it is likely that Michigan's Lead and Copper Rule will confer benefits by expediting and completing replacement.

Study Results

Lead Service Line Counts And Cost Model

The 2020 Distribution System Materials Inventory data summary reported the status of 2,648,185 lines from 1,337 utilities (data not shown). A total of 331,523 (12.5 percent) lines were categorized as known lead; likely lead; or galvanized, previously connected to lead; whereas 2,010,482 (75.9 percent) were classified as not lead or likely not lead. After we adjusted for utilities with significant numbers of unknowns, the remaining 272,751 (10.3 percent) lines of unknown material were classified as lead service lines or non–lead service lines on the basis of the ratio of lead service lines to non–lead service lines in Michigan (18.5 percent). When the resulting 423,479 lead service lines were categorized by county and mapped onto US census population projections over the next forty years, we found that more than 565,600 newborn children would be expected to live in a home served by a community water system's lead service line in the absence of the Lead and Copper Rule.

Michigan's Lead and Copper Rule requires that utilities replace known lead service lines at an average pace of 5 percent per year, replacing all lines by 2041. Exhibit 1 shows the cost per line and the total cost of these proactive replacements, using data from the EPA's Economic Analysis for the final Lead and Copper Rule revisions.[24] Prior case studies of large-scale replacement programs were used to estimate the proportion of the lines replaced in the "planned," "unplanned," and "building-side-only" settings.[30] Planned replacements are those that can be done simultaneously with other needed water infrastructure work, such that the cost per line is lower, whereas unplanned replacements are those done without coinciding with planned, existing maintenance. Building-side-only replacements are those in which lead remains only on the homeowner side of the property line and a full lead service line replacement is being done after a previous partial replacement (no new partial replacements are allowed by the Michigan Lead and Copper Rule). Cases 1–3 in exhibit 1 assume that the work is scheduled to take advantage of cost savings from using planned replacements while the total number of replacements each year remains constant (details are in appendix A).[27]

It is important to note that all lead service line replacements mandated by the revised Michigan

EXHIBIT 1

Estimates of the cost of total Michigan Lead and Copper Rule proactive lead service line replacement, by implementation and replacement assumption cases

	Case 1 (base): 5% per year replacement rate (20-year timeline)	Case 2 (expedited): 10% per year replacement rate, beginning in 2021 (10-year timeline)	Case 3 (delayed): 10% per year replacement rate, beginning in 2030 (10-year timeline)	Case 4 (all unplanned): 5% per year replacement rate (20-year timeline)
Average no. of lines replaced per year	21,174	42,348	42,348	21,174
Percent of all lines as planned replacements	55.0%	41.3%	55.0%	0.0%
Percent of all lines as "building-side-only" replacements	20.0%	20.0%	20.0%	20.0%
Nominal average cost per line replaced	\$4,087	\$4,224	\$4,087	\$4,989
Total discounted program replacement cost	\$1.33 billion	\$1.57 billion	\$1.13 billion	\$1.62 billion

SOURCE Authors' cost model, using data on the number of lines from Michigan's Distribution System Materials Inventories, average costs per line from the Environmental Protection Agency's (EPA's) Economic Analysis of the federal Lead and Copper Rule Revisions, and planned replacement schedules over time from previous city case studies. **NOTES** EPA nominal average cost per replacement by type is as follows: planned replacement, \$3,991; unplanned replacement, \$4,989; and building-side-only replacement, \$3,222; these replacement types are described in the text. Details on the proportion of each replacement type by year for each case are in appendix A (see note 27 in text).

Lead and Copper Rule and modeled in this analysis are full replacements, meaning that all portions of the service line made of lead are removed. Partial replacements have been shown to increase water lead levels.[31] The 20 percent of cases shown in exhibit 1 in which building-side-only replacements are expected represent locations where a portion of lead service lines remain from previous partial replacements.

Across the four policy cases, the total cost of proactively replacing Michigan's lead service lines would range from \$1.13 billion to \$1.62 billion.[32] The base case of replacing 5 percent per year and assuming a phased-in approach of using planned replacements would result in an estimated cost of \$1.33 billion. Expedited replacement—10 percent per year (case 2)—would increase the average cost per line and total cost because a lower proportion can be planned replacements and the costs occur sooner, whereas delaying the replacement start until 2030 (case 3) would decrease total costs because replacements occur farther in the future.

NEWBORNS AFFECTED Mapping the replacement of the estimated 423,479 lead service lines to the population of newborns during the period 2021–60, we found that 420,800 newborns would benefit from proactive replacement of a lead service line that would have remained in the absence of Michigan's Lead and Copper Rule (exhibit 2, case 1). Given the distribution of lead service lines across counties and incorporating demographic projections, our benefits model predicted that more than 153,100 (36 percent) of the benefiting children would be non-White, of whom approximately 78,300 (19 percent) would be Black or African American only. Also, 106,900 (25 percent) would be in households below 100 percent of the federal poverty level, and 361,200 (86 percent) in households below 250 percent of the poverty level (data not shown).

If only 5 percent of lead service lines were replaced per year, as in exhibit 2, case 1, 144,900 newborns between 2021 and 2041 would continue to drink water from a lead service line as the lines were slowly replaced. If instead an expedited ten-year replacement schedule were implemented (10 percent of lines per year; case 2), the number of future children drinking from a lead service line would be almost cut in half, to 76,100, resulting in a larger protected population of 489,500. Conversely, delaying the replacement policy to begin in 2030 (case 3) would increase the number of future newborn children in Michigan consuming water from a lead service line to 213,600 over the next twenty years (data not shown). Such scenarios are possible; for example, Detroit requested a replacement schedule over a forty-year period, to be completed in 2060.[33]

COST-BENEFIT RESULTS Incorporating the expected reduction in average blood lead levels for the 420,800 newborns who would have been served by a lead service line absent the lead service line replacement policy results in \$3.24 bil-

EXHIBIT 2

Cost-benefit analysis results of Michigan's Lead and Copper Rule, by implementation and replacement assumption cases

	Case 1 (base): 5% per year replacement rate (20-year timeline)	Case 2 (expedited): 10% per year replacement rate, beginning in 2021 (10-year timeline)	Case 3 (delayed): 10% per year replacement rate, beginning in 2030 (10-year timeline)	Case 4 (all unplanned): 5% per year replacement rate (20-year timeline)
Total discounted program replacement cost	$1.33 billion	$1.57 billion	$1.13 billion	$1.62 billion
Total discounted societal benefits through the 2060 birth cohort	$3.24 billion	$4.00 billion	$2.48 billion	$3.24 billion
Earnings benefits	$3.02 billion	$3.72 billion	$2.31 billion	$3.02 billion
Health cost benefits	$130 million	$153 million	$106 million	$130 million
Education cost benefits	$43 million	$53 million	$32 million	$43 million
QALYs benefits	$47 million	$64 million	$29 million	$47 million
Household and private-sector benefits	$2.08 billion	$2.56 billion	$1.60 billion	$2.08 billion
Federal government benefits	$852 million	$1.06 billion	$650 million	$852 million
State and local government benefits	$305 million	$384 million	$227 million	$305 million
Net societal program benefit (ROI)	$1.91 billion (2.44)	$2.42 billion (2.54)	$1.35 billion (2.20)	$1.62 billion (2.00)
Break-even year when societal benefits first exceed costs	2038	2035	2044	2042
Total no. of newborns benefiting through 2060	420,800	489,500	352,000	420,800

SOURCE Authors' Value of Health tool economic benefits model results, incorporating data on the number and costs of lead service line replacements from the cost model and number of newborns benefiting from replacement, based on population data from the American Community Survey. **NOTES** Benefits per newborn from lead service line replacement are estimated in the underlying benefits model, incorporating health and productivity lifetime outcome projections described in the Study Data And Methods section and in appendix A (see note 27 in text). QALYs is quality-adjusted life-years. ROI is return on investment (dollars saved per dollar spent).

lion in discounted societal benefits over the forty-year period 2020–60 (exhibit 2, case 1). The majority of these benefits, $3.02 billion, would accrue from increased productivity and lifetime earnings, with an additional $220 million coming from reduced health care costs, lower education spending, and the implied value of gained QALYs. The largest component of health care savings would be reduced cardiovascular disease costs later in life, and the largest education savings would be reduced special education costs (data not shown). All benefits were calculated for the population of newborns born between 2020 and 2060 and included benefits throughout their lifetimes.

When we compared the costs of proactive replacement with the total costs of replacement under case 1, $1.33 billion, we found that proactive replacement would yield a net societal program benefit that would exceed $1.91 billion. This would result in a cost-benefit ratio of 2.44, meaning that for every dollar invested in replacement, $2.44 in societal returns is expected. Across the four replacement scenarios modeled, all lead service line replacement returns remained positive, with the cost-benefit ratios ranging from 2.00 (case 4) to 2.54 (case 2). Benefits by source and for specific stakeholders are shown in exhibit 2.

EQUITY IMPACTS Lead service lines in Michigan are concentrated in historically marginalized and underresourced areas, including older communities, poorer regions, and households of racial and ethnic minorities.[9,10] Thus, the modeling revealed that an outsize share of the overall benefits of the Lead and Copper Rule would come from households of color and low-income households. Exhibit 3 shows the split of benefits by race and poverty status. Twenty-five percent of the total benefits would be expected to come from children in households living below the federal poverty level, and 18.6 percent ($602.9 million) of the total benefits would come from children in households with a Black head of household, with an additional 17.8 percent ($574.6 million) coming from other non-White households. This combined percentage (36.4 percent) is much greater than the current proportion of Michigan residents who are non-White (21 percent), and the benefits would be even greater if lead service line replacements completed before 2021 were considered.[34]

BENEFITS OVER TIME AND PACE OF REPLACEMENT Assessing the benefits of alternative policy

EXHIBIT 3

Estimated split of gross, discounted benefits to newborns from lead service line replacement under Michigan's Lead and Copper Rule, by race and poverty status of head of household, 2020–60

SOURCE Authors' projection of total benefits to newborns, according to the race and poverty status of the newborn's head of household, based on American Community Survey Michigan population data and census population projections. **NOTE** Poverty is indicated by the household's percentage of the federal poverty level.

options that varied the speed of lead service line replacements, we found that expediting replacement has the potential to increase the number of children affected, the total societal benefits, and the cost-benefit ratio. Although expediting replacements by 2030 (a ten-year schedule) would increase the total cost of the policy from $1.33 billion to $1.57 billion (a $245 million increase), it would also increase the total societal benefits from $3.24 billion to $4.00 billion (exhibit 2, case 2). This would increase the total net societal program benefit to $2.42 billion and would move up the first year in which program benefits would exceed costs (exhibit 4). Expedited lead service line replacement over a ten-year schedule would also significantly increase the total number of children born through 2060 benefiting from the policy to 489,500 (exhibit 2, case 2), for an increase of 68,700 children. The opposite is true for a policy that would delay or slow replacement, decreasing total benefits to $2.48 billion and the number of children benefiting to just 352,000 (exhibit 2, case 3).

Discussion

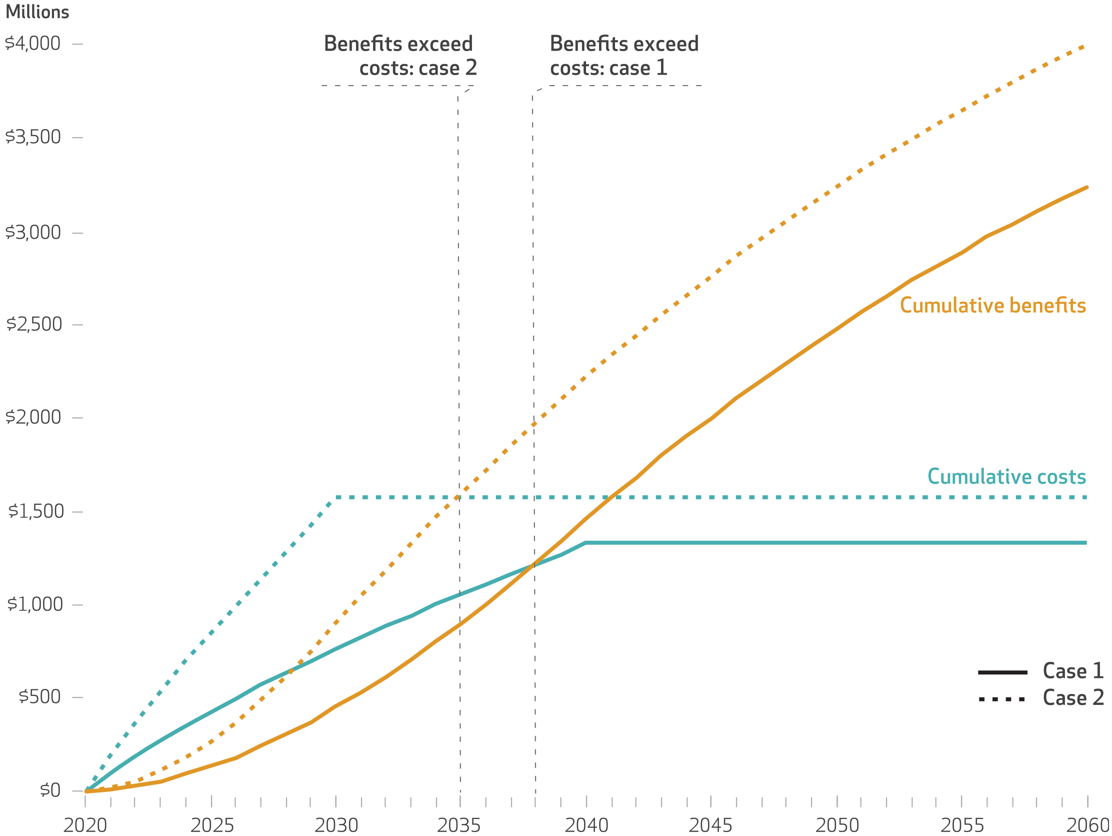
These results demonstrate that proactive lead service line replacement is likely to protect hundreds of thousands of children, generating large net societal gains: $1.91 billion in total and $2.44 per dollar invested in replacement. These return-on-investment results are similar to findings in well-regarded studies of highly effective investments in other social determinants. For example, two studies of supportive housing investments[35,36] estimated cost-benefit ratios of 3.2 and 2.9, respectively. Similarly, two studies of care management or broader social support interventions[37,38] revealed cost-benefit ratios of 1.9 and 2.5, respectively.

We found that lead service line replacement benefits would accrue in greater shares to minority and low-income populations because lead service lines are more likely to remain in areas subjected to discrimination, government neglect and disinvestment, and perpetuated environmental racism (a form of systemic racism wherein communities of color are disproportionately subject to environmental hazards such as toxins, waste, pollutants, disruptive commercial activity, and industrial extraction activity such as mining).[9,10] Therefore, line replacement policies are likely to provide meaningful health equity benefits above and beyond the net societal returns. Policy can maximize the equity impacts of replacement by providing expedited and targeted funding to communities hardest hit by exposure risks, including areas with older homes, greater proportions of low-income families, and previously marginalized and discriminated-against communities (such as those affected by redlining). Furthermore, after lead service lines have been removed, it must be ensured that proper lead recycling practices are followed, lest the toxins removed from US homes be exported to other countries with more lax environmental standards.

Certain potential benefits of lead service line replacement were not counted in this analysis, making our societal return-on-investment estimates a likely underestimate. In particular, we included the benefits of reducing water lead levels for newborns only, excluding benefits for older children or adults already exposed, given the uncertainty of the impact after previous ex-

EXHIBIT 4

Cumulative discounted costs and benefits of lead service line replacement under Michigan's Lead and Copper Rule over time, 2020–60



SOURCE Authors' Value of Health tool economic benefits model results, incorporating data on the number and costs of lead service line replacements from the cost model and the number of newborns benefiting from replacement, based on population data from the American Community Survey. **NOTES** Benefits per newborn from lead service line replacement are estimated in the underlying benefits model, incorporating health and productivity lifetime outcome projections described in the Study Data And Methods section and in appendix A (see note 27 in text). The vertical lines mark the years in which the total discounted benefits exceed costs for the two cases. Benefits exceed costs three years earlier (2035 versus 2038) under the 10 percent of lines per year replacement schedule (case 2) compared with the base case of 5 percent per year (case 1). The cases are presented in more detail in exhibits 1 and 2.

posure except at high blood lead levels.[39] We also excluded impacts on crime and incarceration,[40] impacts on fertility rates,[41] and in utero impacts.[1,42] We did not include the benefits of new jobs and economic activity generated by federal investment hiring local workers in potentially slack labor markets to complete replacements,[43] as economic returns of those hirings are dependent on labor-market conditions.[44] Ancillary job benefits could include lower social safety-net spending (for example, unemployment and Medicaid) and better worker health, because many new jobs would be union jobs, offering stability and health insurance benefits.[45]

Since we constructed these economic models and completed the cost-benefit analyses for this work, there has been some increased economic uncertainty around the model inputs of future wage growth, interest rates and appropriate discount rates, and expected future costs of lead service line replacement as a result of rising US inflation. A period of long-term higher price growth would be expected to increase both future program costs and benefits and may warrant additional analyses of lead service line replacement policies under new economic scenarios.

Our cost-benefit analyses demonstrated the need for states to expedite lead service line replacement, as faster replacements would increase the number of children benefiting and overall societal benefits. Greater net benefits would occur despite a greater up-front discounted cost, as the longer period of safe water for newborns would provide offsetting and larger long-term benefits. This research therefore supports calls for a ten-year time frame for lead service line replacement, as has been proposed in recent congressional legislation.[46,47] Our analyses also suggest that lead service line replacements should prioritize areas with children and areas with a greater proportion of historically marginalized populations.

In a meaningful sign of progress toward completing nationwide lead service line replacement, the 2021 Bipartisan Infrastructure Law provided $15 billion in committed funding and should allow states to increase the pace of replacements. However, the initial round of funding is insufficient and has been allocated suboptimally, as it did not consider the number of lead service lines in each state.[17] As a result, Michigan will receive $69 million, which would be expected to fund fewer than 5 percent of its lead service line replacements. Cities can also use funds from the American Rescue Plan Act of 2021 for lead service line replacement, but there is no specific set-aside in that law for replacement programs. To maximize societal benefits, additional federal funding for lead service line replacement is necessary, and the EPA should consider reallocating current and future Bipartisan Infrastructure Law funding to states with more lead service lines.

From loans; the American Rescue Plan Act; and other COVID-19 dollars, such as Coronavirus Aid, Relief, and Economic Security Act of 2020 funding via the Economic Development Administration's Public Works and Economic Adjustment Assistance programs, states have leveraged additional funding sources to complete lead service line replacement and, with political will, have proven the ability to expedite this work. In Benton Harbor, Michigan, the state committed to replacing all lead service lines within eighteen months and had completed 99 percent of this work within twelve months, using funding contained within the larger nearly $5 billion Building Michigan Together Plan.[48] An untapped funding source includes damages collected from the lead plumbing industry that profited from lead service line installation and promoted city codes requiring lead service lines.[49]

Conclusion

Our analysis of Michigan's Lead and Copper Rule policy revealed that proactive and expedited removal of lead service lines would produce a substantial societal return on investment and that lead service line replacement would afford an opportunity to address long-standing health inequities while protecting the health and development of children. ■

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