United States
Environmental Protection
Agency

Health Risk Reduction and Cost Analysis of the Proposed Perchlorate National Primary Drinking Water Regulation

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Abbreviations and Acronyms

Acryonym	Definition
ACS	American Community Survey
ADHD	attention-deficit/hyperactive disorder
AFQT	Armed Forces Qualifying Test
Agency	U.S. Environmental Protection Agency
ANSI	American National Standards Institute
ASVAB	Armed Services Vocational Aptitude Battery
BBDR	biologically based dose response
BLS	Bureau of Labor Statistics
CCL	Contaminant Candidate List
CCR	Consumer Confidence Report
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
ClO_4^-	perchlorate
Council	National Drinking Water Advisory Council
CPI	Consumer Price Index
CRF	Concentration Response Function
CSFII	Continuing Survey of Food Intakes by Individuals
CVD	cardiovascular disease
CWS	community water system
CWSS	Community Water System Survey
DWI	drinking water intake
EFH	Exposure Factors Handbook
EO	Executive Order
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FASEB/LSRO	Federation of American Societies for Experimental Biology/Life Science Research Organization
FRN	Federal Register Notice
fT4	free thyroxine
GW	gestational week
HHS	Health and Human Services
HRL	Health Reference Level
HRRCA	Health Risk Reduction and Cost Analysis
ICC	intraclass correlation coefficient
IQ	intelligence quotient
LDL	low-density lipoprotein
L/kg/day	Liters per kilogram per day
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MHI	mean household income
µg/day	micrograms per day
µg/kg/day	micrograms per kilogram per day

Acryonym	**Definition**
µg/L	micrograms per liter
MGD	million gallons per day
MOA	mode of action
MRL	minimum reporting level
NCES	National Center for Education Statistics
NCOD	National Contaminant Occurrence Database
NCWS	non-community water system
NDWAC	National Drinking Water Advisory Council
NHANES	National Health and Nutrition Examination Survey
NIS	sodium-iodide symporter
NLSY	National Longitudinal Survey of Youth
NLSY79	National Longitudinal Survey of Youth 1979 cohort
NLSY97	National Longitudinal Survey of Youth 1997 cohort
NPDWR	national primary drinking water regulation
NRC	National Research Council
NSF	National Science Foundation
NTNCWS	non-transient non-community water system
NTTAA	National Technology Transfer and Advancement Act
O&M	operating and maintenance
OMB	Office of Management and Budget
ClO_4^-	Perchlorate
PBPK	physiologically based pharmacokinetic
PD	pharmacodynamic
pmol/L	picomoles per liter
POTW	publicly owned treatment works
POU	point-of-use
pph	persons per household
PUMS	Public Use Microdata Sample
PWS	public water system
RFA	Regulatory Flexibility Act
RfD	reference dose
SAB	Science Advisory Board
SBA	Small Business Administration
SBREFA	Small Business Regulatory Enforcement Fairness Act
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SDWIS/FED	Federal Safe Drinking Water Information System
SSA	Social Security Administration
SSCT	small system compliance technology
T3	triiodothyronine
T4	thyroxine
TNCWS	transient non-community water system
TSH	thyroid stimulating hormone
UCMR	Unregulated Contaminant Monitoring Rule

Acryonym	Definition
UCMR 1	first Unregulated Contaminant Monitoring Rule
UMRA	Unfunded Mandates Reform Act
WBS	work breakdown structure

1 Introduction

The U.S. Environmental Protection Agency (EPA or the Agency) is proposing to regulate perchlorate in drinking water distributed by certain public water systems (PWSs). In 2011, the EPA determined that a national primary drinking water regulation (NPDWR) for perchlorate would result in a meaningful opportunity to reduce health risks (USEPA, 2011a). Based on the best available scientific information on the health effects of perchlorate, the EPA is proposing a maximum contaminant level goal (MCLG) of 56 micrograms per liter (µg/L). The EPA is also proposing an enforceable maximum contaminant level (MCL) of 56 µg/L and compliance monitoring requirements consistent with the Standardized Monitoring Framework for inorganic contaminants in the Title 40 Code of Federal Regulations (CFR) 141.23(c).

1.1 Purpose of Economic Analysis

The purpose of this economic analysis is to provide a description of the potential benefits and costs of the proposed perchlorate NPDWR. An economic analysis is required for all significant rules under Executive Order (EO) 12866 (*Regulatory Planning and Review*). In addition, Section 1412(b)(3)(C) of the 1996 Amendments to the Safe Drinking Water Act (SDWA) requires the EPA to prepare a Health Risk Reduction and Cost Analysis (HRRCA) in support of any NPDWR that includes an MCL. The analysis in this document addresses these and other regulatory reporting requirements. With respect to the HRRCA requirements, this document provides the following:

- Quantifiable and non-quantifiable health risk reduction benefits for which there is a factual basis in the rulemaking record to conclude that such benefits are likely to occur as the result of treatment to comply with each level (Chapter 4);
- Quantifiable and non-quantifiable health risk reduction benefits for which there is a factual basis in the rulemaking record to conclude that such benefits are likely to occur from reductions in co-occurring contaminants that may be attributed solely to compliance with the MCL, excluding benefits resulting from compliance with other proposed or promulgated regulations (Chapter 4);
- Quantifiable and non-quantifiable costs for which there is a factual basis in the rulemaking record to conclude that such costs are likely to occur solely as a result of compliance with the MCL, including monitoring, treatment, and other costs, and excluding costs resulting from compliance with other proposed or promulgated regulations (Chapter 5);
- Incremental costs and benefits associated with each alternative MCL considered (Chapter 6);
- Effects of the contaminant on the general population and on groups within the general population, such as infants, children, pregnant women, the elderly, individuals with a history of serious illness, or other sub-populations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population (Chapter 4);
- Any increased health risk that may occur as the result of compliance, including risks associated with co-occurring contaminants (Chapter 4); and

- Other relevant factors, including the quality and extent of the information, the uncertainties in the analysis, and factors with respect to the degree and nature of the risk (Chapters 4 to 6).

1.2 Outline

This document contains the following:

- Chapter 2 – Consideration of Regulatory Alternatives – describes the proposed NPDWR and alternatives the Agency considered;
- Chapter 3 – Baseline Analysis – provides key information about current conditions that form the baseline for the subsequent benefit and cost analysis, including a description of perchlorate occurrence in drinking water and the potentially affected entities;
- Chapter 4 – Health Effects and Benefits Analysis – provides a summary of the health effects of concern, the basis for the proposed MCLG, and the method that the Agency used to estimate the health risk reductions of proposing an enforceable MCL;
- Chapter 5 – Economic Impact and Cost Analysis – describes the potentially affected entities and the basis for estimating costs to implement the proposed rule and comply with the MCL;
- Chapter 6 – Comparison of Benefits and Costs – provides side-by-side comparison of the benefits and costs by the proposed rule alternative;
- Chapter 7 – Administrative Requirements – addresses several reporting requirements under various statutes and Executive Orders; and
- Appendices – provide additional details for selected topics in the main document.

Information in the chapters often summarizes more detailed technical support documents, which are cited throughout the text.

1.3 Public Health Concerns to Be Addressed

Perchlorate is an anion containing one chlorine atom bound to four oxygen atoms (ClO_4^-). It combines with cations to form salts including ammonium perchlorate and potassium perchlorate. Each salt has different chemical properties including molecular weight, density, boiling/melting points, and solubility (USEPA, 2019b).

Perchlorate ingestion – via drinking water or food – can adversely affect human health. The main target organ for perchlorate toxicity is the thyroid gland, where perchlorate competes with iodide for transport into the thyroid via the sodium iodide symporter. Decreases in iodide uptake in the thyroid can adversely affect hormone production levels. These changes in thyroid hormones in a pregnant or nursing woman may be linked to changes in the intelligence quotient (IQ) in her offspring using dose-response functions derived from the peer-reviewed literature. Chapter 4 describes these relationships in more detail because they form the basis for a quantitative benefits analysis. Chapter 4 also identifies the potential for increased risk of other adverse neurological effects and cardiovascular disease (CVD) that may be linked to elevated perchlorate exposure. Though not separately quantified in this benefits assessment, the EPA assumes the proposed MCLG protects against these effects because it is based on the risks to the most sensitive population.

1.3.1 Rule Objectives and Public Health Concerns

The proposed rule will reduce perchlorate concentrations in the drinking water distributed by PWSs that exceed the proposed MCL under the baseline scenario, which are the perchlorate occurrence and exposure conditions expected in the absence of finalizing the proposed regulation. Achieving the proposed concentrations of perchlorate could protect some individuals from experiencing a reduction of IQ points (specifically, compliance with the MCL will reduce the risk of adverse IQ impacts among offspring born to women exposed to perchlorate concentrations greater than the baseline level). The reductions may also reduce risks of other neurodevelopmental effects. The proposed rule also includes requirements for every affected drinking water system to conduct initial monitoring to determine whether perchlorate exceeds the proposed MCL, and provide public notice for an MCL violation. Customers of these systems will benefit from knowing whether they are exposed to perchlorate in excess of the MCL and, if so, what measures they can take to protect themselves and their families until the treatment or other control efforts reduce perchlorate to a compliant level.

1.3.2 Sources and Mechanisms of Exposure

The Agency's *Perchlorate Occurrence and Monitoring Report* technical support document (USEPA, 2019b) provides a review of perchlorate sources, fate, and transport. The following discussion provides a brief summary of that discussion.

Perchlorate is naturally occurring and man-made. Natural sources include geologic materials such as potash ore from New Mexico and sodium nitrate-rich soils in Chile, which produces fertilizers applied in the United States. Man-made sources include the use of ammonium perchlorate as an oxidizer in solid fuels for rockets and fireworks.

Perchlorate is likely to be mobile in soil and aqueous media because perchlorate salts are highly soluble and unlikely to sorb to minerals or organic matter. Dissolved in water, the perchlorate ion is unlikely to undergo reduction, hydrolysis, or direct photolysis; form insoluble metal complexes; or volatilize from water. Therefore, perchlorate is likely to persist in water absent biological removal or uptake processes. Releases to air are likely to result in eventual deposition to soil or water. Thus, once perchlorate reaches surface or ground water sources of drinking water, these characteristics suggest it is likely to persist in the water. These same characteristics indicate that effective treatment processes include biological removal and anion exchange.

1.4 Regulatory History and Background

This section provides a brief summary of the process that led the Agency to propose an NPDWR for perchlorate. Section 1412(b)(1)(B)(i) of the SDWA requires the EPA to publish every five years a Contaminant Candidate List (CCL). The CCL is a list of drinking water contaminants that are known or anticipated to occur in PWS and are not currently subject to the EPA drinking water regulations. The EPA uses the CCL to identify priority contaminants for regulatory decision-making and information collection. The EPA included perchlorate on the first, second, and third CCLs published in 1998, 2005, and 2009, respectively.

Once listed on the CCL, the Agency continues to collect data on CCL contaminants to better understand their potential health effects and to determine the levels at which they occur in drinking water. Section 1412(b)(1)(B)(ii) of the SDWA requires that every five years the EPA, after public comment, issue a determination whether or not to regulate at least five contaminants on the CCL. The EPA's efforts regarding perchlorate included additional health risk research and occurrence data collection, described below.

As part of its responsibilities under the SDWA, EPA implements section 1445(a)(2), "Monitoring Program for Unregulated Contaminants." This section requires that once every five years, the EPA issue a list of no more than 30 unregulated contaminants to be monitored by PWSs. This monitoring is implemented through the Unregulated Contaminant Monitoring Rule (UCMR), which collects data from community water systems (CWSs) and non-transient, non-community water systems (NTNCWSs). The UCMR collects data from all large water systems (serving more than 10,000 people) and from a statistically representative sample of small water systems. On September 17, 1999, the EPA published its first UCMR (UCMR1;64 FR 50556; USEPA, 1999), which required monitoring for perchlorate and 25 other contaminants.

The EPA and other federal agencies asked the National Research Council (NRC) to evaluate the health implications of perchlorate ingestion. The NRC concluded that perchlorate exposure inhibits the transport of iodide[1] into the thyroid by the sodium-iodide symporter (NIS), which may lead to decreases in triiodothyronine (T3) and thyroxine (T4), and increases in the thyroid stimulating hormone (TSH; NRC, 2005). Additionally, the NRC concluded that the most sensitive population to perchlorate exposure are "the fetuses of pregnant women who might have hypothyroidism or iodide deficiency" (p. 178). The EPA established a reference dose (RfD) consistent with the recommended NRC RfD of 0.7 micrograms per kilogram per day (μg/kg/day) for perchlorate. The RfD is an estimate of a daily exposure to humans that is likely to be without an appreciable risk of adverse effects. This RfD was based on a study (Greer et al., 2002) of perchlorate's inhibition of radioactive iodine uptake in healthy adults and the application of an uncertainty factor of 10 for intraspecies variability (USEPA, 2005).

In October 2008, the EPA published a preliminary regulatory determination not to regulate perchlorate in drinking water and requested public comment (73 FR 60262; USEPA, 2008a). In that preliminary determination, the EPA tentatively concluded that perchlorate did not occur with a frequency and at levels of public health concern and that development of a regulation did not present a meaningful opportunity for health risk reduction for persons served by PWSs. The EPA derived and used a Health Reference Level (HRL) of 15 μg/L based on the RfD of 0.7 μg/kg/day in making this conclusion (USEPA, 2008a). Based primarily on the UCMR 1occurrence data, the EPA estimated that less than 1% of drinking water systems (serving approximately 1 million people) had perchlorate levels above the HRL of 15 μg/L.

Based on this information the Agency determined that perchlorate did not occur frequently at levels of health concern. The EPA also determined that there was not a meaningful opportunity for a NPDWR to reduce health risks.

In January 2009 the EPA published an interim health advisory for perchlorate of 15 μg/L, consistent with the HRL derivation for perchlorate of 15 μg/L described above. Health

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[1] For the purposes of this document, "iodine" will be used to refer to dietary intake before entering the body. Once in the body, "iodide" will be used to refer to the ionic form.

Advisories are non-regulatory and provide technical information to state agencies and other public health officials on health effects, analytical methods, and treatment technologies associated with drinking water contamination. Health Advisories provide the public, including the most sensitive populations, with a margin of protection from a lifetime of exposure. The EPA developed the perchlorate health advisory for subchronic exposure (USEPA, 2008c).

In August 2009, the EPA published a supplemental request for comment with a new analysis that derived potential alternative HRLs for 14 life stages, including infants and children. The analysis used the RfD of 0.7 µg/L and life stage-specific bodyweight and exposure information (74 FR 41883; USEPA, 2009c). After careful consideration of public comments on the October 2008 and August 2009 notices, on February 11, 2011, the EPA published its determination to regulate perchlorate (76 FR 7762; USEPA, 2011a). The Agency stated then that when considering the alternative HRL benchmarks described in the 2009 notice, the likelihood of perchlorate to occur at levels of concern had significantly increased in comparison to the levels described in the 2008 preliminary negative determination. The EPA concluded that as many as 16 million people could potentially be exposed to perchlorate at levels of concern, up from 1 million people originally described in the 2008 notice.

In its 2011 determination, the Agency found that perchlorate may have an adverse effect on the health of persons, that it is known to occur in public drinking water systems with a frequency and at levels that present a public health concern, and in the judgment of the Administrator, regulation of perchlorate presented a meaningful opportunity for health risk reduction for persons served by PWSs. As a result of the determination, and as required by Section 1412(b)(1)(E), the EPA initiated the process to develop an MCLG and NPDWR for perchlorate.

1.5 Rationale for the Proposed Regulation

This section provides the statutory and economic rationales for choosing a regulatory approach to address the public health consequences of drinking water contamination.

1.5.1 Statutory Authority

Section 1412(b)(1)(A) of the SDWA requires the EPA to establish NPDWRs for contaminants that may have an adverse public health effect; that are known to occur or that present a substantial likelihood of occurring once in PWSs, at a frequency and level of public concern; and that present a meaningful opportunity for health risk reduction for persons served by PWSs.

1.5.2 Economic Rationale for Regulation

The Office of Management and Budget (OMB) Circular A-4 (2003) states that “in order to establish the need for the proposed action, the analysis should discuss whether the problem constitutes a significant market failure.” This section describes the types of market failures that NPDWRs address.

In a perfectly competitive market, market forces guide buyers and sellers to attain the most efficient social outcome. A perfectly competitive market occurs when both buyers and sellers are price takers, usually when there are many producers and buyers of a product and both producers and buyers have complete knowledge about that product. Also, there must not be any barriers to entry into the industry, and existing producers in the industry must not have any advantage over potential new producers. Several factors in the public water supply industry do not satisfy the requirements for a perfectly competitive market and lead to market failures that may require regulation.

First, it is not economically efficient to have multiple suppliers who would, for example, compete by building multiple systems of pipelines, reservoirs, wells, and other facilities. Instead, economic efficiency leads to a single firm or government entity performing these functions generally under public control. Under these monopoly conditions, consumers are provided only one level of service with respect to drinking water quality. If consumers do not believe that the quality of tap water is adequate, they cannot simply switch to another water utility. Consumers may purchase bottled water, but this option can be much more expensive due to the inefficiencies of bottling and transporting bottled water. Consumers may also install and operate home treatment systems, but this can also be considerably more expensive because they do not have the economies of scale that large centralized water systems have and home treatment systems potentially can lead to increased health risks when not regularly maintained by the consumer.

Second, high information and transaction costs impede the public's understanding of health and safety issues concerning drinking water quality. The types of health risks potentially posed by trace quantities of drinking water contaminants involve the analysis and distillation of complex toxicological and health sciences data. The EPA developed the Consumer Confidence Report (CCR) rule to make water quality information more easily available to consumers. The CCR rule requires CWSs to mail their customers an annual report on local drinking water quality. The report provides customers with information on levels of detected contaminants in their drinking water and provides limited health risk information associated with contaminant exposure when levels exceed MCLs and utility contact information. Even if informed consumers are able to engage utilities regarding these health issues, the costs of such engagement, known as "transaction costs" (in this case measured in personal time and commitment), can be a barrier to efficient market outcomes.

SDWA regulations are intended to provide a level of protection from exposure to drinking water contaminants that would not otherwise occur in the existing market environment of public water supply. The regulations set minimum performance requirements for all public water supplies in order to reduce the risk confronted by all consumers from exposure to drinking water contaminants. SDWA regulations are not intended to restructure market mechanisms or to establish competition in supply. Rather, SDWA standards establish the level of service to be provided in order to better reflect the public's preference for safety. Federal regulations remove the high information and transaction costs by acting on behalf of all consumers in balancing the risk reduction and the social costs of achieving this reduction.

2 Consideration of Regulatory Alternatives

The Agency's proposed rule comprises the following elements: an MCLG, an MCL, and monitoring and reporting requirements. This section describes each element of the proposed rule and identifies the alternatives that the Agency considered during the rule-making process.

2.1 MCLG

Section 1412 (b)(4)(A) of the SDWA requires that – when regulating a contaminant – the EPA first sets an MCLG "at the level at which no known or anticipated adverse effects on the health of persons occur and which allows an adequate margin of safety." MCLGs are non-enforceable health goals. For this rulemaking, the EPA is proposing to set an MCLG of 56 µg/L for perchlorate based on a 2 IQ point decrease associated with this level of exposure. Chapter 4 describes the basis for this MCLG. The Agency also considered alternative MCLGs of 18 µg/L based on a 1 IQ point decrease associated with this level of exposure and 90 µg/L based on a 3 IQ point decrease. This approach implements a policy decision to reflect the uncertainty about the IQ decrement that should form the basis for an MCLG, highlighting the challenges associated with identifying a perchlorate MCLG. There are no robust population studies to inform the precise decrement in population IQ that represents an adverse impact. By selecting this approach, the EPA is not establishing a precedent for future Agency actions on other contaminants, because this approach might not be appropriate for conducting risk assessments or informing Agency policy for other contaminants and associated health effects.

2.2 MCL Alternatives

Section 1412 (b)(4)(B) of the SDWA requires that when the EPA sets an enforceable MCL, it is "as close to the maximum contaminant level goal as is feasible." Section 1412 (b)(4)(D) defines feasible as follows: "feasible with the use of the best technology, treatment techniques and other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration)." Furthermore, Section 1401 (1)(A)(i) defines an MCL as feasible when "it is economically and technologically feasible to ascertain the level of such contaminant in water in public water systems." Finally, under Section 1412 (b)(6), the Administrator can determine that the benefits of an MCL as close as feasible to the MCLG "would not justify the costs of complying with the level" and promulgate an MCL "that maximizes health risk reduction benefits at a cost that is justified by the benefits." The EPA determined that an MCL of 56 µg/L is feasible and, therefore, is proposing to set the MCL equal to the MCLG of 56 µg/L. For the alternative MCLGs of 18 µg/L and 90 µg/L, the Agency determined that setting the MCL equal to these MCLGs, respectively, was feasible.

The proposed rule applies to certain PWSs. A PWS is a system that provides water for human consumption to the public through pipes or other constructed conveyances and has at least 15 service connections or regularly serves at least 25 individuals for at least 60 days per year (USEPA, 2017). PWSs may be publicly or privately owned. Types of PWSs include CWSs and non-community water systems (NCWSs), which may be transient or non-transient. The EPA defines PWS types as follows (USEPA, 2009a; 2017):

- CWSs supply water to at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents.
- NCWSs do not serve year-round residents. These water systems serve areas where the people do not stay for long periods of time or where the same population is served less than year-round. The two categories of NCWSs are:
    - Non-transient non-community water systems (NTNCWSs) serve at least 25 of the same people for at least 6 months of the year. Examples include schools and office buildings.
    - Transient non-community water systems (TNCWSs) serve fewer than 25 of the same people over 6 months of the year. Examples include gas stations and campgrounds.

The EPA proposes to regulate perchlorate at CWSs and NTNCWSs.

2.3 Monitoring Requirements

The EPA is proposing the following monitoring requirements for perchlorate:

- Initial monitoring – one year of monitoring by all affected systems to determine compliance with the proposed MCL; and
- Long-term monitoring consistent with the Standardized Monitoring Framework for inorganic contaminants.

2.3.1 Initial Monitoring Requirements

The Agency is proposing that all CWSs and NTNCWSs conduct one year of initial monitoring. Large CWSs, which serve more than 10,000 people, will conduct initial monitoring within the first 3 years after the effective date. Small CWSs, which serve up to 10,000 people, and all NTNCWSs have 6 years after the effective date to conduct initial monitoring. To meet the initial monitoring requirement, all water systems must collect four samples over consecutive quarters within the specified time period.

2.3.2 Long-Term Monitoring Requirements

Following their respective initial monitoring period, CWS and NTNCWSs will conduct long-term monitoring according to the Standardized Monitoring Framework (USEPA, 2004). Monitoring frequency depends on the water source and whether a system qualifies for a perchlorate monitoring waiver or exceeds the MCL. Exhibit 2-1 shows the proposed monitoring frequencies.

Exhibit 2-1: Long-Term Perchlorate Monitoring Requirements

Water Source	Waiver	No Waiver, Reliably and Consistently ≤ MCL	> MCL or Not Reliably and Consistently ≤ MCL
Ground water	1 sample every 9 years	1 sample every 3 years	Quarterly samples
Surface water	1 sample every 9 years	Annual sample	Quarterly samples

Source: USEPA (2004).

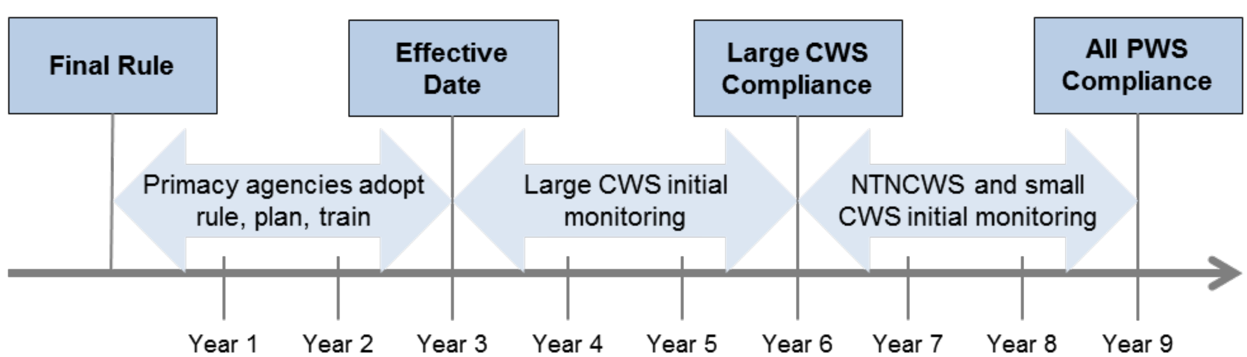
2.4 Reporting Requirements

The proposed rule includes several reporting requirements. Water systems must provide perchlorate monitoring results to primacy agencies. These agencies must report perchlorate violation-related information to the EPA. Systems may also include perchlorate monitoring information in their annual CCR. Finally, systems will have public notification requirements in the event of an MCL violation. All of these reporting requirements would supplement existing baseline requirements for other regulated contaminants. Reporting responsibilities are the same regardless of system size or source water.

2.5 Implementation Schedule

The EPA is proposing effective dates that vary by system size and type. Exhibit 2-2 provides an overview of the implementation schedule. The effective date of the rule is three years after the final rule publication, which is expected to occur in late 2019. Thus, the first three years roughly coincide with the time period from 2020 to 2022. Then, large CWSs will have three years (i.e., the first compliance period after the effective date) to complete their initial monitoring and install needed controls. NTNCWSs and small CWSs will complete their initial monitoring in the subsequent 3-year compliance period (i.e., years six to nine). All covered systems will be in compliance by year nine.

Exhibit 2-2: Proposed Rule Timeline



3 Baseline Analysis

3.1 Introduction

This chapter presents the data and assumptions used to establish the baseline for calculating the costs, benefits, and economic impacts of the proposed perchlorate rule. The baseline is the EPA's expectation of the conditions that would exist in the absence of perchlorate regulation. The baseline includes a profile of the PWSs that are potentially affected by a perchlorate regulation and current demographic information to characterize the exposed population. The baseline also includes estimates of perchlorate occurrence and exposure, which affect the Agency's analysis of costs and benefits of the proposed rule.

3.1.1 Background and Purpose

The purpose of the baseline analysis is to describe the data available to develop baseline characterization of the water supply industry, prior to the promulgation and implementation of an NPDWR for perchlorate. In the baseline analysis, the EPA defines the various types of water systems and provides information on the number and size of these water systems. The EPA also presents characteristics of the water systems, including the population served, the number of entry points, current treatment technologies that are in place, and the amount of production. The baseline analysis also discusses water consumption per household, estimates of current perchlorate occurrence, and population groups that may be susceptible to the health effects of perchlorate exposure.

3.1.2 Chapter Organization

The remainder of this chapter is organized into three sections. Section 3.2 provides a description of the data sources used in the baseline analysis. Section 3.3 characterizes the water supply industry as outlined above; this section also includes assumptions made in the analysis. The EPA then discusses current perchlorate occurrence in Section 3.4, and sensitive life stages and other populations in Section 3.5.

3.2 Data Sources

Data sources for the baseline analysis include data specific to the water supply industry and other information needed to characterize baseline conditions. Specifically, the EPA characterizes water systems using the EPA's Safe Drinking Water Information System (SDWIS) database and the 2006 Community Water System Survey (CWSS). The Agency uses perchlorate monitoring data from the UCMR 1 and comparable, but more recent, data sources to characterize baseline exposure to perchlorate in drinking water. The data sources are described in detail below.

3.2.1 SDWIS/FED and Other Sources for Water System Data

The EPA uses the SDWIS Fed Data Warehouse (SDWIS/FED) to characterize the universe of affected systems. SDWIS/FED contains information on more than 146,000 active PWSs in the United States, as reported by states and the EPA Regions (USEPA, 2018d) through electronic reporting to SDWIS. Information reported includes basic information on each water system, details on each PWS's compliance and violation history, and states' actions to enforce drinking water regulations (USEPA, 2018d). Basic information about PWSs includes location, number of people served, system type (e.g., CWS or NTNCWS), operation schedule (year-round or seasonal), ownership type (public or private), and characteristics of the source water. To characterize baseline conditions for this analysis, the EPA downloaded data from SDWIS/FED in August 2018.[2]

Another data source specific to the water supply industry is the 2006 CWSS report (USEPA, 2009a; 2009b). This survey has been administered periodically since 1976 and the most recent version is the 2006 CWSS. In the survey, the EPA collected information on major operational and financial characteristics of CWSs. CWSs are PWSs that have at least 15 service connections used year-round or regularly serve at least 25 people year-round (USEPA, 2009a).

3.2.2 Other Data and Information Used

The EPA's *Perchlorate Occurrence and Monitoring Report* is the source for national perchlorate occurrence data (USEPA, 2019b). This document describes the available data and analytical approaches that the EPA used to assess the baseline perchlorate occurrence in CWSs and NTNCWSs. The document also provides detailed estimates of perchlorate occurrence in drinking water.

Additional data and information used in analyzing the baseline conditions include data on the number of people in population groups that may be particularly susceptible to the health effects of perchlorate exposure. These data include U.S. Census Bureau population data and the National Center for Health Statistics annual live birth rates.

3.3 Baseline Profile

The proposed rule for perchlorate will apply to CWSs and NTNCWSs, and will not affect TNCWSs. Key characteristics of the affected systems are their service population size, type, ownership, and source water. This section provides details on these systems grouped by these characteristics.

3.3.1 Number and Size of PWSs

The proposed rule will affect CWSs and NTNCWSs. The EPA uses a SDWIS data extract from August 2018 to determine the number of these water systems in the United States by system size category, source water, ownership, and system type. Both CWSs and NTNCWSs have more ground water sources than surface water sources (Exhibit 3-1). CWSs make up approximately three-fourths (49,879 out of 67,497) of regulated water systems. NTNCWSs are more likely to be privately owned than CWSs (Exhibit 3-2) and be a small system (Exhibit 3-3). The exhibits show national totals and revised national totals that exclude systems in California and Massachusetts, which are the subset of regulated systems that would incur costs and benefits under the proposed rule. As noted in Section 3.4.1, California and Massachusetts regulations supersede the proposed MCL. The systems in these states must comply with MCLs that are less than the proposed MCL or alternative MCLs. Therefore, the EPA assumed that the proposed rule would not impose any incremental compliance costs on these systems.

[2] https://ofmpub.epa.gov/apex/sfdw/f?p=108:1:::NO:1, data extracted August 14, 2018.

Exhibit 3-1: Distribution of Affected Systems by Water Source and System Type

Water Source	CWSs (including CA and MA)	NTNCWSs (including CA and MA)	Total Systems (including CA and MA)	CWSs (excluding CA and MA)	NTNCWSs (excluding CA and MA)	Total Systems (excluding CA and MA)
Ground water	38,202	16,860	55,062	35,568	15,220	50,788
Surface water	11,677	758	12,435	10,634	654	11,288
Total	49,879	17,618	67,497	46,202	15,874	62,076

Source: SDWIS/FED 2018 data extract (USEPA, 2018d).

Exhibit 3-2: Distribution of Affected Systems by Ownership and System Type

Ownership	CWSs (including CA and MA)	NTNCWSs (including CA and MA)	Total Systems (including CA and MA)	CWSs (excluding CA and MA)	NTNCWSs (excluding CA and MA)	Total Systems (excluding CA and MA)
Private	22,865	12,266	35,131	20,742	11,153	31,895
Public/other	27,014	5,352	32,366	25,460	4,721	30,181
Total	49,879	17,618	67,497	46,202	15,874	62,076

Source: SDWIS/FED 2018 data extract (USEPA, 2018d).

Exhibit 3-3: Distribution of Affected Systems by Size and System Type

Service Population	CWSs (including CA and MA)	NTNCWSs (including CA and MA)	Total Systems (including CA and MA)	CWSs (excluding CA and MA)	NTNCWSs (excluding CA and MA)	Total Systems (excluding CA and MA)
Small (≤ 10,000)	45,553	17,585	63,138	42,481	15,844	58,325
Large (> 10,000)	4,326	33	4,359	3,721	30	3,751
Total	49,879	17,618	67,497	46,202	15,874	62,076

Source: SDWIS/FED 2018 data extract (USEPA, 2018d).

3.3.2 System Size and Population Served

SDWIS/FED also provides information on the retail population served by each system. Baseline health risks are a function of service populations. National population served estimates can also be disaggregated by water source (Exhibit 3-4), ownership (Exhibit 3-5), and system size category (Exhibit 3-6).[3] CWS service populations are substantially larger than NTNCWS service populations. Among CWSs, publicly owned systems and large systems account for a large majority of the total population served. The exhibits include total national estimates as well as national estimates, but exclude the service populations of systems in California and Massachusetts. Systems in these states must meet state MCLs that are lower than the proposed MCL, so there will be no perchlorate reductions associated with the proposed rule and, therefore, no benefits or costs.

[3] The populations across CWSs and NTNCWSs are not additive because the population served by an NTNCWS can also be served by a CWS. For example, students at a school that is served by an NTNCWS may also consume water provided by a CWS at home.

Exhibit 3-4: Aggregate Service Population by Water Source and System Type

Water Source[a]	CWSs (including CA and MA)	NTNCWSs (including CA and MA)	CWSs (excluding CA and MA)	NTNCWSs (excluding CA and MA)
Ground water	89,232,288	5,216,951	80,367,122	4,804,167
Surface water	219,408,388	1,289,825	176,786,648	1,175,137
Total	308,640,676	6,506,776	257,153,770	5,979,304

Source: SDWIS/FED 2018 data extract (USEPA, 2018d).
a. Forty-four systems serving 41,316 people (24 systems serving 37,635 people in included states) have unspecified water source; for the purpose of this analysis, the EPA assumed that these systems use ground water.

Exhibit 3-5: Aggregate Service Population by Ownership and System Type

Ownership	CWSs (including CA and MA)	NTNCWSs (including CA and MA)	CWSs (excluding CA and MA)	NTNCWSs (excluding CA and MA)
Private	36,740,435	3,481,164	29,240,150	3,286,132
Public	271,900,241	3,025,612	227,913,620	2,693,172
Total	308,640,676	6,506,776	257,153,770	5,979,304

Source: SDWIS/FED 2018 data extract (USEPA, 2018d).

Exhibit 3-6: Aggregate Service Population by Size and System Type

Service Population	CWSs (including CA and MA)	NTNCWSs (including CA and MA)	CWSs (excluding CA and MA)	NTNCWSs (excluding CA and MA)
Small (≤ 10,000)	53,121,502	5,573,773	53,121,502	5,573,773
Large (> 10,000)	255,519,174	933,003	204,032,268	405,531
Total	308,640,676	6,506,776	257,153,770	5,979,304

Source: SDWIS/FED 2018 data extract (USEPA, 2018d).

The EPA did not incorporate population growth factors in the benefit and cost analysis. Although the overall national population will tend to grow over time, the Agency does not assume that the same growth rate applies individually to each CWS and NTNCWS affected by the rule, in particular those systems that need to implement treatment changes to meet the proposed MCL. Some systems may actually be experiencing population declines. Therefore, the analysis of benefits and costs will be based on current population estimates.

3.3.3 Production Profile

As noted above, the SDWIS/FED data contain estimates of service population. Treatment costs, however, are based on the volume of water treated per day, expressed as either design flow (a maximum daily treatment capacity) or average flow (the average daily production rate). The EPA uses equations to translate population served (*pop*) into design flow and average flow estimates (USEPA, 2000b). The functional forms of the flow equations (measuring flow in thousands of gallons per day) are as follows:

$$Average\ Flow = a_A(pop)^{b_A}$$

$$Design\ Flow = a_D(pop)^{b_D}.$$

Parameters a_A, b_A, a_D, and b_D are estimated regression function coefficients that define the relationship between the population served by the water system and flow. The point values for the parameters in the flow equations vary by source water (Exhibit 3-7). For the design flow, the EPA selected the maximum of either design flow or two times the calculated average flow.

Exhibit 3-7: Flow Parameters by Water Source

Water Source	a_A	b_A	a_D	b_D
Ground water	0.08575	1.05839	0.54992	0.95538
Surface water	0.14004	0.99703	0.59028	0.94573

Source: USEPA (2000b).

3.4 Occurrence of Perchlorate

EPA's *Perchlorate Occurrence and Monitoring Report* provides estimates of the baseline perchlorate occurrence in PWSs (USEPA, 2019b). After reviewing the available data on perchlorate in drinking water, the EPA determined that the best nationally representative source is data from the UCMR 1.

This section summarizes the EPA's perchlorate occurrence analysis (USEPA, 2019b). Section 3.4.1 provides an overview of UCMR 1 and its perchlorate occurrence data, Section 3.4.2 summarizes the EPA's analysis of the UMCR 1 data, Section 3.4.3 summarizes the national perchlorate occurrence estimates used in the cost and benefit analyses, and Section 3.4.4 summarizes the number of entry points per system.

3.4.1 Overview of UCMR 1 Data

The UCMR is a national drinking water monitoring program administered by the EPA. The UCMR 1 monitoring cycle included a census of all large CWSs and NTNCWSs (i.e., those serving more than 10,000 people), and a statistical sample of 800 small CWSs and NTNCWSs (i.e., those serving 10,000 people or fewer) (USEPA, 2019b). The UMCR1 cycle was from 2001 to 2005, and most of the data collection occurred between 2001 and 2003.

The UCMR 1 data comprise perchlorate monitoring samples from systems in all 50 states, the District of Columbia, the Tribal Nations, and 4 U.S. territories (Puerto Rico, Virgin Islands, Guam, and the Northern Mariana Islands). Response rates were high: 99.6 percent of small systems and 99.0 percent of large systems provided data (USEPA, 2019b).

Systems collected samples at each entry point to their customer distribution system.[4] Entry points are the point of compliance for the proposed rule and systems can have multiple entry points. The sampling frequency varied by source water: four quarterly samples in a one-year period for surface water systems, and two samples at least six months apart for ground water systems (USEPA, 2019b). The minimum reporting level (MRL) was 4 µg/L (USEPA, 2019b).

[4] In response to comments on UCMR 1 data quality (U.S. Chamber of Commerce, 2012), the EPA reviewed the UCMR 1 data to identify instances where source water monitoring samples were accompanied by corresponding "downstream" entry point monitoring samples. In these instances, only the entry point samples provide the perchlorate concentration in water delivered to customers. Therefore, the 2013 version of the UCMR 1 dataset excludes these types of source water samples (USEPA, 2019c).

The summary statistics in Exhibit 3-8 show total samples, entry points, and systems in the UCMR 1 perchlorate dataset. It also shows the number of reported perchlorate detections (≥ 4 µg/L) along with the corresponding number of entry points and systems reporting those results.

Exhibit 3-8: UCMR 1 Data Summary Statistics

Item	Small Systems[a]	Large Systems	Total
Total samples	3,295	30,837	34,132
➢ Measurements ≥ 4 µg/L	15	525	540
Total entry points	1,454	13,482	14,936
➢ Measurements ≥ 4 µg/L	8	328	336
Total systems	797	3,068	3,865
➢ Measurements ≥ 4 µg/L	8	141	149

Source: USEPA (2019b)
a. The small system values shown are sample results that have not been extrapolated to national estimates.

Exhibit 3-9 shows the populations that correspond with the occurrence summary in Exhibit 3-8. The entry point population estimates reflect the assumption that system population is uniformly distributed across entry points (e.g., the entry point population for a system with two entry points is one-half the total system population).

Exhibit 3-9: UCMR 1 Data Service Population Summary Statistics

Item	Small Systems[a]	Large Systems	Total
Total entry point population	2,760,570	222,853,101	225,613,671
➢ Measurements ≥ 4 µg/L	9,484	4,281,937	4,291,420
Total system population	2,760,570	222,853,101	225,613,671
➢ Measurements ≥4 µg/L	13,483	16,159,082	16,172,565

Source: USEPA (2019b) Totals may differ from detail because of independent rounding.
a. The small system values shown are sample results that have not been extrapolated to national estimates.

Because the UCMR 1 data are well over a decade old, the EPA considered potential sources of uncertainty because of changes between current conditions and conditions at the time of data collection. One important change is the adoption of perchlorate drinking water limits in two states: Massachusetts adopted a drinking water standard for perchlorate of 2 µg/L in 2006 (MassDEP, 2006), and California promulgated a drinking water standard of 6 µg/L in 2007 (California Department of Public Health, 2007). Systems in these states cannot exceed these limits, which are lower than the proposed federal MCL and alternative MCLs. Therefore, any exceedances in the UCMR 1 data in these states overstate baseline occurrence and exposure under current conditions.

For the purpose of estimating the costs and benefits of the proposed rule, the EPA assumed that systems in California and Massachusetts comply with baseline perchlorate MCLs. Therefore, these systems will not incur incremental control costs to comply with the proposed rule. Exhibit 3-10 summarizes the UCMR 1 data pursuant to this assumption, including information about sample measurements exceeding 18 µg/L, 56 µg/L, and 90 µg/L.

Exhibit 3-10: UCMR 1 Data Summary Statistics, Excluding California and Massachusetts

Item	Small Systems [a]	Large Systems	Total
Total samples	2,984	21,128	24,112
➢ Measurements ≥ 4 µg/L	13	206	219
➢ Measurements > 18 µg/L	1	16	17
➢ Measurements > 56 µg/L	0	2	2
➢ Measurements > 90 µg/L	0	1	1
Total entry points	1,327	9,118	10,445
➢ Measurements ≥ 4 µg/L	7	159	166
➢ Measurements > 18 µg/L	1	16	17
➢ Measurements > 56 µg/L	0	2	2
➢ Measurements > 90 µg/L	0	1	1
Total systems	737	2,591	3,328
➢ Measurements ≥ 4 µg/L	7	91	98
➢ Measurements > 18 µg/L	1	14	15
➢ Measurements > 56 µg/L	0	2	2
➢ Measurements > 90 µg/L	0	1	1
Total entry point population	2,537,888	183,525,431	186,063,319
➢ Measurements ≥ 4 µg/L	5,430	2,380,918	2,386,348
➢ Measurements > 18 µg/L	2,155	618,406	620,561
➢ Measurements > 56 µg/L	0	32,432	32,432
➢ Measurements > 90 µg/L	0	25,972	25,972
Total system population	2,537,888	183,525,431	186,063,319
➢ Measurements ≥ 4 µg/L	9,429	7,762,593	7,772,022
➢ Measurements > 18 µg/L	4,309	696,871	701,180
➢ Measurements > 56 µg/L	0	64,733	64,733
➢ Measurements > 90 µg/L	0	25,972	25,972

Source: USEPA (2019b).
a. The values shown are sample results that have not been extrapolated to national estimates.

The age of the UCMR 1 data introduces additional sources of uncertainty. One is the effect of remediation efforts to reduce the sources of perchlorate in drinking water. The *Perchlorate Occurrence and Monitoring Report* (USEPA, 2019b) describes remediation efforts that have effectively reduced perchlorate levels in Colorado River water from a range of 4 µg/L to 9 µg/L during the UCMR 1 data collection period to 1 µg/L to 2 µg/L after 2009. Systems that use the Colorado River as a water source may have lower concentrations at entry points than the values reported in the UCMR 1. Another type of change that has an uncertain impact on occurrence is the change in the universe of systems over time. Some systems operating during the UCMR 1 data collection period are now inactive. There are also new systems that were not operating during the UCMR 1 period. Such changes over time have an uncertain impact on perchlorate occurrence and exposure.

3.4.2 Summary of the EPA's Analysis of UCMR 1 Data

The analytical approach that the EPA used to estimate perchlorate occurrence and exposure is the approach that it used to evaluate the national contaminant occurrence analyses for the six-year reviews of NPDWRs (USEPA, 2003b), the UCMR 1 data (USEPA, 2019b), and prior regulatory determinations (USEPA, 2003a; 2008a). In each case, the data analysis process and presentation were peer-reviewed and subject to public and stakeholder review and comment. The approach relevant for the proposed perchlorate MCL and alternative MCLs is the "Stage 1" analysis, for which an exceedance occurs if a single sample concentration is greater than a threshold such as the MCL.

The EPA conducted the Stage 1 analysis at the entry-point level to derive estimates of benefits and costs that reflect the fact that a system may not have exceedances at all entry points and, therefore, benefits and costs should reflect a population smaller than the total system population.

3.4.3 Summary of National Perchlorate Occurrence

The EPA estimated Stage 1 occurrence for the proposed MCL of 56 µg/L and alternative MCLs of 18 µg/L and 90 µg/L. The results in Exhibit 3-11 through Exhibit 3-13 show the number of entry points and systems at which the highest perchlorate concentration exceeds these respective values, along with corresponding entry point service populations. Regardless of the threshold, there are exceedances at relatively few entry points or systems.

Exhibit 3-11: Expected Stage 1 Perchlorate Occurrence Greater than 56 µg/L

Affected Entity	Small Systems	Large Systems	Total Systems
Entry points	0	2	2
Population served	0	32,432	32,432
Water systems	0	2	2
Population served	0	64,733	64,733

Source: USEPA (2019b).

Exhibit 3-12: Expected Stage 1 Perchlorate Occurrence Greater than 18 µg/L

Affected Entity	Small Systems[a]	Large Systems	Total Systems
Entry points	1	16	17
Population served	2,155	605,485	607,640
Water systems	1	14	15
Population served	4,309	696,871	701,180

Source: USEPA (2019b).

a. These estimates reflect the sample data. The EPA also applied the statistical sampling weights to the results to extrapolate them to national results. The entry point at which a measurement exceeds 18 µg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the 6 UCMR 1 systems in the stratum. Overall, the stratum population served accounts for 1.32% of the national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers may be exposed to perchlorate greater than 18 µg/L.

Exhibit 3-13: Expected Stage 1 Perchlorate Occurrence Greater than 90 µg/L

Affected Entity	Small Systems	Large Systems	Total Systems
Entry points	0	1	1
Population served	0	25,972	25,972
Water systems	0	1	1
Population served	0	25,972	25,972

Source: USEPA (2019b).

3.4.4 Number of Entry Points

The point of compliance for the proposed perchlorate MCL is the entry point to the distribution system, which can have one or more entry points. The number of entry points for CWSs are identified in the occurrence data. For systems that are not included in the occurrence data, the EPA assigned the number of entry points based on the population size classification of the system, calculated from the occurrence data. Exhibit 3-14 summarizes the number of entry points by source and population served, based on the occurrence data.

Exhibit 3-14: Average Number of Entry Points per System by Population Served and Source Water

Size Category	Maximum Population	Average Entry Points per System, Ground Water	Average Entry Points per System, Surface Water
Very small	500	1.2	1.1
Small	3,300	1.8	1.0
Medium	10,000	2.7	1.2
Large	100,000	4.6	2.1
Very large	7,000,000	14.7	5.5

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780).

3.5 Sensitive Life Stages and Other Subpopulations

SDWA 1412(b)(3)(C)(V) requires that the EPA consider "the effects of the contaminant on the general population and on groups within the general population such as infants, children, pregnant women, the elderly, individuals with a history of serious illness, or other subpopulations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population." In 2005, the EPA finalized guidance to differentiate health risk across life stages associated with development and growth (e.g., childhood age groups, pregnancy, and nursing) (USEPA, 2005a). In this analysis, the EPA refers to subpopulations (as defined by the SDWA) that are associated with development and growth as life stages in recognition that all humans were once occupants of early developmental life stages. Chapter 4 identifies the sensitive life stages with respect to perchlorate ingestion. In addition, subpopulations are susceptible to perchlorate health effects due to low iodine intake and other diseases or conditions. These subpopulations include people with thyroid diseases and those with high levels of thiocyanate ingestion. There are approximately 20 million Americans with thyroid diseases (American Thyroid Association, undated).

4 Health Effects and Benefits Analysis

This chapter describes the quantifiable benefits of regulating perchlorate in drinking water, which mainly arise from reduced adverse health impacts. An overview of health effects associated with exposure to perchlorate based on the *Health Effects Technical Support Document* (USEPA, 2019a) is in Section 4.1. Section 4.2 presents the approach and results for quantifying the impact of reduced perchlorate exposure from drinking water based on the subsequent reduction in lost IQ points. Next, Section 4.3 provides a brief discussion of additional potential benefits from reducing perchlorate exposure from drinking water that could not be quantified at this time. Because many of the potential health effects of perchlorate exposure cannot be accurately quantified, the estimated benefits associated only with avoidance of lost IQ are likely an underestimate of the total benefits of a reduction of perchlorate in drinking water.

4.1 Overview of the Health Effects of Perchlorate Exposure

Perchlorate inhibits uptake of iodide into the thyroid gland by competitively binding to the protein that transports iodide from blood to the thyroid gland, the sodium/iodide symporter (NIS) (Greer et al., 2002; NRC, 2005; ATSDR, 2008; SAB 2013; Taylor et al. 2014). Iodide is necessary for the synthesis of thyroid hormones and decreased iodide uptake into the thyroid can adversely affect thyroid hormone production (Blount et al., 2006; Steinmaus et al., 2007, 2013, 2016; SAB, 2013, McMullen et al., 2017; Knight et al., 2018). These changes in thyroid hormone levels in a pregnant woman may be linked to changes in the neurodevelopment of her offspring (SAB, 2013; Korevaar et al., 2016; Fan and Wu, 2016; Wang et al., 2016; Alexander et al., 2017; Thompson et al., 2018). In addition, alterations in thyroid homeostasis may impact other body systems including the reproductive (Hou et al., 2016; Maraka et al., 2016; Alexander et al., 2017) and cardiovascular systems (Asvold et al., 2012; Sun et al., 2017).

More specifically, exposure to perchlorate is known to inhibit the uptake of iodide by the thyroid gland through the NIS (NRC, 2005; SAB, 2013). A sufficient inhibition of iodide uptake results in iodide deficiency within the thyroid. Given that thyroid hormones (triiodothyronine (T3) and thyroxine (T4) require iodide for production, a decrease in intra-thyroidal iodide can result in decreased production of these hormones. This could in turn result in increased thyroid stimulating hormone (TSH), the hormone that acts on the thyroid gland to stimulate iodide uptake to increase thyroid hormone production (Blount et al, 2006; NRC, 2005; Steinmaus et al., 2013, 2016). For populations with developing brains (e.g., fetuses, neonates, and children), disruptions in homeostatic thyroid hormone function can result in adverse neurodevelopmental effects (Glinoer and Delange, 2000; Glinoer and Rovet, 2009; SAB, 2013; Alexander et al., 2017). Specifically, decreased maternal thyroid hormone levels during pregnancy, including in the hypothyroxinemic range,[5] have been linked to decrements in neurocognitive function in offspring (Wang et al., 2016; Alexander et al., 2017; Thompson et al., 2018). There is also limited evidence to suggest an association with other adverse neurodevelopmental outcomes including attention-deficit/hyperactive disorder (ADHD), expressive language delay, reduced school performance, autism, and delayed cognitive development (Pop et al., 2003, 1999;

[5] Maternal hypothyroxinemia is defined as TSH in the reference range and fT4 in the lower percentiles. The SAB notes that hypothyroxinemia has been defined by a "variety of cutoffs…ranging from fT4 below the 10th or 5th percentiles to below the 2.5th percentile" (SAB, 2013, p.10) in the population.

Henrichs et al., 2010; Ghassabian et al., 2011; van Mil et al., 2012; SAB, 2013; Noten et al., 2015; Gyllenberg et al., 2016; Korevaar et al., 2016; Alexander et al., 2017).

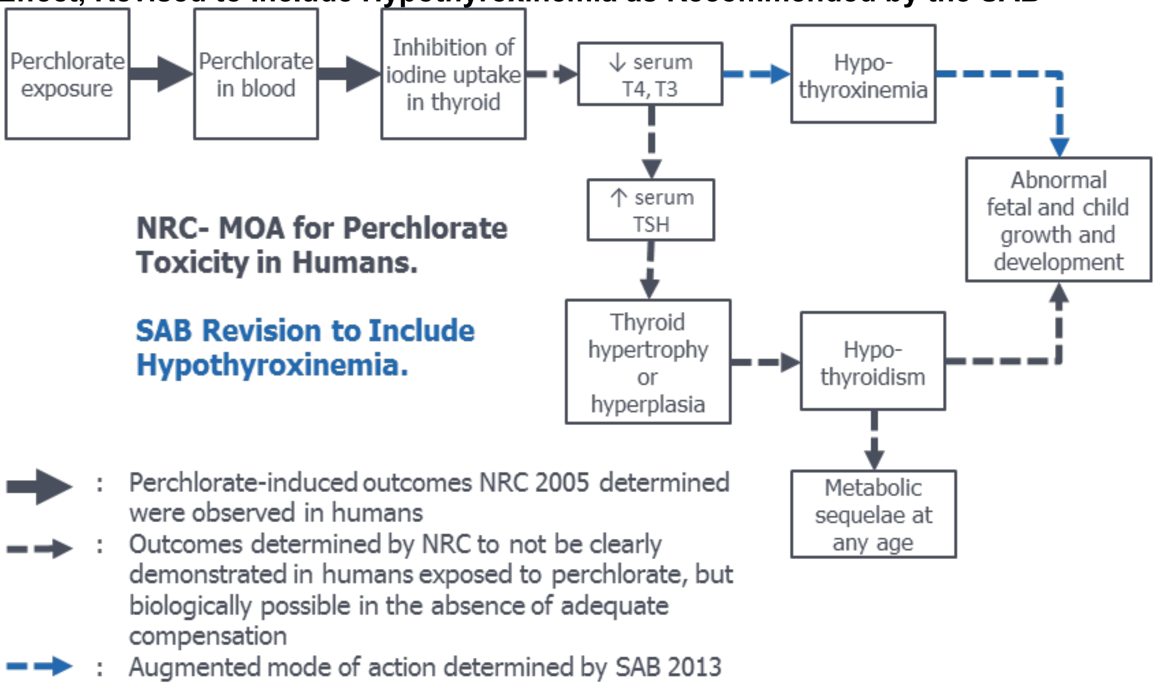
The difficulty in estimating the likelihood and magnitude of the potential implications of perchlorate's mode of action on expressed neurodevelopmental health effects in humans exposed to perchlorate during development is the lack of robust epidemiological studies, especially in sensitive populations. Therefore, based on the known mode of action of perchlorate the agency estimated potential health risks using a novel approach suggested by the EPA's Science Advisory Board (SAB, 2013). The EPA's approach to estimating perchlorate risks has evolved over time with improved research and modeling capabilities.

In 2005, the NRC evaluated the health implications of perchlorate exposure at the request of several Federal agencies. The NRC concluded that perchlorate exposure could inhibit the transport of iodide into the thyroid, leading to thyroid hormone deficiency (NRC, 2005). A significant inhibition of iodide uptake results in intra-thyroid iodide deficiency, decreased synthesis of T3 and T4, and increased TSH. The NRC also concluded that a prolonged decrease of thyroid hormones is potentially more likely to have adverse effects in sensitive populations (e.g., the fetuses of pregnant women who might have hypothyroidism or iodide deficiency). Based on these findings, the NRC recommended a reference dose of 0.7 μg/kg/day.

In support of the EPA Office of Water's analyses related to perchlorate, the EPA's Science Advisory Board (SAB) reviewed the current state of the science on perchlorate and thyroid physiology in 2013 and largely supported the NRC's mode of action (MOA), but revised it to include hypothyroxinemia as an additional outcome to consider (SAB, 2013). Hypothyroxinemia is a condition that is defined as free T4 (fT4; T4 that is not bound to a protein) levels in the lower end of the reference range and normal TSH concentrations; it is not currently a medically treated condition. Both maternal hypothyroxinemia and maternal hypothyroidism during pregnancy have been associated with adverse neurodevelopmental outcomes (i.e., abnormal fetal and child development). (SAB, 2013; Fan and Wu, 2016; Korevaar et al., 2016; Wang et al., 2016; Alexander et al., 2017; Thompson et al., 2018). Exhibit 4-1 presents both the NRC original and SAB modified MOA of perchlorate's thyroid-related adverse health effects.

When the NRC conducted its review of the health effects of perchlorate exposure in 2005, it stated that although none of the steps that follow iodine uptake inhibition in the MOA have been clearly observed in humans, they are biologically plausible (these are demonstrated with the dotted arrows in Exhibit 4-1). Since the 2005 NRC report was published, however, several epidemiological studies have demonstrated an association between perchlorate exposure and changes in serum thyroid hormone levels (Blount et al., 2006; Steinmaus et al., 2013; 2016). Additionally, Taylor et al. (2014) demonstrated the association between high maternal perchlorate exposure and risk of low IQ in offspring.

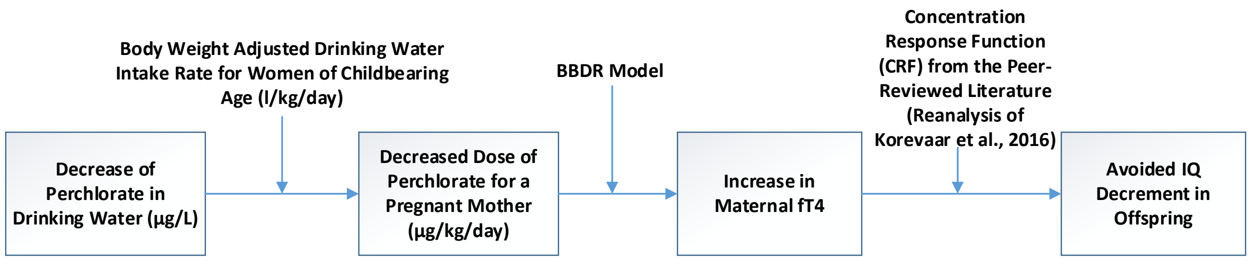
Exhibit 4-1: Modified Representation of NRC's Suggested MOA for Perchlorate Toxicity in Humans Indicating First Adverse Effect in the Continuum of Perchlorate Exposure to Effect, Revised to Include Hypothyroxinemia as Recommended by the SAB



As such, the EPA drew on the MOA proposed by the SAB to estimate benefits from reduced perchlorate exposure as a result of an NPDWR. The EPA took a two-step approach to relate perchlorate exposure to changes in a quantifiable health endpoint. Specifically, the EPA related changes in perchlorate to changes in thyroid hormones in a pregnant woman using a biologically based dose response (BBDR) model, and applied the resulting changes in thyroid hormones to changes in IQ in her offspring using dose-response functions derived from the peer-reviewed literature (USEPA, 2019c). IQ was chosen as a surrogate for subtle neurodevelopmental effects because it is amenable to quantification and monetization. This analysis is underpinned by the appreciable evidence that maternal hypothyroxinemia during pregnancy is related to increase risk of adverse neurodevelopmental outcomes in offspring (Henrichs et al., 2010; Ghassabian et al., 2011; van Mil et al., 2012; Román et al., 2013; SAB, 2013; Noten et al., 2015; Gyllenberg et al., 2016; Alexander et al., 2017). This evidence suggests that minor perturbations in maternal thyroid hormones, in what would be considered a "normal range" in the clinical setting, may increase the risk of altered neurodevelopmental outcomes in offspring, including decreased IQ. A peer-review panel evaluated this multi-step approach in the context of setting an MCLG and concurred with the approach (External Peer Reviewers for USEPA, 2018).

Exhibit 4-2 summarizes the approach taken to evaluate the benefits of avoided decrements in IQ as a result of a reduction in perchlorate exposure due to the proposed MCLs. IQ is the only endpoint currently being monetized in this economic analysis. The EPA has deemed perchlorate not likely to be carcinogenic to humans (USEPA, 2005b), and subsequently no cancer endpoints have been assessed. Additional benefits that may arise from reducing perchlorate exposure but could not be monetized are discussed in Section 4.2.7.

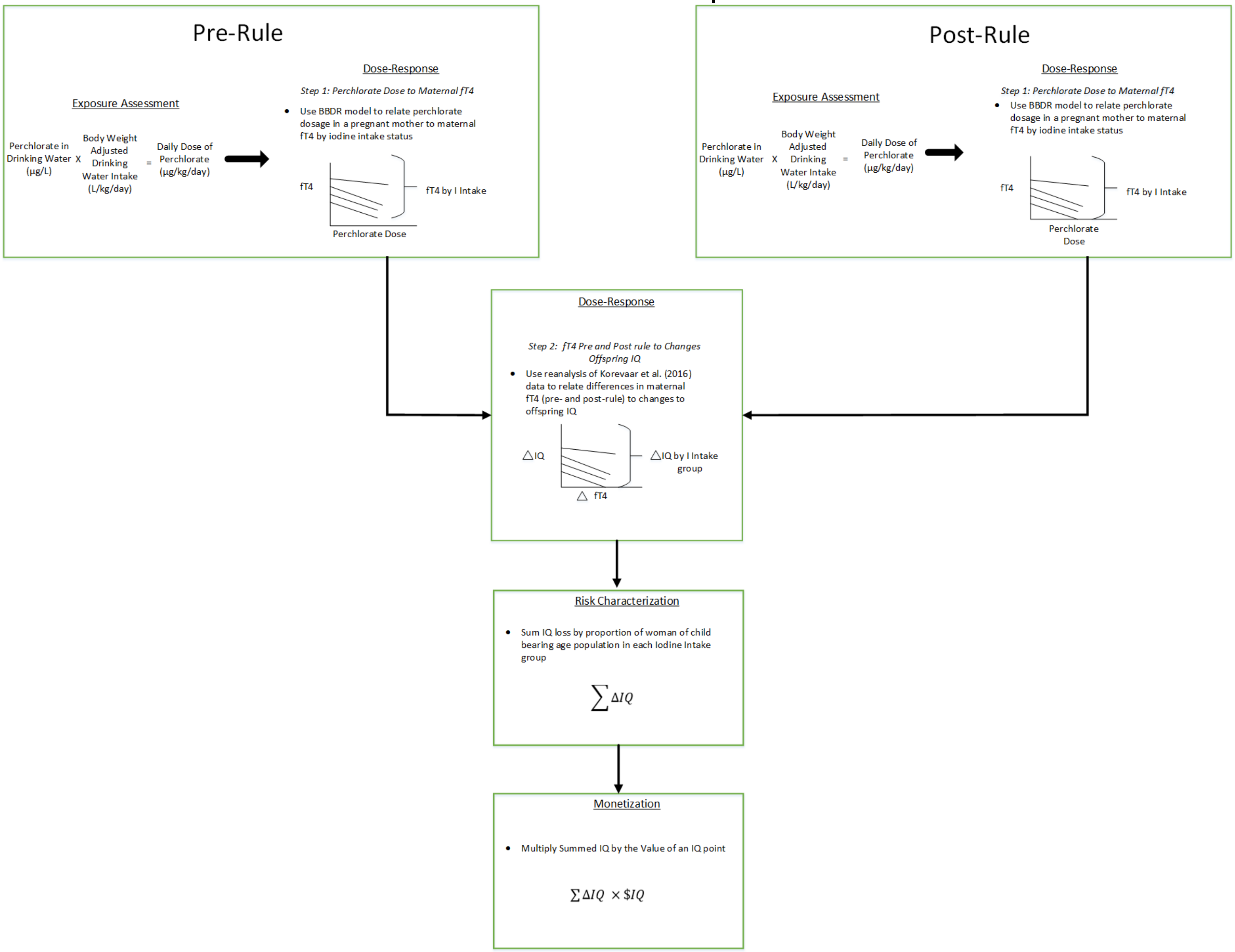
Exhibit 4-2: Overview of the Approach for Estimating Avoided Decrements in IQ in Offspring from Reduced Perchlorate Exposure in a Pregnant Mother



4.2 Quantitative Benefits Assessment

As outlined in Exhibit 4-2, the EPA is utilizing a multi-step process to evaluate the human health-related impacts of perchlorate. Exhibit 4-3 elaborates more on this process. The figure demonstrates that an analysis to determine pre- and post-rule exposures to perchlorate is conducted first, followed by a two-step, dose-response analysis that relates pre- and post-rule perchlorate exposure to pre- and post-rule maternal fT4 levels, which is then translated to a change in offspring IQ and monetized. The dose-response relationship between perchlorate exposure and maternal fT4 is dependent on maternal iodine intake status, and as such this analysis is repeated for several categories of iodine intake. Ultimately, the change in IQ for all iodine intake groups is averaged based on the proportion of individuals in each iodine intake category. Total avoided IQ decrements on an annual basis is estimated over a 35-year timeframe used for the cost analysis described in Chapter 5. Additional details on each step of the benefits analysis are in subsequent sections.

Exhibit 4-3: Overview of Process to Estimate Benefits from Perchlorate Exposure



4.2.1 Exposure Assessment

To assess the benefits of reduced exposure to perchlorate in drinking water, the EPA must first define who is exposed and at what levels. Additionally, the EPA must also define and enumerate the population experiencing quantitative benefits due to the reduction in exposure. Therefore, this section outlines the key inputs to understand who will be exposed and who will experience quantitative benefits, and the amount of perchlorate exposure in both pre- and post-rule scenarios.

4.2.1.1 Perchlorate Occurrence in U.S. Drinking Water

Section 3.4 reports the current occurrence of perchlorate. As a reminder, Exhibit 3-11 and Exhibit 3-13 repeated as Exhibit 4-4 through Exhibit 4-6. These tables summarize the systems impacted when considering maximum perchlorate concentrations at 56 µg/L, 18 µg/L, or 90 µg/L. The concentrations of perchlorate in these systems are the pre-rule exposure concentrations.

Exhibit 4-4: Expected Stage 1 Perchlorate Occurrence Greater than 56 µg/L

Affected Entity	Small Systems	Large Systems	Total Systems
Entry points	0	2	2
Population served	0	32,432	32,432
Water systems	0	2	2
Population served	0	64,733	64,733

Source: USEPA (2019b).

Exhibit 4-5: Expected Stage 1 Perchlorate Occurrence Greater than 18 µg/L

Affected Entity	Small Systems	Large Systems	Total Systems
Entry points	1	16	17
Population served	2,155	618,406	620,560
Water systems	1	14	15
Population served	4,309	696,871	701,180

Source: USEPA (2019b).

Exhibit 4-6: Expected Stage 1 Perchlorate Occurrence Greater than 90 µg/L

Affected Entity	Small Systems	Large Systems	Total Systems
Entry points	0	1	1
Population served	0	25,972	25,972
Water systems	0	1	1
Population served	0	25,972	25,972

Source: USEPA (2019b).

For the post-rule scenario, the EPA assumed that any system exceeding an MCL will include a safety factor of 80 percent when implementing treatment (i.e., treat to 0.8 × MCL) to avoid future MCL exceedances.[6] Therefore, when considering systems that are at or above 18 µg/L, the

[6] Safety factors are commonly used, but the values can vary. For example, the 10 States Standards (Great Lakes - Upper Mississippi River Board of State and Provincial and Public Health and Environmental Managers, 2012) recommends design targets below MCLs, as low as 50 percent for arsenic treatment. The EPA selected 80 percent, which allows a 25 percent excursion from design performance while still achieving compliance.

system is assumed to design and implement treatment to achieve a target of 14.4 μg/L. If the MCL is 56 μg/L, the system is assumed to achieve a target of 44.8 μg/L. If the MCL is 90 μg/L, the system is assumed to achieve a target of 72 μg/L.

4.2.1.2 Drinking Water Consumption Rates

The EPA Exposure Factors Handbook (EFH) (USEPA, 2011b) reports mean, 90th, and 95th percentile bodyweight-adjusted drinking water intakes for pregnant, lactating, and non-pregnant non-lactating women of childbearing age. These figures are reported from the Kahn and Stralka (2008) study, which is based on the Continuing Survey of Food Intakes by Individuals (CSFII) data collected from 1994 to 1996 and 1998. This study estimated bodyweight-adjusted drinking water intake rates for direct and indirect community water ingestion, as well as for direct and indirect water intake from all sources, on both a per-capita and consumers-only basis. As the potential MCLs are specific for the offspring of pregnant women consuming community drinking water, the EPA chose to focus on community drinking water intake estimates on a consumers-only basis as potential inputs. These estimates reported in Table 3-81 in the EFH (USEPA, 2011b), are reproduced in Exhibit 4-7.

Exhibit 4-7: Consumers-Only Estimated Direct and Indirect Community Water Ingestion Rates from Kahn and Stralka (2008) (liters per kilogram per day, L/kg/day)

Women Categories	Sample Size	Mean	90th Percentile	95th Percentile
Pregnant[a]	65	0.014	0.033	0.043
Lactating[a]	33	0.026	0.054	0.055
Non-pregnant, non-lactating, 15 to 44 years of age	2,028	0.015	0.032	0.038

Source: Kahn and Stralka (2008)
a. The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, which covers 1994–1996 (FASEB/LSRO, 1995).

The EPA chose to use exposure factor estimates specific to women of childbearing age in conducting this benefits assessment for the proposed MCL (i.e., non-pregnant, non-lactating, 15–44 years of age). This determination was reached as the calibration of the BBDR model was performed using a population of women of childbearing age from the National Health and Nutrition Examination Survey (NHANES). The EPA has chosen to apply the 90th percentile drinking water intake rate in order to remain consistent with the assumption made in supporting the derivation of the MCLG. Thus, according to Table 3-81 in the EFH (USEPA, 2011b), the bodyweight-adjusted drinking water intake rate for women of childbearing age is 0.032 L/kg/day. The EPA used this intake rate to derive the MCLG and the dose-response equations for the benefits analysis (see Section 4.2.4). This approach results in a protective MCLG value, but may overstate intake for the benefits analysis. On the other hand, the EPA did not include a perchlorate dietary dose in the benefits analysis, which would be unchanged between baseline and proposed MCL scenarios if many areas do not irrigate with drinking water. For people who obtain a significant portion of their fruit, vegetables, and milk from areas irrigated with the water from the same sources as the drinking water, we would expect their exposure to drop with the cleaning of the aquifer. Because of the natural log form of the IQ response function, this approach slightly understates the avoided IQ decrement estimates.

4.2.2 Daily Dose of Perchlorate

By combining the information on the concentration of perchlorate in drinking water from UCMR 1 and the specified drinking water intake rate, it is possible to estimate the daily dose of perchlorate being consumed at each PWS. This dose is estimated by the following equation:

$$D = DW_{ClO_4^-} \times DWI \ ,$$

where:

D = dose of perchlorate (µg/kg/day)
$DW_{ClO_4^-}$ = the concentration of perchlorate in drinking water in µg/L
DWI = the bodyweight-adjusted drinking water intake rate in L/kg/day.

This dose is calculated based on both the pre- and post-rule concentration of perchlorate in drinking water.

4.2.3 Population Impacted

The population impacted by the rule for which benefits can be quantified is specific to live births from mothers who were served by a PWS with perchlorate concentrations at or above the potential MCLs. To determine the nationwide population of children who will experience a quantifiable benefit of avoided IQ decrements from reducing maternal perchlorate exposure during pregnancy, the EPA first estimated the total population being served by systems at or above the MCL based on data from UCMR 1. The EPA then multiplied the total population served for each effected PWS by the proportion of women of childbearing age (aged 15–44) in the United States, which is 19.7 percent (U.S. Census Bureau, 2017b). The number of women of child-bearing age for each PWS was then multiplied by the annual number of live births in the United States, or 62 births per 1,000 women (6.2 percent) (Martin et al., 2017). The resulting impacted population characterized for the monetized benefits is summarized in Exhibit 4-8.

Exhibit 4-8: Size of the Total U.S. Population, Women of Child-Bearing Age, and Live Births Exposed at or above the Potential MCLs to Perchlorate in Drinking Water

Potential MCL (µg/L)	Total at or above MCL (A)	Women of Child-Bearing Age at or above the MCL (B = A x 19.7%)	Annual Live Births Occurring at or above the MCL (C = B x 6.2%)
56	32,432	6,385	396
90	25,972	5,113	317
18 (UCMR 1)	620,560	122,168	7,574
18 (national)[a]	659,547	129,843	8,050

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. The EPA applied statistical sampling weights to the results to extrapolate small system results to national results. The entry point at which a measurement exceeds 18 µg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the 6 UCMR 1 systems in the stratum (40,574). Currently, the stratum population of 774,780 accounts for 1.32% of the 58.7 million national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers (approximately 41,100) may be exposed to perchlorate greater than 18 µg/L. The EPA assumed that this population would incur benefits equivalent to the sampled entry point's population.

These resulting populations were then further divided into the proportion of live births born to women of each level of iodine intake, given that the dose-response relationship between perchlorate and altered maternal fT4 is dependent on the level of daily iodine intake (see Section 4.2.4.1).

The EPA estimated the distribution of iodine intakes of non-pregnant women of childbearing age (ages 20–44) using data from NHANES 2011–2014 (CDC and NCHS, 2011; 2013). This was accomplished by first taking each participant's urinary iodine sample concentration from the NHANES and implementing the data smoothing technique outlined in Pleil and Sobus (2016). This technique accounts for the relative representativeness of a single spot measurement of iodine by predicting an intra-individual geometric mean concentration for each participant. The EPA applied the average of the published intraclass correlation coefficients (ICCs) for urinary spot measurements of iodine from Amouzegar and Azizi (2013) as the basis for this smoothing technique. The EPA then multiplied each participant's predicted geometric mean urinary iodine concentration by their estimated daily urinary output based on their NHANES measured urinary output data. When urinary output data were not available, each missing value was replaced with median urinary output, or 1.33 L/day. The EPA then estimated the proportion of the population of non-pregnant women of childbearing age that fell into each daily iodine intake rate category, as summarized in Exhibit 4-9.

Exhibit 4-9: Proportion of Population Based on Maternal Iodine Intake Status

Iodine Intake Range (μg/day) Used for Benefits Analysis	Proportion of the Population
0 to < 55	7.14%
55 to < 60	2.15%
60 to < 65	1.06%
65 to < 70	1.86%
70 to < 75	1.31%
75 to < 80	3.10%
80 to < 85	2.62%
85 to < 90	1.20%
90 to < 95	1.83%
95 to < 100	2.94%
100 to < 125	13.56%
125 to < 150	9.08%
150 to < 170	10.31%
170 to < 300	24.47%
≥ 300	17.36%

μg/day = micrograms per day.

4.2.4 Dose-Response

The process of connecting maternal perchlorate exposure to offspring IQ decrements requires two steps. The first step relates perchlorate exposure with changes in maternal fT4, and the second step relates the changes in maternal fT4 from the pre- to post-rule to changes in offspring IQ. Each step is described more thoroughly in the subsequent sections.

4.2.4.1 Step 1: Perchlorate Exposure to Changes in Maternal fT4

The EPA developed a BBDR model to describe the impact of perchlorate exposure on maternal fT4 levels in early pregnancy (USEPA, 2019c). This model has two main components: (1) a pharmacokinetic model for perchlorate and iodide, which describes chemical absorption, distribution, metabolism, and excretion of these two anions; and (2) a pharmacodynamic (PD) model, which describes the combined effect of varying perchlorate and iodide blood concentrations on the thyroidal uptake of iodide and subsequent production of thyroid hormones, most significantly T4. The pharmacokinetic portion contains a physiological description (e.g., organ volumes, blood flows) and chemical-specific information (e.g., partition coefficients; volume of distribution; rate constants for transport, metabolism, and elimination) that enable a prediction of perchlorate and iodide internal concentration at the critical target [i.e., thyroidal NIS in association with a particular exposure scenario (route of exposure, age, dose level)]. This portion of the model is similar to other physiologically based pharmacokinetic (PBPK) models and for perchlorate is simplified by the absence of metabolism. The PD portion of the model uses this internal concentration to simulate how the chemical will act within a known mechanism of action to perturb host systems and lead to a toxic effect. Thus, BBDR modeling attempts to predict the internal dose of a chemical associated with a particular exposure scenario, and the perturbation this internal dose can have on host systems.[7]

The BBDR model predicts serum thyroid hormone levels at:

- Specific gestational weeks. The EPA data that connect maternal fT4 concentrations to offspring IQ have a mean week of fT4 data collection of approximately 13 gestational weeks (GWs). Subsequently in this benefits analysis, GW 13 data from the BBDR model have been used.
- A specific TSH feedback loop strength. As the benefits of reducing perchlorate exposure may extend to the entire population exposed, the BBDR model was run with the TSH feedback loop adjusted to its median level.
- Specific levels of iodine intake. Given that the dose-response relationship between perchlorate and fT4 is dependent on daily iodine intake concentrations, the EPA derived dose-response relationships based on BBDR model output for 13 different levels of iodine intake spanning from 50 µg/day to 300 µg/day.

To derive the dose-response functions for each level of daily iodine intake, the EPA first converted each dose of perchlorate that was input into the BBDR model to its equivalent drinking water concentration using the defined drinking water intake rate (see Section 4.2.1.2). Then, the EPA estimated a linear regression function of perchlorate concentration in drinking water on maternal fT4. This was done in order to derive a function specific to each iodine intake group that could be used to estimate the benefits of reduced exposure to perchlorate at any possible water concentration, as opposed to just the water concentrations input into the BBDR model. The R^2 values of each regression analysis were evaluated to confirm the fit of the linear functional relationship between perchlorate and fT4. In all instances the R^2 values were 0.98 or greater, confirming a reasonable predictive power for values in-between the original perchlorate doses input into the BBDR model. The high R^2 values also confirm the linearity of the relationship between fT4 and perchlorate for each iodine intake level in the dose-range evaluated (0 to 10 µg/kg/day).

The BBDR model can only be run at discrete iodine intake levels and, therefore, the results for a single value of iodine intake were assigned to a range of iodine intake values for the purposes of informing a benefits assessment. The functions relating perchlorate to fT4 are summarized in Exhibit 4-10. The raw output from the BBDR model is presented in Appendix A.

[7] For additional information on the BBDR model, refer to Chapter 3 and Appendix A in the *Proposed Approaches to Inform the Derivation of a Maximum Contaminant Level Goal for Perchlorate in Drinking Water* report (EPA, 2019d).

Exhibit 4-10: Effect Estimates Relating Perchlorate in Drinking Water to Changes in fT4 Based on Analysis of BBDR Model Results

Iodine Intake Used for BBDR Model (µg/day)	Iodine Intake Range (µg/day) Used for Benefits Analysis	Intercept	β Relating Perchlorate in Drinking Water (µg/L) to fT4 (pmol/L)
50	0 to < 55	8.26	-0.0008
55	55 to < 60	8.46	-0.0009
60	60 to < 65	8.66	-0.0010
65	65 to < 70	8.85	-0.0011
70	70 to < 75	9.05	-0.0012
75	75 to < 80	9.25	-0.0013
80	80 to < 85	9.45	-0.0015
85	85 to < 90	9.66	-0.0016
90	90 to < 95	9.86	-0.0017
95	95 to < 100	10.04	-0.0017
100	100 to < 125	10.19	-0.0016
125	125 to < 150	10.41	-0.0004
150	150 to < 170	10.47	-0.0002
170	170 to < 300	10.50	-0.0001
300	≥ 300	10.57	-0.00003

Using the inputs in Exhibit 4-10, pre- and post-rule maternal fT4 values are estimated using the following equation:

$$fT4_{i,p} = \beta_i \times P_p + I_i \,,$$

where:

$fT4_{i,p}$ = fT4 concentration for population *p* at iodine intake range *i* (in picomoles per liter, pmol/L)
β_i = β from Exhibit 4-10 for iodine intake range *i*
P_p = perchlorate concentration in drinking water for population *p* (µg/L)
I_i = intercept from Exhibit 4-10 for iodine intake range *i*.

4.2.4.2 Step 2: Maternal fT4 to Offspring IQ

Following the SAB's recommendation, the EPA conducted a literature review to evaluate the most rigorous study or studies to use that associated changes in maternal fT4 to changes in offspring IQ.[8] To identify studies that connected incremental changes in maternal T4 or fT4 to incremental changes in offspring neurodevelopment, the EPA assessed 71 epidemiological studies using a 4-step approach and also assessed the feasibility of conducting de novo analysis on available datasets. Ultimately, the EPA selected its own reanalysis of the Korevaar et al. (2016) dataset to be the basis for the function relating maternal fT4 to offspring IQ. This selection was based on the large sample size of the analysis dataset compared to the other

[8] This process, analysis, and justification of the ultimate selection is presented in Chapters 5 and 6 of the *Proposed Approaches to Inform the Derivation of a Maximum Contaminant Level Goal for Perchlorate in Drinking Water* report (EPA, 2019d).

studies; the ability to control for an appropriate set of confounders; the feasibility of assessing the appropriate dose-response relationship; and the ability to develop a function that is specific to particular ranges of fT4, but span the entire distribution of possible fT4 levels.[9] Based on the EPA's reanalysis, the concentration-response function relating fT4 to IQ is as follows:

When $fT4_1$ and $fT4_0$ are both less than or equal to 11.76 pmol/L[10]:

$$\Delta IQ = (\gamma \times \ln(fT4_1)) - (\gamma \times \ln(fT4_0)) ,$$

where:

> γ = coefficient from the EPA reanalysis of Korevaar et al. (2016), or 17.26 (3.77, 30.75)
> $fT4_1$ = maternal fT4 under the perchlorate rule option in drinking water scenario
> $fT4_0$ = maternal fT4 under the baseline perchlorate concentration in drinking water scenario.

When the fT4 values exceed 11.76, it is assumed that no benefits will accrue. This is based on the fact that the function derived for fT4 levels between 11.76 and 18.94 [the 10th to 90th percentiles from the Korevaar et al. (2016) dataset] does not demonstrate a statistically significant relationship between fT4 and IQ (p-values greater than 0.8). However, given that the BBDR model results estimate the median fT4 to be 10.7 pmol/L with adequate iodine (i.e., iodine intake = 170 µg/day), it is unlikely that any significant benefits based on this cutpoint will be missed.

Combining the fT4 equation in Step 1 of the dose-response function with the ΔIQ equation in Step 2 for each iodine intake range group yields the following full dose-response equation:

$$\Delta IQ = \sum_{i=1}^{15}[([\gamma \times \ln(\beta_i P_{1p} + I_i)] - [\gamma \times \ln(\beta_i P_{0p} + I_i)]) \times IProp_i] ,$$

where:

> γ = coefficient from the EPA reanalysis of Korevaar et al. (2016), or 17.26 (3.77, 30.75)
> β_i = β from Exhibit 4-10 for iodine intake range *i*
> P_{1p} = perchlorate concentration in drinking water (µg/L) under the rule scenario for population *p*
> P_{0p} = perchlorate concentration in drinking water (µg/L) under the baseline scenario for population *p*
> I_i = intercept from Exhibit 4-10 for iodine intake range *i*
> i = iodine intake range group
> $IProp_i$= proportion of population from Exhibit 4-9 in iodine intake range *i*.

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[9] See Chapter 6 of the *Proposed Approaches to Inform the Derivation of a Maximum Contaminant Level Goal for Perchlorate in Drinking Water* report (USEPA, 2019d).

[10] This fT4 value represents untransformed values of the ln(fT4) values at each knot of the spline. The values were obtained by calculating exp(ln(fT4)).

4.2.5 Value of an IQ Point

To determine the value of avoided IQ losses, the EPA used estimates of the change in a child's future expected lifetime earnings per one IQ point reduction. Based on methods developed by Salkever (1995), the EPA estimates that a one point change in IQ results in a 1.865 percent change in lifetime earnings for males and a 3.397 percent change in lifetime earnings for females. The EPA estimated lifetime earnings separately for males and females using average education enrollment and annual earnings from 10 American Community Survey (ACS) Public Use Microdata Sample (PUMS) single-year samples (2008 to 2017) (U.S. Census Bureau, 2017a). Then, the EPA weighted the male and female lifetime earnings by the proportion of the adult population that is male and female, based on life tables from the Social Security Administration (SSA).

Additionally, the EPA adjusted the change in lifetime earnings to account for the decreased average length of education associated with an IQ decrement. Also based on the methods developed by Salkever (1995), the EPA estimated that a one IQ point reduction leads to an average reduction in schooling of 0.0811 years for males and 0.0916 years for females. To estimate the costs associated with the change in educational attainment, the EPA used ACS PUMS enrollment data to determine the level at which the change occurs (i.e. secondary school versus postsecondary school) together with data on educational costs from the Digest of Education Statistics (Snyder and Dillow, 2018). The EPA also adjusted the values to account for lost earnings during the additional educational enrollment.

The net monetized value of a one IQ point change is change in lifetime earnings, net of the change in educational costs and foregone earnings. See Appendix B for a description of the methodology and results.

Exhibit 4-11 summarizes the net value of an IQ point. Estimates are presented in 2017 dollars and are discounted using both a 3 percent and a 7 percent discount rate. The original analysis of the discounted present value of lifetime income differentials associated with a one-point IQ loss (USEPA, 2018f) was discounted to the third year of life to reflect a typical exposure age to lead in dust. For the proposed perchlorate rule, the EPA further discounted the present value of lifetime income differentials three additional years to align the benefits of reduced perchlorate exposure more closely with prenatal exposure. This adjustment does not affect the total value of an IQ point over a lifetime but rather reflects the present value at birth rather than at age three. These revised values are presented in the bolded row in Exhibit 4-11.

Exhibit 4-11: Average Effects of a One-Point Change in IQ on Earnings by Discount Rate and Gender (2017$)

Estimate Parameter	3%, Male	3%, Female	7%, Male	7%, Female
Present value of lifetime earnings, at age 3	$1,069,129	$695,243	$244,738	$164,427
IQ value (percent × lifetime earnings)	$20,008	$23,700	$4,580	$5,605
Additional education costs and lost earnings	$1,352	$1,372	$625	$624
Net value of an IQ point (IQ value less additional education costs and lost earnings) discounted to the third year of life	$18,656	$22,328	$3,955	$4,981
Net value of an IQ point, weighted average[a]		**$20,419**		**$4,448**
Net value of an IQ point, discounted to birth[b]		**$18,686**		**$3,631**

Source: USEPA (2018f, 2019d)

a. The overall estimate for males and females combined is estimated assuming a population that is 52 percent male based on the male:female ratio of births (CDC 2017). Section 6.4.2 provides a sensitivity analysis using an IQ valuation alternative study, Lin et al. (2018)

b. The EPA's reanalysis values developed for lead-related rules reflect avoided IQ decrements that occur at age 3. For benefits associated with reductions in perchlorate exposure, the avoided IQ decrements coincide with live birth. Therefore, the applicable values reflect discounting from age 3 to age zero.

4.2.6 Summary of Benefits due to Avoided IQ Decrements

Following the approach shown in Exhibit 4-3, the EPA used the final equation in Section 4.2.4.2 to estimate entry-point-specific changes in IQ for the entry points with baseline perchlorate greater than the proposed MCL. For each of the 15 iodine intake levels, the EPA estimated fT4 levels for two perchlorate concentrations (baseline and reduced to comply with MCL) using the parameter values in Exhibit 4-10, and calculated the avoided IQ decrement using the gamma value of either 17.26 (central estimate) or 3.77 (lower bound estimate) or 30.75 (upper bound estimate). Then, the EPA used the iodine intake probability weights in Exhibit 4-9 to calculate a weighted average avoided IQ decrement. Finally, for each gamma value, the EPA multiplied the average avoided IQ decrement by the estimate of annual live births given the entry point population. Aggregating the results across the entry points, the EPA estimates between 30 and 243 points of lost IQ will be avoided in the affected populations each year, after full implementation. The EPA estimated the value of these benefits over a 35-year analysis period and accounted for a phase-in of control technology in year 6 for large CWSs and year 9 for all other systems (see Section 5.1). As such, benefits begin to accrue in year 6.

The EPA calculated the present value of total benefits in each year of the analysis period and discounted benefits to year 1 using both a 3 percent and 7 percent discount rate. Exhibit 4-12 through Exhibit 4-14 summarize the results at MCLs of 56 µg/L, 18 µg/L, and 90 µg/L, respectively.

Exhibit 4-12: Annualized Benefits of Avoided IQ Decrements at an MCL of 56 µg/L (millions 2017$)

Gamma Value	Annual Delta IQ[a]	Annual Benefits[b] 3% Discount	Annual Benefits[b] 7% Discount
Upper	243	$3.57	$0.60
Central	136	$2.00	$0.34
Lower	30	$0.44	$0.07

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)
a. Annual change in IQ points in affected population is after full implementation.
b. Annualized benefits are calculated over a 35-year period and account for a phase-in of benefits corresponding to compliance in year 6 for large CWSs and in year 9 for all other systems.

Exhibit 4-13: Annualized Benefits of Avoided IQ Decrements at an MCL of 18 µg/L (millions 2017$)

Gamma Value	Annual Delta IQ[a]		UCMR 1[c]		National[b,c]	
	UCMR 1	National[b]	3% Discount	7% Discount	3% Discount	7% Discount
Upper	442	447	$6.50	$1.10	$6.56	$1.11
Central	248	251	$3.65	$0.62	$3.68	$0.62
Lower	54	55	$0.80	$0.13	$0.80	$0.14

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)
a. Annual change in IQ points in affected population is after full implementation.
b. The EPA applied statistical sampling weights to the results to extrapolate small system results to national results. The entry point at which a measurement exceeds 18 µg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the 6 UCMR 1 systems in the stratum (40,574). Currently, the stratum population of 774,780 accounts for 1.32% of the 58.7 million national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers (approximately 41,100) may be exposed to perchlorate greater than 18 µg/L. The EPA assumed that this population would incur benefits equivalent to the sampled entry point's population.
c. Annualized benefits are calculated over a 35-year period and account for a phase-in of benefits corresponding to compliance in year 6 for large CWSs and in year 9 for all other systems.

Exhibit 4-14: Annualized Benefits of Avoided IQ Decrements at an MCL of 90 µg/L (millions 2017$)

Gamma Value	Annual Delta IQ[a]	Annual Benefits[b] 3% Discount	Annual Benefits[b] 7% Discount
Upper	222	$3.26	$0.55
Central	124	$1.83	$0.31
Lower	27	$0.40	$0.07

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)
a. Annual change in IQ points in affected population is after full implementation.
b. Annualized benefits are calculated over a 35-year period and account for a phase-in of benefits corresponding to compliance in year 6 for large CWSs and in year 9 for all other systems.

4.2.7 Limitations to Benefits Assessment

The quantitative benefits analysis has several limitations. The primary limitation is that it includes only one health endpoint and, therefore, excludes benefits of avoiding other types of adverse health effects of perchlorate exposure. For the evaluated endpoint, the benefit estimates are limited to lifetime earnings impacts and do not include non-earnings benefits of improved cognition. Section 4.3 provides a qualitative discussion of other health effects. Other limitations include the health risks based on maximum recorded concentration estimates do not account for the possibility of exposure to concentrations greater than or less than this maximum concentration assuming that:

- Baseline fT4 is equal to the median likely underestimates disease benefits as the logarithmic relationship between maternal fT4 and child IQ leads to larger relative changes in fT4 with increasing levels of perchlorate with lower levels of baseline fT4, and
- A median TSH feedback loop strength for the exposed population does not incorporate the variability in the feedback mechanism of the body's creation of TSH in response to decreasing fT4.

4.3 Non-Monetized Benefits of Reduced Perchlorate Exposure

The monetized benefits do not include several types of non-quantifiable benefits of reduced perchlorate exposure. These consist of other health effects associated with perchlorate due to its alteration of iodine and thyroid hormone levels (see Section 4.3.2), improved perception of water quality (see Section 4.3.3), and the possibility of reducing other contaminants if perchlorate is reduced (see Section 4.3.4).

4.3.1 Additional Neurological Endpoints Associated with Reduced Iodine and Altered Thyroid Hormones

Given the evidence that perchlorate can alter iodine uptake, evidence examining the impact of reduced or low iodine is relevant in understanding the potential impacts of perchlorate exposure. One such study, a review by Bleichrodt and Born (1994), looked at 18 studies of iodine deficiency and mental development. In a meta-analysis, the authors calculated an effective size of 0.90 for iodine deficiency on cognitive development, indicating the mean scores for the two groups (the iodine-deficient group and the non-iodine-deficient group) were 0.90 of a standard deviation apart, or 13.5 IQ points.

Further, many studies evaluate the relationship between hypothyroxinemia and altered neurodevelopmental outcomes. The body of literature evaluates different populations, at different ages for neurodevelopmental assessment, and at various cut points for fT4 to define hypothyroxinemia, and finds a significant difference in performance on global cognitive tests when comparing the offspring of hypothyroxinemic women to those of non-hypothyroxinemic women (Costeira et al., 2011; Ghassabian et al., 2014; Júlvez et al., 2013; Korevaar et al., 2016; Li et al., 2010; Pop et al., 2003; 1999). These findings are supported by several systematic reviews and/or meta-analyses including Fan and Wu (2016), Wang et al. (2016), and Thompson et al. (2018). Fan and Wu (2016) and Wang et al. (2016) found that hypothyroxinemia was associated with a 5.7 point lower score on intelligence tests and a three-fold increased risk of delayed cognitive development in children, respectively. Thompson et al. (2018) found maternal hypothyroxinemia to be associated with increased risk of cognitive delay, intellectual impairment, or lower scores on performance tests; but they did not find this association with ADHD or autism.

Additionally, studies have related maternal hypothyroxinemia with many of other outcomes, including offspring's increased risk of schizophrenia (Gyllenberg et al., 2016), ADHD (Modesto et al., 2015), expressive language delay (Henrichs et al., 2010), reduced school performance (Noten et al., 2015), increased odds of autism (Román et al., 2013), and more (Finken et al., 2013; Kooistra et al., 2006; Noten et al., 2015; Oostenbroek et al., 2017; Päkkilä et al., 2015; van Mil et al., 2012). These studies demonstrate the sensitivity of the offspring of hypothyroxinemic mothers to adverse neurodevelopmental effects. As such, it can be reasonably concluded that any compound that may reduce maternal fT4, such as perchlorate, can increase the odds of these adverse neurodevelopmental outcomes.

4.3.2 Thyroid Hormone Levels and CVD

Multiple studies have established an association between overt thyroid disorders and CVD risk (Becker, 1985; Boelaert and Franklyn, 2005; Vanhaelst et al., 1967). Additionally, Canaris et al. (2000) found that there are statistically significant trends when examining a person's TSH and T4 levels compared to total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides. Further, Asvold et al. (2007) found that increases in TSH, even within the normal range, can increase an individual's risk of fatal coronary heart disease.

4.3.3 Reduction of Other Co-Occurring Contaminants

Many of the treatment techniques used to remove perchlorate from drinking water could also potentially remove co-occurring contaminants. Removals of co-occurring contaminants vary by technology. For example, the perchlorate-selective anion exchange treatment that EPA used to estimate costs may remove other negatively charged ions such as nitrate, arsenic, and uranium, which are regulated under the SDWA. In an analysis of California drinking water sources, perchlorate was found to co-occur with nitrate, a goitrogen.[11] Although nitrate concentrations were also found to be significantly higher and to occur over a broader geographic area (Kimbrough and Parekh, 2007). Additionally, in a study of 326 ground water samples from "pristine" locations across the contiguous United States, a highly significant positive correlation was found between perchlorate and nitrate concentrations (Parker et al., 2008).

Each of the perchlorate treatment technologies evaluated in this analysis (ion exchange, biological treatment, and reverse osmosis) can also remove co-occurring nitrate (Water Research Foundation, 2014). For biological treatment and reverse osmosis, nitrate removal would be continuous along with perchlorate throughout operation. Ion exchange run to full exhaustion for perchlorate without consideration of nitrate breakthrough, however, could result in a "peaking" situation. Peaking can occur when nitrate adsorbed early in the resin's life is displaced by competing perchlorate, resulting in a treated water concentration of nitrate greater than the influent concentration. Therefore, perchlorate-selective ion exchange would require careful operation to maintain nitrate removal throughout the process. A quantitative evaluation of the

[11] Goitrogens are substances that suppress the function of the thyroid by interfering with iodide uptake, which can cause an enlargement of the thyroid (e.g., a goiter is a swelling of the thyroid).

potential benefits associated with the added advantage of nitrate removal was not included in this benefits assessment.

In the *Office of Inspector General: Scientific Analysis of Perchlorate* (USEPA, 2008b), the EPA suggested that the best approach to conduct a risk assessment for perchlorate would include all four NIS stressors acting on the thyroid: thiocyanate, nitrate, perchlorate, and lack of iodide. Perchlorate is a strong NIS inhibitor; however, exposure to humans may be relatively low. In contrast, nitrate and thiocyanate are weak NIS inhibitors; however, exposure levels to these two chemicals are much greater than perchlorate (USEPA, 2008b). Consequently, reductions of the co-occurring contaminant nitrate could lead to additional health benefits.

4.3.4 Improved Public Perception of Water Quality

PWS customers may avoid using tap water when they believe it is contaminated and poses health risks. When the public perception of water quality declines, consumers purchase bottled water or point-of-use (POU) filters if they have the means to do so.

In addition, or as an alternative, they may avoid the use of tap water, ingesting and cooking with other liquids, substituting pre-mixed baby formula, and using other strategies to limit ingestion. Consumer avoidance of tap water sources usually results in costs to the consumers, either in the cost of obtaining substitute fluids or in potential health impacts of reduced fluid intake.

The relationship between perchlorate in tap water and changes in consumer behavior is a complex one. Factors that impact the choice to avoid tap water depend on public information that is provided on levels of the contamination, potential health effects, individual aversions to risk taking, and other considerations. A quantitative evaluation of these responses and the potential benefits of avoiding associated costs to the consumer or governments is not included in this benefits assessment. Nevertheless, consumers purchase bottled water or invest in other methods of improving drinking water quality, such as POU devices, specifically to avoid ingestion of contaminants such as perchlorate. Thus, it is possible that a reduction in perchlorate contamination may reduce mitigation expenditures.

5 Economic Impact and Cost Analysis

This chapter presents estimates of the total national costs of the proposed perchlorate rule. To estimate the national costs of the rule, the EPA calculated the incremental costs of rule components associated with the proposed rule compared to the current requirements under the SDWA. Specifically, the costs associated with the proposed rule include (1) costs borne by water systems to understand and comply with the new NPDWR, and (2) costs to the primacy agencies to implement and enforce the NPDWR.

Costs to water systems include monitoring costs, treatment costs, and administrative costs. For treatment costs, the EPA identified the treatment technologies that would likely be used to comply with the MCL and estimates capital costs and operating and maintenance (O&M) costs for these technologies (USEPA, 2018e). Administrative costs to water systems include one-time costs to understand the rule and provide training, as well as ongoing costs for activities associated with compliance monitoring (e.g., sampling, applying for waivers, and reporting of compliance results).

Similarly, primacy agencies (states, territories, and tribal nations) incur one-time administrative costs for reading and understanding the rule, and modifying existing regulations. Ongoing administrative costs to primacy agencies include labor costs for reviewing compliance monitoring reports, making determinations on monitoring waivers, and reviewing proposed changes in treatment.

For the analysis of costs, the EPA used the PWS and occurrence data described in Sections 3.3 and 3.4, with exceptions as noted.

Section 5.1 describes the methods used to estimate the monitoring and administration costs for PWSs and primacy agencies. Section 5.2 summarizes methods used to identify systems that may need to control perchlorate to meet the MCL and estimate associated control costs. Section 5.3 presents the total cost results, and Section 5.4 summarizes household-level costs for affected systems with control costs.

5.1 Administrative and Monitoring Costs Method

The proposed rule has several implementation activities that must occur for systems to demonstrate compliance with an MCL. These activities result in the following costs:

- **State administrative costs.** States incur costs associated with adopting and enforcing the NPDWR and administering compliance monitoring programs. Each state must conduct one-time activities: reading and understanding the rule, and modifying existing state regulations. Other state costs accrue per entry point activity, and include reviewing compliance monitoring reports and making determinations on monitoring waivers.
- **Sampling costs.** PWSs incur O&M and labor costs for taking and analyzing a single water sample. The EPA assumes that all PWS size categories are subject to the same per-sample costs. Since these costs are per entry point, the cost per PWS may reflect multiple entry points.

- **Other PWS administrative costs.** Administrative costs may be per PWS or per entry point. Activities that result in administrative costs per PWS include reading the rule and providing training. Administrative costs per entry point include those for applying to the state for a monitoring waiver and reporting of perchlorate compliance monitoring results.

As noted in Section 3.4.1, California and Massachusetts are excluded from the analysis of treatment-related costs and benefits. Nevertheless, the EPA expects that California and Massachusetts will incur one-time administrative costs to read and understand the rule to ensure state regulations are at least as protective. As such, these states are included in the counts and costs for one-time primacy agency costs, but system counts, monitoring, waiver, and control costs exclude these states.

5.1.1 Labor Rates

Because administrative and monitoring activities primarily require labor time, the EPA estimated current labor rates for the cost analysis. State labor rates are based on the 2017 mean hourly wage rate of $31.67 for the Bureau of Labor Statistics (BLS) Standard Occupational Classification code 19-2041 (State Government – Environmental Scientists and Specialists, Including Health; BLS. 2018c). After applying the 60% load factor that the EPA used to estimate burden for the PWS supervision program (USEPA, 2018b), the fully loaded hourly labor rate is $50.67 for states.

To estimate costs to PWSs associated with compliance monitoring and other administrative costs, the EPA used the labor rates in the work breakdown structure (WBS) models for technical staff (i.e., treatment plant operators) and managerial staff (i.e., utility managers for smaller systems and environmental managers for larger systems). The labor rates are in 2017 dollars and include wages and benefits. They vary by occupation and by water system size: technical rates range from $31.91 per hour for systems up to 3,300 people to $43.84 per hour for systems serving more than 100,000 people; and managerial rates range from $45.24 to $71.85 across system size categories. The EPA estimated a weighted average wage rate of $34.71. This average rate incorporates within-size category weights for a mix of managerial and technical labor time based on employment data in the *2006 Community Water System Survey* (USEPA, 2009b), and across-size category weights based on the number of systems. Appendix C provides data and calculation details.

5.1.2 Labor Hours

As described above, PWSs and states will both include monitoring and administrative costs, including one-time costs, and recurring monitoring and waiver application costs. Exhibit 5-1 shows the activities, their frequency, and hours per activity per primacy agencies for each of 55 primacy agencies (including 49 states, 1 tribal nation, and 5 territories). Exhibit 5-2 itemizes the administrative and monitoring activities for PWSs, and shows the frequency and number of hours for each activity.

Exhibit 5-1: Labor Hours for Primacy Agency Administrative Requirements

Activity	Frequency	Hours	Aggregate Hours[a]
Read and understand the rule, adopt regulatory changes[b]	One time per state	416	22,128
Provide training and assistance to PWSs	One time per state	2,080	110,240
Provide training to staff	One time per state	250	13,250
Review waiver applications	Once every 9 years per eligible system	8	849,384
Review monitoring reports	Per monitoring event[c]	1	1,003,410

Source: USEPA (2000a)

a. The total hours for one-time activities equal the value in the Hours column multiplied by 53 states except as noted in table comment b. The total hours for waiver or monitoring report review are per event. The aggregate hour estimates reflect a schedule of events that occur over a 35-year analysis period.

b. The EPA assumed that two states that already regulate perchlorate in drinking water would not incur most of the burdens listed, but included 40 hours for this activity. Thus, the total hours estimate comprises 416 hours for each of 53 primacy agencies and 40 hours for each of 2 states.

c. See Section 5.1.5 for monitoring frequency requirements.

Exhibit 5-2: Labor Hours for Drinking Water Systems' Administrative and Monitoring Requirements

Activity	Frequency	Small Systems		Large Systems	
		Hours per Activity	Aggregate Hours	Hours per Activity	Aggregate Hours
Read the rule[a]	One time per system	4	233,300	4	15,004
Provide training[a]	One time per system	16	933,200	32	120,032
Apply to state for monitoring waiver[b]	Once every 9 years per eligible system	16	1,594,080	16	105,067
Take and analyze a single finished water sample[b]	Per monitoring event[a]	1	806,924	1	196,486

Source: USEPA (2000a)

a. Aggregate hours are the product of hours per activity and the number of small or large systems performing the activity.

b. Total hours are the product of hours per activity and the number of waivers or samples estimated over the 35-year analysis period. See Section 5.1.5 for monitoring frequency requirements.

5.1.3 Analytical Costs for Monitoring

PWSs will also incur analytical costs for each water sample. The EPA assumes that these costs will be in the range of $64 per sample based on an average of costs per sample from laboratories (Eurofins, 2016; TestAmerica Laboratories, 2015; Utah DEQ, 2016).

5.1.4 Costs per Administrative/Monitoring Event

Based on the hours per activity, the labor rates for PWSs and primacy agencies, and the analytical costs for monitoring, the EPA calculated a per-activity cost for PWSs and primacy agencies, as shown in Exhibit 5-3. As noted above, California and Massachusetts are assumed to incur upfront costs to read and understand the rule, but will not incur incremental costs to provide training, or to review waiver applications or monitoring reports.

Exhibit 5-3: Costs per Administrative/Monitoring Event for PWSs and Primacy Agencies

Event	PWS[a]		Primacy Agencies[b]	
	Small	Large	Included	Excluded
Monitoring	$99	$99	$51	$0
Waiver application	$555	$555	$405	$0
Read the rule, provide training, adopt regulatory or programmatic changes	$694	$1,249	$139,140	$2,027

a. The cost estimates equal the average PWS labor cost multiplied by applicable labor hours. The monitoring costs include $64 per sample in addition to labor costs.
b. The cost estimates equal the average primacy agency labor cost multiplied by applicable labor hours.

5.1.5 Number of Monitoring Events

The EPA estimated costs for two phases of perchlorate monitoring: the initial monitoring and long-term monitoring. The Agency assumed that initial perchlorate monitoring requirements would be uniformly implemented during the two 3-year initial monitoring periods. Monitoring requirements vary by size and type of system. Large CWSs will collect initial monitoring samples over four consecutive quarters during the first three years following the effective date. Because the effective date is three years after publication of the rule, this initial monitoring would occur in years four, five, and six of the analysis period. The EPA assumed that one-third of these systems would collect samples per year over three years. Small CWSs and NTNCWSs would collect initial monitoring samples over four consecutive quarters in the subsequent three-year period (i.e., years seven to nine of the analysis period). The EPA assumed that, within these periods, all systems would conduct initial monitoring – one year of quarterly monitoring to determine whether perchlorate concentrations are consistently and reliably below the proposed MCL.

The schedule for long-term monitoring is based on the EPA's Standardized Monitoring Framework for drinking water contaminants (USEPA, 1991; 2004). Under this framework, systems with MCL exceedances would continue to monitor quarterly, while systems below the MCL that obtain waivers will monitor annually for three years (surface water systems) or triennially for nine years (ground water systems), and then incur costs for a waiver application. Thereafter, these systems will continue reduced monitoring – once every nine years – under subsequent waivers. Systems that are below the MCL without waivers will monitor once yearly (surface water systems) or once every three years (ground water systems).

For other inorganic contaminants with MCLs currently in place (e.g., mercury), the EPA assumes that 90 percent of eligible systems with ground water sources apply for and receive system-specific waivers; for eligible systems with surface water sources, this proportion is 40 percent (USEPA, 2008c). The EPA also applied this assumption in this analysis.

Exhibit 5-4 summarizes the timing of expected activities for affected entities based on the requirements. Appendix C provides the estimates of the entry points affected by monitoring requirements per year and the number of systems submitting applications for entry point monitoring waivers by year. It also shows counts of monitoring samples and waiver applications by analysis year and source water.

Exhibit 5-4: Schedule of Administrative Requirements

Year	Primacy Agencies	Large CWS	NTNCWS and Small CWS
1	Read/understand rule, adopt rule, and training		
2			
3			
4	Review monitoring reports and waiver applications	Conduct initial monitoring; implement treatment	
5			
6			
7		Monitor per Standardized Monitoring Framework	Conduct initial monitoring; implement treatment
8			
9			
10			Monitor per Standardized Monitoring Framework
11			
12			
13			
14			
15			
16			
17			
18			
19			
20 and after	↓	↓	↓

The monitoring schedule based on the Standardized Monitoring Framework is per entry point. To estimate the number of monitoring events per PWS, the EPA estimated the average number of entry points for very small, small, medium, large, and very large PWSs (with categories based on the population served) based on the occurrence data (USEPA, 2019b), as described in Section 3.2.2. Exhibit 3-14 summarizes the average number of entry points per PWS based on population served. For PWSs that were included in the occurrence data, EPA used the number of entry points from that dataset. For PWSs not included in the occurrence data, EPA used the average number of entry points based on the population served from Exhibit 3-14.

The EPA estimated the total number of monitoring samples across all entry points from years 4 to 35 of the analysis period shown in Exhibit 5-5 reflect the following phases:

- 1. Initial monitoring; four quarterly samples at every CWS and NTNCWS entry point;

- 2. Preliminary regular monitoring before waiver application: three regular monitoring samples for every CWS and NTNCWS entry point (collected annually at surface water system entry points and triennially at ground water system entry points); and

- 3. Long-term monitoring at either (a) regular monitoring frequency for entry points at systems not granted waivers (60% of surface water system and 10% of ground water systems), or (b) reduced monitoring frequency for entry points at systems receiving waivers from primacy agencies (40% of surface water systems and 90% of ground water systems), which is one sample during every nine-year compliance monitoring cycle.

Exhibit 5-5: Estimates of Compliance Monitoring Samples by Phase and System Type, Size, and Source Water

Monitoring Phase (sampling frequency)	System Type, Size, and Source Water	Number of Entry Points[a]	Aggregate Samples[b]
1. Initial monitoring (4 quarterly samples in one year)	All CWS and NTNCWS	92,656	370,624
2. Preliminary regular monitoring (3 annual entry point samples for surface water systems and 3 triennial entry point samples for ground water systems)	All CWS and NTNCWS	92,654	277,962
3a. Long-term monitoring, no waiver (annual entry point samples)	60% of large surface water CWS	3,324	86,424
	60% of small surface water CWS and all surface water NTNCWS	6,064	139,472
3a. Long-term monitoring, no waiver (triennial entry point samples)	10% of large ground water CWS	680	4,080
	10% of small ground water CWS and all ground water NTNCWS	7,021	35,105
3b. Long-term monitoring, waiver (1 sample every 9 years)	40% of large surface water CWS	2,216	4,432
	40% of small surface water CWS and all surface water NTNCWS	4,043	8,086
3b. Long-term monitoring, waiver (1 sample every 9 years)	90% of large ground water CWS	6,117	12,234
	90% of small ground water CWS and all ground water NTNCWS	63,189	63,189

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780). See Appendix C below for annual sample estimates; totals may differ because of independent rounding.

a. The EPA estimated a total of 92,656 entry points based on the total number of potentially affected systems in SDWIS/FED and the average number of entry points per system in the UCMR 1 data by size category and source water. The initial monitoring phase includes all entry points. The EPA assumed that the two entry points with MCL exceedances at the proposed MCL of 56 μg/L would continue to take quarterly samples for the duration of the analysis period, for a total of 232 samples. Thus, they are excluded from the estimates for the subsequent phases of regular and long-term monitoring. Primacy agencies may, however, allow monitoring to return to a regular schedule if treatment process operation can reliably and consistently reduce perchlorate below the MCL.

b. For Phase 3, the estimate of aggregate samples is the product of the number of entry points and the frequency of sampling during the remaining years of the analysis period. For example, large surface water CWS without a waiver conduct long-term annual monitoring for 26 years because they complete preliminary regular monitoring in year 9. In contrast, large ground water CWS without a waiver begin long-term triennial monitoring in year 16 because their preliminary regular monitoring phase lasts for 9 years (3 triennial samples) instead of 3 years (3 annual samples). The estimates also reflect schedule differences by size because large CWS begin monitoring schedules three years earlier than small CWS and all NTNCWS.

5.2 Control Costs Method

The EPA assumed that the entry points with exceedances will need to implement a control technology to comply with the proposed MCL or alternative MCLs. The cost method overview in this section includes brief technology descriptions (Section 5.2.1), a brief discussion of the Agency's treatment cost estimating tools, and assumptions about compliance options (Section 5.2.2).

5.2.1 Description of Available Control Technologies

The EPA has identified the following technologies as effective for the removal of perchlorate from drinking water:

- Ion exchange;
- Biological treatment;
- Centralized reverse osmosis; and
- POU reverse osmosis.

In addition, non-treatment options such as changing source water might be used in lieu of treatment to comply with a perchlorate standard. The sections below describe each of the technologies and non-treatment options, along with key assumptions and scenarios used to estimate unit costs for each. The document *Technologies and Costs for Treating Perchlorate-Contaminated Waters* (USEPA, 2018e) contains a more complete discussion of the technologies and cost estimating method.

5.2.1.1 Ion Exchange

Ion exchange is a physical/chemical separation process in which an ion (such as perchlorate) in the feed water is exchanged for an ion (typically chloride) on a resin generally made of synthetic beads or gel. A variety of resin types have been tested for perchlorate removal. These resin types include strong-base polyacrylic, strong-base polystyrenic (including nitrate-selective), weak-base polyacrylic, weak-base polystyrenic, and perchlorate-selective.[12]

In application, feed water passes through a bed of resin in a vessel or column. The operation typically continues until the resin is exhausted, meaning that the chloride on enough of the resin's available exchange sites has been replaced with ions from the feed water so that the resin no longer effectively removes the ion. At this point, the resin may be disposed of and replaced or regenerated. The length of time until resin exhaustion and replacement or regeneration is a critical factor in the cost-effectiveness of ion exchange as a treatment technology. It is typically measured by the number of bed volumes of water that can be treated before the breakthrough of perchlorate and can vary based on a variety of factors, including the type of resin used.

Based on data from full-scale operations (USEPA, 2018e), it is likely that most systems using ion exchange to comply with a perchlorate MCL would use a perchlorate-selective resin that would be disposed of, rather than regenerated, when exhausted. The ion exchange unit costs presented here assume the use of perchlorate-selective resin in two scenarios. The first scenario assumes the resin bed treats 250,000 bed volumes before disposal and replacement. The second scenario assumes 170,000 bed volumes. Both scenarios assume disposal of the spent resin by incineration, although some systems might have the slightly cheaper option of landfill disposal available (USEPA, 2018e). The cost estimating method incorporates waste disposal costs. Perchlorate-selective resins are unlikely to remove substantial amounts of co-occurring contaminants because the resins maximize perchlorate removal at the expense of removing co-occurring contaminants like nitrate. Therefore, ancillary benefits are unlikely to occur.

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[12] While Tripp et al. (2003) also examined strong base polyvinylpyridine resins, comparable quantitative data on their removal efficiency are not available.

5.2.1.2 Biological Treatment

Biological treatment of perchlorate uses bacteria to reduce perchlorate to chlorate, chlorite, chloride, and oxygen. Biological treatment offers complete destruction of the perchlorate ion, eliminating the need for management of perchlorate-bearing waste streams. Although biological treatment is a relatively new technology for the treatment of drinking water in the United States, the State of California has identified biological treatment (along with ion exchange) as one of two best available technologies for achieving compliance with its standard for perchlorate in drinking water (California Code of Regulations, Title 22, Chapter 15, Section 64447.2). The first full-scale facility using biological treatment of perchlorate to supply municipal drinking water began operation in 2016 (Webster and Crowley, 2016; Webster and Litchfield, 2017).

The most promising designs for biological treatment of perchlorate at drinking water facilities are those that operate either in a fixed bed or a fluidized bed configuration. Both fixed bed and fluidized bed designs involve a media bed that provides a surface on which perchlorate-reducing bacteria grow. For fixed bed reactors, influent water is typically passed under pressure through a static media bed located in a vessel. An alternative fixed bed design uses a gravity-fed concrete basin to hold the biologically active media. Fluidized bed bioreactor designs use vessels where high influent rates in an up-flow design fluidize the media bed, allowing for more surface area for biomass growth. The biological treatment unit costs presented here consider three design scenarios: a fixed bed using pressure vessels, a fixed bed using gravity basins, and a fluidized bed.

5.2.1.3 Centralized Reverse Osmosis

Membrane filtration processes physically remove perchlorate ions from drinking water. These processes separate a solute such as perchlorate ions from a solution by forcing the solvent to flow through a membrane at a pressure greater than the normal osmotic pressure. The membrane is semi-permeable, transporting different molecular species at different rates. Water and low-molecular weight solutes pass through the membrane and are removed as permeate or filtrate. Dissolved and suspended solids are rejected by the membrane and are removed as concentrate or reject. This technique does not destroy the perchlorate ion and, therefore, creates a subsequent need for disposal or treatment of the perchlorate-contaminated waste (the concentrate).

Membranes may remove ions from feed water by a sieving action (called steric exclusion), or by the electrostatic repulsion of ions from the charged membrane surface. Membrane filtration technologies evaluated for perchlorate treatment include reverse osmosis, nanofiltration, and ultrafiltration. Bench studies of nanofiltration and ultrafiltration membranes show significant variability in these membranes' abilities to remove perchlorate, depending on other constituents of the source water. Across multiple studies, however, reverse osmosis membranes consistently achieve perchlorate removal by up to 95–98 percent (Liang et al., 1998; Nam et al., 2005; Sanyal et al., 2015; Yoon, Amy, et al., 2005; Yoon, Yoon, et al., 2005).

The centralized reverse osmosis unit costs presented here assume the use of relatively low-pressure reverse osmosis membrane elements (consistent with the type of elements shown to be effective in the literature) to remove perchlorate. The designs on which the unit costs are based achieve recovery rates from 70 percent to 85 percent, meaning 15 to 30 percent of the influent water becomes perchlorate-laden concentrate. The unit costs assume discharge of this concentrate to a publicly owned treatment works (POTW). Although it might be impractical for most POTWs to treat very large concentrate flows, this assumption results in more conservative estimates (i.e., erring on the side of higher costs) than surface water (ocean) discharge or deep well injection, options that might be available to a limited number of systems.

5.2.1.4 POU Reverse Osmosis

For perchlorate removal, the National Science Foundation (NSF) Joint Committee on Drinking Water Treatment Units has added a protocol to the *NSF/ American National Standards Institute (ANSI) Standard 58: Reverse Osmosis Drinking Water Treatment Systems* that requires a reverse osmosis unit to be able to reduce perchlorate from a challenge level of 130 µg/L to a target level of 4 µg/L (NSF International, 2004). NSF International, the Underwriters Laboratories, and the Water Quality Association provide third-party testing and certification that POU devices meet drinking water treatment standards. There are no perchlorate certification standards for other types of POU devices such as those using ion exchange media.

The operating principle for POU reverse osmosis devices is the same as centralized reverse osmosis: steric exclusion and electrostatic repulsion of ions from the charged membrane surface. In addition to a reverse osmosis membrane for dissolved ion removal, POU reverse osmosis devices often have a sediment pre-filter and a carbon filter in front of the reverse osmosis membrane, a 3- to 5-gallon treated water storage tank, and a carbon filter between the tank and the tap.

The POU reverse osmosis unit costs the EPA developed (USEPA, 2018e) assume small drinking water systems would purchase, install, and maintain certified POU devices for all customers. When a system installs, controls (i.e., owns), and maintains POU devices at all customer locations where water is consumed (e.g., residences), it can forego centralized treatment (USEPA, 2006a). The costs also include development of a public education program and monitoring of the POU devices.

5.2.1.5 Non-Treatment Alternatives

For small water utilities that lack the financial and/or technical capacity to implement a new treatment-based compliance strategy, non-treatment options may offer a more cost-effective path to compliance. Non-treatment options essentially replace the contaminated water source with water that meets drinking water standards, including the proposed standard for perchlorate.

Non-treatment solutions for drinking water compliance include well rehabilitation, contaminant source elimination, new well construction, and interconnecting with another system to purchase water (USEPA, 2006b). The feasible non-treatment options will depend on site-specific circumstances such as system size, source water type, contaminant reduction needs, and proximity to alternative water sources. For small systems, neither the well rehabilitation for contaminated ground water sources nor source elimination (e.g., remediation of perchlorate-contaminated sediments or ground water) is likely to be a feasible and cost-effective solution. Another option – blending water from existing wells – may be a feasible, low-cost option for systems with multiple wells, including some for which perchlorate does not exceed the proposed perchlorate standard. For systems that cannot blend source water to comply with the proposed standard, two feasible non-treatment options include a new well to replace the contaminated source water and an interconnection to purchase water from a supplier. These two options are likely to have higher costs than the other options (USEPA, 2006b).

The non-treatment unit costs presented here consider two scenarios: interconnecting with another system and drilling a new well to replace a contaminated one. The costs associated with drilling a new well include well casing, screens, plugs, and pumps; well installation; buried piping and valves to connect the new well to the system; and operator labor, materials, and energy for operating and maintaining the well pumps and valves. The interconnection option involves laying a pipeline to connect the affected system to the distribution network of a neighboring system that can provide adequate water that meets all applicable drinking water standards. Costs include construction of a buried interconnecting pipeline and valves, the cost of purchased water, and maintenance of the pipeline.

5.2.2 Treatment Assumptions and Unit Costs

To generate unit costs for the treatment technologies and non-treatment alternatives discussed above, the EPA used its WBS cost-estimating models. The WBS models are spreadsheet-based engineering models for individual treatment technologies that are linked to a central database of component unit costs. Each WBS model contains the work breakdown for a particular treatment process, and preprogrammed engineering criteria and equations that estimate equipment requirements for user-specified design requirements (e.g., system size and influent water quality). Based on these user-specific inputs, each model generates outputs that include total capital cost and annual O&M cost.

The EPA used the WBS models to generate total capital and O&M cost estimates for each technology and non-treatment option for up to 49 different system flow rates. The EPA generated separate estimates that correspond to different water sources (ground water or surface water), three different cost levels (low, mid, and high), and different technology-specific scenarios (e.g., 250,000 or 170,000 bed volumes for ion exchange). The EPA then fit cost equations to the resulting WBS estimates for each scenario modeled, and separately for total capital and O&M costs. The cost equations for total capital costs depend on system peak production or design flow, measured in million gallons per day (MGD). The equations for O&M cost depend on average daily flow in MGD. For each scenario, the EPA fit up to three curves: one covering small systems (less than 1 MGD design flow), one covering medium systems (1 MGD to less than 10 MGD design flow), and one covering large systems (10 MGD design flow and greater). The document *Technologies and Costs for Treating Perchlorate-Contaminated Waters* (USEPA, 2018e) contains a more complete discussion of the WBS models and the cost-estimating approach.

For each entry point in the UCMR 1 dataset, the EPA compared the maximum perchlorate concentration to the MCL, and identified those that have a concentration that exceeds the MCL. These entry points may incur some control costs to comply with the proposed rule. The EPA estimated design and average flows based on entry point populations using the method described in Section 3.3.4 and a blending ratio. Based on the flows, the EPA used the cost curves in *Technologies and Costs for Treating Perchlorate-Contaminated Waters* (USEPA, 2018e) to compare costs across the technologies, which indicated that ion exchange with perchlorate-selective resin was the most cost-effective treatment option.[13] This outcome is consistent with the treatability literature, which contains substantially more full-scale ion exchange treatment plants compared to biological treatment or reverse osmosis. Therefore, the EPA used the capital cost and O&M cost curves to estimate treatment costs using the following assumptions (see USEPA, 2018e for more details):

- perchlorate selective resin with 170,000 bed volumes;
- 95 percent removal effectiveness;
- 80 percent safety factor (e.g., treatment target 14.4 µg/L for an MCL of 18 µg/L); and
- Design and average flow rates reflect the use of blending of treated and non-treated water to meet the treatment target.

Appendix C provides the cost curves used in this analysis. It also contains the formula used to calculate a blending ratio.

5.3 Total Cost Results

The EPA estimated the costs over a 35-year analysis period and assumed that control technologies would be implemented by the end of the initial monitoring phase (e.g., by year six for large CWSs; if small CWSs or NTNCWSs incurred control costs, those costs would be phased in by year nine). The EPA calculated the present value of total costs in each year of the analysis period and discounted to rule finalization using both a 3 percent and 7 percent discount rate. Exhibit 5-6 through Exhibit 5-8 summarize the results at MCLs of 56 µg/L, 18 µg/L and 90 µg/L, respectively.

[13] This approach may overestimate costs for any system that has a lower cost non-treatment option such as drilling a new well or purchasing water. The feasibility of pursuing non-treatment options is highly site-specific.

Exhibit 5-6: Summary of Total Annualized Costs at an MCL of 56 µg/L (millions 2017$)

Cost Component	3% Discount	7% Discount
Drinking water systems costs		
Treatment costs[a]	$0.65	$0.70
Monitoring and administration[b]	$5.93	$6.38
Drinking water systems total	$6.58	$7.07
State costs		
Administration	$3.09	$3.20
Total costs	***$9.67***	***$10.28***

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)
a. The values shown are the mid-cost estimates for the two entry points incurring costs. Low-cost estimates are 1% to 2% lower than the mid-cost estimates at the 3% and 7% discount rates, respectively; the high-cost estimates are 13% to 20% higher across discount rates.
b. Costs include monitoring for all CWSs and NTNCWSs. Some consecutive systems that purchase 100% of their water from wholesale systems may not be required to monitor for perchlorate, provided the states allow integrated system agreements to include perchlorate among the monitoring requirements that the wholesale system fulfills for the consecutive system. The potential number of consecutive systems excluded from perchlorate monitoring depends on the system and state decisions and, therefore, is unknown. Excluding monitoring costs for approximately 8,400 consecutive systems that do not report a water source facility (e.g., well or intake) in SDWIS/FED from the monitoring cost analysis reduces annualized monitoring costs by $0.8 million.
Note: Totals may not sum because of rounding.

Exhibit 5-7: Summary of Total Annualized Costs at an MCL of 18 µg/L (millions 2017$)

Cost Component	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
Drinking water systems costs				
Treatment costs[b]	$6.92	$7.29	$7.92	$8.37
Monitoring and administration[c]	$5.94	$6.38	$5.94	$6.38
Drinking water systems total	$12.85	$13.67	$13.86	$14.75
State costs				
Administration	$3.09	$3.21	$3.09	$3.21
Total costs	***$15.95***	***$16.88***	***$16.95***	***$17.96***

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)
a. The EPA applied statistical sampling weights to the results to extrapolate small system results to national results. The entry point at which a measurement exceeds 18 µg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the six UCMR 1 systems in the stratum. Overall, the stratum population served accounts for 1.32% of the national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers may be exposed to perchlorate greater than 18 µg/L. Based on this population estimate, the EPA calculated per-capita costs for the system and extrapolated them to national levels.
b. The values shown are the mid-cost estimates. Low-cost estimates are 1% to 2% lower than the mid-cost estimates at the 3% and 7% discount rates, respectively; the high-cost estimates are 13% to 20% higher across discount rates.

c. Costs include monitoring for all CWSs and NTNCWSs. Some consecutive systems that purchase 100% of their water from wholesale systems may not be required to monitor for perchlorate, provided the states allow integrated system agreements to include perchlorate among the monitoring requirements that the wholesale system fulfills for the consecutive system. The potential number of consecutive systems excluded from perchlorate monitoring depends on the system and state decisions and, therefore, is unknown. Excluding monitoring costs for approximately 8,400 consecutive systems that do not report a water source facility (e.g., well or intake) in SDWIS/FED from the monitoring cost analysis reduces annualized monitoring costs by $0.8 million.
Note: Totals may not sum because of rounding.

Exhibit 5-8: Summary of Total Annualized Costs at an MCL of 90 µg/L (millions 2017$)

Cost Component	3% Discount	7% Discount
Drinking water systems costs		
Treatment costs[a]	$0.49	$0.52
Monitoring and administration[b]	$5.93	$6.37
Drinking water systems total	$6.42	$6.89
State costs		
Administration	$3.09	$3.20
Total costs	***$9.51***	***$10.10***

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)
a. The values shown are the mid-cost estimates. Low-cost estimates are 1% to 2% lower than the mid-cost estimates at the 3% and 7% discount rates, respectively; the high-cost estimates are 13% to 19% higher across discount rates.
b. Costs include monitoring for all CWSs and NTNCWSs. Some consecutive systems that purchase 100% of their water from wholesale systems may not be required to monitor for perchlorate, provided the states allow integrated system agreements to include perchlorate among the monitoring requirements that the wholesale system fulfills for the consecutive system. The potential number of consecutive systems excluded from perchlorate monitoring depends on the system and state decisions and, therefore, is unknown. Excluding monitoring costs for approximately 8,400 consecutive systems that do not report a water source facility (e.g., well or intake) in SDWIS/FED from the monitoring cost analysis reduces annualized monitoring costs by $0.8 million.
Note: Totals may not sum because of rounding.

5.4 Household Costs

Water systems typically recover control costs through increased household rates, resulting in increased costs at the household level. To calculate the magnitude of this cost increase, the EPA first estimated the number of households that may incur costs as a result of the rule based on the population served by affected PWSs and the state-specific average household size (U.S. Census Bureau, 2017c). For PWSs that are expected to incur control costs, EPA estimates that approximately 23,893 households will bear increase water rates under an MCL of 56 µg/L. Under an MCL of 18 µg/L, 264,361 households would incur control costs. Under an MCL of 90 µg/L, 9,376 households would incur control costs. The EPA divided the total annual PWS-level costs by the number of households served by the system.

Exhibit 5-9 summarizes the results. Appendix C provides this calculation for each entry point expected to incur control costs. This approach may result in an overestimation of household costs because it assumes that all control costs will be passed to residential customers, although some costs may accrue to industrial or commercial customers.

Exhibit 5-9: Summary of Household-Level Annual Control Costs (2017$)

MCL Value and Household-Level Cost Range	3% Discount[a]	7% Discount[a]
MCL = 56 µg/L		
Minimum	$11	$14
Average	$40	$47
Maximum	$69	$80
MCL = 18 µg/L[b]		
Minimum	$18	$24
Average	$38	$46
Maximum	$72	$84
MCL = 90 µg/L		
Minimum	$65	$76
Average	$65	$76
Maximum	$65	$76

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. See Appendix C for detailed calculations for all systems.

b. Note that the household-level costs are the same whether or not the small systems costs are extrapolated because the extrapolation is based on per-capita estimated costs.

6 Comparison of Benefits and Costs

6.1 Introduction

This chapter provides a comparison of benefits and costs for each of the regulatory alternatives. The Agency analyzed the costs and benefits of regulating perchlorate concentrations in drinking water to three different MCL standards. In each instance, the MCL is equal to the corresponding MCLG. The alternative MCLG values reflect different risk thresholds.

6.2 Summary of National Costs and Benefits

6.2.1 National Cost Estimates

National compliance costs to PWSs for treatment (both annualized capital and O&M costs); monitoring and administrative activities; and costs to states, including any one-time start-up costs, for regulatory implementation and enforcement, were estimated and described in Chapter 5. Exhibit 6-1 provides a summary of the national costs for PWSs to comply with the three MCL alternatives for two alternative discount rates.

Exhibit 6-1: Summary of Total Annual Costs by Alternative (2017$)

MCL Alternative	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
Preferred MCL (56 µg/L)	$9.67	$10.28	$9.67	$10.28
Alternative MCL (18 µg/L)	$15.95	$16.88	$16.95	$17.96
Alternative MCL (90 µg/L)	$9.51	$10.10	$9.51	$10.10

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. For the proposed MCL of 56 µg/L and the alternative MCL of 90 µg/L, the national estimates are the same as the estimates based on UCMR 1 data because there were no small system sample results to extrapolate to national small system estimates. For an MCL of 18 µg/L, the EPA applied statistical sampling weights to the results to extrapolate small system results to national results. The entry point at which a measurement exceeds 18 µg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the 6 UCMR 1 systems in the stratum (40,574). Currently, the stratum population of 775,000 accounts for 1.32% of the 58.7 million national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers (approximately 41,100) may be exposed to perchlorate greater than 18 µg/L. Based on this population estimate, the EPA calculated per-capita costs for the system and extrapolated them to national levels.

6.2.2 National Benefits Estimates

Chapter 4 provided a description of the expected health effects benefits of regulating perchlorate and described a method to quantify avoided IQ decrements in offspring born to pregnant women exposed to perchlorate above alternative MCLs. The Agency estimated national benefits based on discounted lifetime differential earnings estimates for one-point IQ decrements. Exhibit 6-2 provides a summary of the national benefits for PWSs to comply with the three MCL alternatives for two alternative discount rates.

Exhibit 6-2: Summary of Annual Control Benefits by Alternative (Central Estimate; 2017$)

MCL Alternative	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
Preferred MCL (56 μg/L)	$2.00	$0.34	$2.00	$0.34
Alternative MCL (18 μg/L)	$3.65	$0.62	$3.68	$0.62
Alternative MCL (90 μg/L)	$1.83	$0.31	$1.83	$0.31

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. For the proposed MCL of 56 μg/L and the alternative MCl of 90 μg/L, the national estimates are the same as the estimates based on UCMR 1 data because there were no small system sample results to extrapolate to national small system estimates. For an MCL of 18 μg/L, the EPA applied statistical sampling weights to the results to extrapolate small system results to national results. The entry point at which a measurement exceeds 18 μg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the 6 UCMR 1 systems in the stratum (40,574). Currently, the stratum population of 775,000 accounts for 1.32% of the 58.7 million national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers (approximately 41,100) may be exposed to perchlorate greater than 18 μg/L.

6.3 Comparison of Benefits and Costs

This section provides three comparisons of benefits and costs: a direct comparison of national incremental costs and benefits, a cost-effectiveness analysis, and a break-even analysis. The comparisons include benefits and costs for the proposed MCL of 56 μg/L and the alternative MCLs of 18 μg/L and 90 μg/L.

6.3.1 National Benefit-Cost Comparison

The impact of the proposed rule on national benefits and costs indicates that promulgating an NPDWR for perchlorate is unlikely to result in positive net benefits. Exhibit 6-3 shows costs, benefits, and net benefits for three MCLs. In all instances, net benefits are negative because costs exceed benefits. The exhibit also shows the incremental costs, benefits, and net benefits between the two MCLs.

Exhibit 6-3: Comparison of Incremental Costs and Benefits for Proposed Rule (millions 2017$)

Item	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
MCL = 56 µg/L				
Total annual costs	$9.67	$10.28	$9.67	$10.28
Total annual quantified benefits	$2.00	$0.34	$2.00	$0.34
Total annual quantified net benefits	-$7.67	-$9.94	-$7.67	-$9.94
MCL = 18 µg/L				
Total annual costs	$15.95	$16.88	$16.95	$17.96
Total annual quantified benefits	$3.65	$0.62	$3.68	$0.62
Total annual quantified net benefits	-$12.30	-$16.26	-$13.27	-$17.34
MCL = 90 µg/L				
Total annual costs	$9.51	$10.10	$9.51	$10.10
Total annual quantified benefits	$1.83	$0.31	$1.83	$0.31
Total annual quantified net benefits	-$7.68	-$9.79	-$7.68	-$9.79
Incremental between 56 and 18 µg/L				
Incremental annual costs	$6.28	$6.60	$7.28	$7.68
Incremental annual quantified benefits	$1.65	$0.28	$1.68	$0.28
Incremental annual quantified net benefits	-$4.63	-$6.32	-$5.60	-$7.40
Incremental between 90 and 56 µg/L				
Incremental annual costs	$0.16	$0.18	$0.16	$0.18
Incremental annual quantified benefits	$0.17	$0.03	$0.17	$0.03
Incremental annual quantified net benefits	$0.01	-$0.15	$0.01	-$0.15

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. For the proposed MCL of 56 µg/L and alternative MCL of 90 µg/L, the national estimates are the same as the estimates based on the UCMR 1 data because there were no small system sample results to extrapolate to national small system estimates. At an MCL of 18 µg/L, national estimates include extrapolation for 1 small system entry point to national estimates based on sampling weights, described above.

Note: There are some slight variations in net benefit differences due to rounding.

6.3.2 Cost-Effectiveness Analysis

Cost-effectiveness analysis provides an alternative way of evaluating costs and benefits. Typically, the analysis involves dividing costs by the quantified benefits such as avoided cases of morbidity. For perchlorate, the EPA considered the cost per avoided IQ decrement. Exhibit 6-4 shows the cost-effectiveness inputs – total annual costs and annual avoided IQ decrements – and the results for the proposed MCL, the two alternative MCLs, and the incremental impact between the preferred MCL and each alternative MCL.

Exhibit 6-4: Costs per IQ Decrement Avoided (millions 2017$)

Item	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
MCL = 56 µg/L				
Total annual costs	$9.67	$10.28	$9.67	$10.28
Annual avoided IQ decrement (central)	136.12	136.12	136.12	136.12
Cost per avoided IQ decrement	$0.07	$0.08	$0.07	$0.08
MCL = 18 µg/L				
Total annual costs	$15.95	$16.88	$16.95	$17.96
Annual avoided IQ decrement (central)	248.20	248.20	250.90	250.90
Cost per avoided IQ decrement	$0.06	$0.07	$0.07	$0.07
MCL = 90 µg/L				
Total annual costs	$9.51	$10.10	$9.51	$10.10
Annual avoided IQ decrement (central)	124.45	124.45	124.45	124.45
Cost per avoided IQ decrement	$0.08	$0.08	$0.08	$0.08
Incremental between 56 and 18 µg/L				
Total annual costs	$6.28	$6.60	$7.28	$7.68
Annual avoided IQ decrement (central)	112.08	112.08	114.78	114.78
Cost change per avoided IQ decrement	-$0.01	-$0.01	$0.00	-$0.01
Incremental between 90 and 56 µg/L				
Total annual costs	$0.16	$0.18	$0.16	$0.18
Annual avoided IQ decrement (central)	11.67	11.67	11.67	11.67
Cost change per avoided IQ decrement	-$0.01	$0.00	-$0.01	$0.00

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. For the proposed MCL of 56 µg/L and the alternative MCL of 90 µg/L, the national estimates are the same as the estimates based on the UCMR 1 data because there were no small system sample results to extrapolate to national small system estimates. At an MCL of 18 µg/L, national estimates include extrapolation for 1 small system entry point to national estimates based on sampling weights, described above.

6.3.3 Break-Even Analysis

When costs exceed benefits, a break-even analysis identifies what level of quantifiable health risk reduction would be needed to generate benefits that equal costs. For perchlorate, the quantifiable and monetizable health endpoint is avoided IQ decrements. Exhibit 6-5 shows the inputs to this analysis are the annual costs and unit values for a 1-point IQ loss reported in Section 4.2.5. Dividing the annual cost by the unit value generates an estimate of the avoided IQ decrements that would be needed for benefits to equal costs. For the proposed and alternative MCLs, these estimates are substantially higher than the estimated rule impact on avoided IQ decrements, for which central estimates are 136.12 for an MCL of 56 µg/L, 248.20 for an MCL of 18 µg/L, and 124.45 for an MCL of 90 µg/L.

Exhibit 6-5: Break-Even Analysis Results (millions 2017$)

Item	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
MCL = 56 µg/L				
Total annual costs	$9.67	$10.28	$9.67	$10.28
Value per IQ point	$0.019	$0.004	$0.019	$0.004
Break-even avoided IQ decrements	487.53	2,674.42	487.53	2,674.42
MCL = 18 µg/L				
Total annual costs	$15.95	$16.88	$16.95	$17.96
Value per IQ point	$0.019	$0.004	$0.019	$0.004
Break-even avoided IQ decrements	853.34	4,648.67	906.89	4,946.09
MCL = 90 µg/L				
Total annual costs	$9.51	$10.10	$9.51	$10.10
Value per IQ point	$0.019	$0.004	$0.019	$0.004
Break-even avoided IQ decrements	509.08	2,780.71	509.08	2,780.71
Incremental between 56 and 18 µg/L				
Total annual costs	$6.28	$6.60	$7.28	$7.68
Break-even avoided IQ decrements	365.81	1,974.25	419.36	2,271.67
Incremental between 90 and 56 µg/L				
Total annual costs	$0.16	$0.18	$0.16	$0.18
Break-even avoided IQ decrements	-21.55	-106.29	-21.55	-106.29

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. For the proposed MCL of 56 and the alternative MCL of 90 µg/L, the national estimates are the same as the estimates based on the UCMR 1 data because there were no small system sample results to extrapolate to national small system estimates. At an MCL of 18 µg/L, national estimates include extrapolation for 1 small system entry point to national estimates based on sampling weights, described above.

6.3.4 Summary of Conclusions

The analysis of costs to implement the proposed rule primarily includes administrative and monitoring costs. The Agency expects very few systems to incur treatment costs to reduce perchlorate from baseline concentrations to comply with the proposed MCL of 56 µg/L or the alternative MCLs of 18 µg/L and 90 µg/L. Because the proposed rule has little impact on drinking water quality, the corresponding health risk reductions are low and estimates of benefits are more than an order of magnitude less than costs.

6.4 Effect of Uncertainties and Non-Quantified Benefit/Cost Estimates on the Estimation of National Benefits and Costs

Estimates of regulatory benefits and costs are subject to a variety of limitations such as data availability and underlying variability. Section 6.4.1 provides an overview of several sources of uncertainty regarding the economic estimates reported above. Section 6.4.2 recognizes that the quantitative benefits analysis is limited to a single health endpoint.

6.4.1 Summary of Major Uncertainties in the Cost and Benefit Analyses

Uncertainties regarding the economic analysis can be grouped into three general categories: baseline occurrence, benefits analysis, and cost analysis. Exhibit 6-6 characterizes the uncertainties and their potential effects on estimated costs and benefits.

Exhibit 6-6: Sources of Uncertainty in Economic Analysis

Description	Potential Effect[a]
Baseline occurrence	
UCMR 1 data are more than one decade old; actual occurrence could be lower (e.g., because of contaminant cleanup) or higher (e.g., because new systems use perchlorate-contaminated source water).	± (benefits and costs will change in the same direction)
UCMR 1 data include a sample of small systems; the Stage 1 results (entry point maximums) indicate that no small systems would exceed 56 µg/L or 90 µg/L and that one small system would exceed 18 µg/L; it is possible that there are additional small systems where the baseline perchlorate is greater than the MCLs that are not captured in the national extrapolation results.	− (benefits and costs will change in the same direction)
The EPA assumed a uniform distribution of system population served across the entry points; the actual entry point service population could be greater than or less than the estimates.	± (benefits and costs will change in the same direction)
Benefits analysis	
The health risks and risk reductions are based on maximum recorded concentration estimates and thus do not account for exposures to concentrations greater than or less than this recorded maximum.	± (benefits only)
The EPA assumed that baseline fT4 is equal to the median, which likely underestimates disease benefits as the logarithmic relationship between maternal fT4 and child IQ leads to larger relative changes in fT4, with increasing levels of perchlorate and lower levels of baseline fT4.	− (benefits only)
The EPA assumed a median TSH feedback loop strength for the exposed population does not incorporate the variability in the feedback mechanism of the body's creation of TSH in response to decreasing fT4.	± (benefits only)
The EPA used a 90th percentile water intake rate to derive the MCLG and the dose-response equations for the benefits analysis. This approach results in a protective MCLG value, but may overstate intake for the benefits analysis.	+ (benefits only)
The benefits analysis is based on a single health endpoint and the value of the endpoint is based solely on lost earnings (see Section 6.4.3).	− (benefits only)

Description	Potential Effect[a]
Cost analysis	
The EPA assumed that systems requiring treatment would incorporate a safety factor – treating to 80% of the proposed MCL or alternative MCLs, which increases costs and benefits.	+ (benefits and costs will change in the same direction)
The EPA assumed that all entry points requiring treatment would implement ion exchange, which may overestimate costs if non-treatment is an option for one or more entry points or underestimate costs if site-specific conditions result in higher costs at one or more entry points.	± (costs only)
The EPA developed a monitoring schedule that assumed a uniform distribution of initial monitoring costs over three years; actual costs will vary.	± (costs only)
The EPA assumed that long-term monitoring costs would occur in the last year of the applicable three-year monitoring period or nine-year monitoring cycle; systems may conduct monitoring in an earlier year of the period or cycle.	− (costs only)
The EPA assumed that 90% of ground water systems and 40% of surface water systems obtained perchlorate monitoring waivers; the actual percentages may vary.	± (costs only)

a. A "−" symbol indicates that benefits and/or costs will tend to be underestimated. A "+" symbol indicates that benefits and/or costs will tend to be overestimated. A "±" symbol indicates an unknown direction of uncertainty (i.e., benefits and/or costs could be underestimated or overestimated).

6.4.2 Sensitivity Analysis

This section provides a sensitivity analysis for the benefits estimates. The sensitivity analysis uses an alternative estimate for the value of an IQ point based on Lin et al. (2018). Below is a comparison of the alternative estimates for benefits and net benefits with the primary estimates, which were based on IQ values from the EPA's reanalysis of Salkever (1995).

Lin et al. (2018) is a recent addition to the IQ valuation literature. Rather than use the Salkever (1995) approach of explicitly modeling the links between IQ, education, and earnings, Lin et al. (2018) modeled a reduced form relationship by including IQ in the earnings equation without controlling for education due its endogeneity. Therefore, the coefficient on IQ captures both the direct effect on earnings and the indirect effect resulting from increased educational attainment. Lin et al. (2018) included three non-cognitive personality traits—sociability, self-esteem, and perceived level of control over one's life. If these variables are correlated with IQ[14], then their inclusion may reduce the estimated effect of IQ on earnings.

The results in Exhibit 6-7 use the preferred Lin et al. (2018) estimates, which are 1.113 and 1.773 percent income reductions for males and females, respectively.[15] Applying these percentages to the estimated lifetime earnings generates lower values for income loss per IQ point. Unlike the estimates based on the Salkever reanalysis, lost earnings while in school are implicitly accounted for in the Lin et al. (2018) IQ effect percentage. Therefore, the only income adjustment is incremental education costs.

[14] Heckman et al. (2006) found positive correlation coefficients among cognitive and non-cognitive scores after controlling for family background and schooling in the NSLY79 data ($\rho = 0.07\text{-}0.21$).

[15] The Lin et al. (2018, footnote 42) parameter estimates can be multiplied by 10/15 to convert them into estimates per IQ point.

Exhibit 6-7: Average Effects of a One-Point Change in IQ on Earnings by Discount Rate and Gender Based on Lin et al. (2018) (2017$)

Estimate Parameter	3%, Male	3%, Female	7%, Male	7%, Female
Present value of lifetime earnings, at age 3[a]	$1,069,129	$695,243	$244,738	$164,427
IQ percent change[b]	1.113%	1.773%	1.113%	1.773%
IQ value (percent × lifetime earnings)	$11,903	$12,329	$2,725	$2,916
Additional education costs and lost earnings[c]	$1,013	$1,147	$473	$524
Net value of an IQ point (IQ value less additional education costs and lost earnings) discounted to the third year of life	$10,890	$11,182	$2,252	$2,392
Net value of an IQ point, weighted average[d]		**$11,030**		**$2,319**
Net value of an IQ point, discounted to birth[e]		**$10,094**		**$1,893**

Source: USEPA (2019d)

a. Lifetime earnings shown in Exhibit 4-11 and described in Appendix B.

b. Percent change in lifetime income based on Lin et al. (2018)

c. Incremental education cost portion (see Appendix B), excluding foregone income.

d. The overall estimate for males and females combined is estimated assuming a population that is 52 percent male based on the male:female ratio of births (CDC 2017). For the reasons described above, the estimated values of an IQ point for males and females based on the Lin et al. estimates are lower than the EPA's reanalysis estimates.

e. The EPA's reanalysis values developed for lead-related rules reflect avoided IQ decrements that occur at age 3. For benefits associated with reductions in perchlorate exposure, the avoided IQ decrements coincide with live birth. Therefore, the applicable values reflect discounting from age 3 to age zero.

Based on the values presented Exhibit 6-8, the EPA estimated revised benefits to compare to those shown in Exhibit 6-2. The revised benefits, shown in Exhibit 6-8 are almost 50 percent lower than the estimates in Exhibit 6-2. Therefore, using the Lin et al., (2018) IQ values results in lower net benefits than using the IQ values based on the EPA's reanalysis of Salkever (1995).

Exhibit 6-8: Summary of Annual Control Benefits by Alternative (Central Estimate; 2017$)

MCL Alternative	UCMR 1		National[a]	
	3% Discount	7% Discount	3% Discount	7% Discount
Preferred MCL (56 μg/L)	$1.08	$0.18	$1.08	$0.18
Alternative MCL (18 μg/L)	$1.97	$0.32	$1.99	$0.32
Alternative MCL (90 μg/L)	$0.99	$0.16	$0.99	$0.16

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. For the proposed MCL of 56 μg/L and the alternative MCl of 90 μg/L, the national estimates are the same as the estimates based on UCMR 1 data because there were no small system sample results to extrapolate to national small system estimates. For an MCL of 18 μg/L, the EPA applied statistical sampling weights to the results to extrapolate small system results to national results. The entry point at which a measurement exceeds 18 μg/L is 1 of 20 in its sample stratum; no other sample in the stratum had a measurement of perchlorate greater than the minimum reporting level. The entry point population of 2,155 represents 5.31% of the total population served by the 6 UCMR 1 systems in the stratum (40,574). Currently, the stratum population of 775,000 accounts for 1.32% of the 58.7 million national population served by small systems. Thus, the UCMR 1 results indicate that 0.07% (5.31% x 1.32%) of small system customers (approximately 41,100) may be exposed to perchlorate greater than 18 μg/L.

6.4.3 Summary of Non-Quantified Costs and Benefits

In addition to the monetized benefits, several other benefits of reducing perchlorate exposure have not been quantified. These consist of other health effects associated with perchlorate due to its alteration of iodine and thyroid hormone levels: additional neurological endpoints related maternal hypothyroxinemia such as the offspring's increased risk of schizophrenia (Gyllenberg et al., 2016), ADHD (Modesto et al., 2015), and expressive language delay (Henrichs et al., 2010); and CVD (Becker, 1985; Boelaert and Franklyn, 2005; Vanhaelst et al., 1967; Canaris et al., 2000; Asvold et al., 2007). Section 4.3.2 provided some discussion regarding these endpoints.

Other benefits that are not associated with health risk reductions include improved perception of water quality (see Section 4.3.3) and the possibility of reducing other contaminants such as nitrate if perchlorate is reduced (see Section 4.3.4). Given the relatively few systems that might need to remove perchlorate, the potential benefits of these impacts are also minimal.

7 Administrative Requirements

This section provides information required by several federal statutes and Executive Orders.

7.1 Executive Order 12866: Regulatory Planning and Review and Executive Order 13563: Improving Regulation and Regulatory Review

Under Executive Order 12866, entitled “Regulatory Planning and Review” (58 FR 51735, October 4, 1993) and reaffirmed by Executive Order 13563, entitled “Improving Regulation and Regulatory Review” (76 FR 3821, January 21, 2011), the Agency must determine whether the regulatory action is “significant” and therefore subject to OMB review and the requirements of the Executive Order. The Order defines “significant regulatory action” as one that is likely to result in a rule that may: (1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities; (2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency; (3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or (4) Raise novel legal or policy issues arising out of legal mandates, the President’s priorities, or the principles set forth in the Executive Order. Although the cost estimates in Chapter 5 do not exceed the annual cost threshold, the EPA determined that this rule is a “significant regulatory action” because it raises novel legal or policy issues. Accordingly, the EPA submitted this action to OMB for review. Changes made in response to OMB recommendations have been documented in the docket for this action.

7.2 Executive Order 13771: Reducing Regulations and Controlling Regulatory Cost

This action is expected to be an Executive Order 13771 regulatory action. Details on the estimated costs of this proposed rule can be found Chapter 5.

7.3 Paperwork Reduction Act

The information collection requirements in this proposed rule have been submitted for approval to OMB under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq*. The information collection requirements are not enforceable until OMB approves them.

The information collected as a result of this rule will allow the States and the EPA to evaluate compliance with the rule. For the first 3-year period following rule promulgation, the major information requirements concern primacy agency activities to implement the rule. Compliance actions for drinking water systems (including monitoring, administration, and treatment costs) do not begin until after Year 3.

The estimate of annual average burden hours for the proposed rule during the first three years following promulgation is 48,539 hours. The annual average cost estimate is $7.4 million for labor. The burden hours per response is 2,648 hours and the cost per response is $134,159. The frequency of response (average responses per respondent) is one for primacy agencies, annually (for upfront administrative activities to implement the rule). The estimated number of likely respondents is 55 over the three year period (for an average of 18.3 each year).

Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information.

An agency may not conduct or sponsor, and a person is not required to respond to a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

7.4 Regulatory Flexibility Act

The Regulatory Flexibility Act (RFA) of 1980, as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996, generally requires an agency to prepare an initial regulatory flexibility analysis for any proposed rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of today's proposed rule on small entities, the EPA considered small entities to be public water systems serving 10,000 or fewer persons. This is the threshold specified by Congress in the 1996 Amendments to the Safe Drinking Water Act for small system flexibility provisions. In accordance with the RFA requirements, the EPA proposed using this alternative definition in the *Federal Register*, (63 FR 7620, February 13, 1998), requested public comment, consulted with the Small Business Administration (SBA), and expressed its intention to use the alternative definition for all future drinking water regulations in the Consumer Confidence Reports regulation (63 FR 44511, August 19, 1998). As stated in that final rule, the alternative definition is applied to this proposed regulation.

The proposed rule contains provisions that will affect 58,325 CWS and NTNCWS serving 10,000 or fewer people. To meet the proposed rule requirements, all of these systems will need to conduct perchlorate monitoring. At the proposed MCL of 56 µg/L, the UCMR 1 monitoring data indicate that no small systems would incur costs to reduce the levels of perchlorate in drinking water. Therefore, all small PWSs will incur monitoring costs only, as shown in Exhibit 7-1.

Exhibit 7-1: Number of PWSs by Size and Ownership

Owner Type	Number of Systems			With Control Costs			Monitoring Costs Only		
	Total	Large	Small	Total	Large	Small	Total	Large	Small
Public/other[a]	30,181	3,366	26,815	2	2	0	30,179	3,364	26,815
Private	31,895	385	31,510	0	0	0	31,895	385	31,510
Total	62,076	3,751	58,325	2	2	0	62,074	3,749	58,325

a. Includes the following owner types: local, state, and federal government, Native American, public/private, and missing owner type for some NTNCWS.

Total annual monitoring and administrative costs for PWSs are approximately $6.6 million to $7.1 million (Exhibit 5-5), with $5.1 million to $5.5 million accruing to small PWSs. Based on 58,325 small systems, this yields an average annual per-system cost of $88 (3% discount rate) to $94 (7% discount rate).

The EPA compared the average annualized costs to revenue estimates that vary by system type and size category. The 2006 Community Water System Survey (CWSS; USEPA, 2009b) reports revenues for four small size categories of both public and private systems. Exhibit 7-2 provides a comparison of public system revenues and average annualized costs. The comparison of private system revenues and costs is in Exhibit 7-3. Based on the cost-to-revenue ratios shown in the tables, the EPA does not expect small entities to incur costs that exceed one percent of revenue.

Exhibit 7-2: Annualized Monitoring and Administrative Costs as a Percentage of Average Annual Revenue for Small Public CWSs by Size Category

Size Category	Average Annual Revenues[a]	3% Discount	7% Discount
Population served <100	$224,248	$88 (0.04%)	$94 (0.04%)
Population served 101-500	$197,315	$88 (0.04%)	$94 (0.05%)
Population served 501-3,300	$202,382	$88 (0.04%)	$94 (0.05%)
Population served 3,301-10,000	$1,092,187	$88 (0.01%)	$94 (0.01%)

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. Based on the CWSS (USEPA, 2009b Table 65) and updated to 2017$ based on the chained consumer price index for fuels and utilities in U.S. city average, all urban consumers (BLS, 2018a). Revenues include all sources of revenue including water revenue, non-water revenue, and municipal transfers to water systems.

Exhibit 7-3: Annualized Monitoring and Administrative Costs as a Percentage of Average Annual Revenue for Small Private CWSs by Size Category

Size Category	Average Annual Revenues[a]	3% Discount	7% Discount
Population served <100	$139,911	$88 (0.06%)	$94 (0.07%)
Population served 101-500	$351,974	$88 (0.03%)	$94 (0.03%)
Population served 501-3,300	$254,706	$88 (0.03%)	$94 (0.03%)
Population served 3,301-10,000	$951,692	$88 (0.01%)	$94 (0.01%)

Source: Perchlorate Benefit-Cost Analysis Spreadsheet, which is available in the proposed rule docket (EPA-HQ-OW-2018-0780)

a. Based on the CWSS (USEPA, 2009b Table 65) and updated to 2017$ based on the chained consumer price index for fuels and utilities in U.S. city average, all urban consumers (BLS, 2018a). Revenues include all sources of revenue including water revenue and non-water revenue.

7.5 Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), Public Law 104–4, establishes requirements for federal agencies to assess the effects of their regulatory actions on State, local, and tribal governments and the private sector. Under section 202 of UMRA, the EPA generally must prepare a written statement, including a cost-benefit analysis, for proposed and final rules with "federal mandates" that may result in expenditures to State, local, and tribal governments, in the aggregate, or to the private sector of $100 million or more in any one year, adjusted annually for inflation, or $156 million based on the most recent guidance (U.S. Department of Transportation, 2016).

Based on the cost estimates detailed in Chapter 5, the EPA determined that compliance costs in any given year will be below the threshold set in UMRA, with maximum single-year costs of approximately $10.2 million. The EPA has determined that this rule does not contain a federal mandate that results in expenditures of $100 million or more for State, local, and tribal governments, in the aggregate, or the private sector in any one year.

7.6 Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order 12898, entitled "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (59 FR 7629, February 16, 1994), establishes federal executive policy on environmental justice. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority and low-income populations in the United States.

The EPA has determined that this proposed rule would not have a disproportionately high and adverse human health or environmental effects on minority or low-income populations because it would increase the level of environmental protection for all affected populations without having any disproportionately high and adverse human health or environmental effects on any population including any minority or low-income population.

7.7 Executive Order 13045: Protection of Children from Environmental Health Risks and Safety Risks

Executive Order 13045, entitled "Protection of Children from Environmental Health Risks and Safety Risks" (62 FR 19885, April 23, 1997), applies to any rule that: (1) Is determined to be "economically significant" as defined under Executive Order 12866, and (2) concerns an environmental health or safety risk that the EPA has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, the Agency must evaluate the environmental health or safety effects of the planned rule on children and explain why the planned regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the Agency.

This proposed rule is not "economically significant" as defined under Executive Order 12866; however, the environmental health risk addressed by this action may have a disproportionate effect on children. Accordingly, and consistent with Executive Order 13045 and the EPA's Policy on Evaluating Health Risks to Children (USEPA, 2018c), the EPA evaluated the environmental health or safety effects of perchlorate on children.. The results of this evaluation are contained in the *Health Effects Technical Support Document* (USEPA, 2019a) and described in Chapter 4. The EPA has evaluated the risk associated with perchlorate in drinking water for the sensitive population – offspring of pregnant women exposed to perchlorate during the first trimester – and established a proposed MCLG that is protective of this population as well as other children. The EPA has also estimated the health risk reduction of the proposed and alternative MCLs. This analysis is described in Chapter 4.

7.8 Executive Order 13132: Federalism

Executive Order 13132, entitled "Federalism" (64 FR 43255, August 10, 1999) requires the EPA to develop an accountable process to ensure "meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications." "Policies that have federalism implications" is defined in the Executive Order to include regulations that have "substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government."

Under Executive Order 13132, the EPA may not issue a regulation that has federalism implications, that imposes substantial direct compliance costs, and that is not required by statute, unless the federal government provides the funds necessary to pay the direct compliance costs incurred by State and local governments, or the EPA consults with State and local officials early in the process of developing the proposed regulation.

The EPA has concluded that this proposed rule does not have federalism implications. It will not have substantial direct effects of greater than $25 million on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government. Annual costs are estimated to range from $9.67 million at a 3 percent discount rate to $10.28 million using a 7 percent, with $6.5 million to $7.0 million annually accruing to public entities. The EPA has concluded that this proposed rule may be of interest because it may impose direct compliance costs on State or local governments, and the federal government will not provide the funds necessary to pay those costs.

7.9 Executive Order 13175: Consultation and Coordination with Indian Tribal Governments

Executive Order 13175, entitled "Consultation and Coordination with Indian Tribal Governments" (65 FR 67249, November 9, 2000) requires the EPA to develop "an accountable process to ensure meaningful and timely input by Tribal officials in the development of regulatory policies that have Tribal implications." The definition of "policies that have Tribal implications" includes regulations that have "substantial direct effects on one or more Indian tribes, on the relationship between the federal government and the Indian Tribes, or on the distribution of power and responsibilities between the Federal government and Indian Tribes." Under Executive Order 13175, the EPA may not issue a regulation that has Tribal implications, that imposes substantial direct compliance costs, and that is not required by statute, unless the federal government provides the funds necessary to pay the direct compliance costs incurred by Tribal governments, or the EPA consults with Tribal officials early in the process of developing the proposed regulation and develops a Tribal summary impact statement.

The EPA has concluded that this proposed rule may have Tribal implications, because it may impose direct compliance costs on Tribal governments, and the federal government would not provide the funds necessary to pay those costs. The EPA has identified 768 water systems with 1,167 entry points under Native American ownership that may be subject to the proposed rule. They would bear an estimated total annualized cost of $74,100 at a 3 percent discount rate ($79,625 at 7 percent) to implement this rule as proposed, with all costs attributable to monitoring and administrative costs. Estimated average annualized cost per system ranges from $96 at a 3 percent discount rate to $104 at a 7 percent discount rate.

Accordingly, the EPA provides the following Tribal summary impact statement as required by section 5(b) of Executive Order 13175. The EPA notes that 751 of the 768 Tribal systems identified by the Agency as subject to the proposed rule are small systems that are expected to incur only monitoring costs. Due to the health risks associated with perchlorate, capital expenditures needed for compliance with the rule would be eligible for federal funding sources, specifically the Drinking Water State Revolving Fund.

7.10 Executive Order 13211: Actions Concerning Regulations that Significantly Affect Energy Supply, Distribution, or Use

This rule is not a "significant energy action" as defined in Executive Order 13211, entitled "Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use" (66 FR 28355, May 22, 2001), because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. This determination is based on the following analysis.

The first consideration is whether the proposed rule would adversely affect the supply of energy. The proposed rule does not regulate power generation, either directly or indirectly. The public and private water systems that the proposed rule regulates do not generate power. Further, the cost increases borne by customers of water utilities as a result of the proposed rule are a low percentage of the total cost of water, except for a few water systems that might install treatment technologies and would likely spread that cost over their customer base. In sum, the proposed rule does not regulate the supply of energy, does not generally regulate the utilities that supply energy, and is unlikely to affect significantly the customer base of energy suppliers. Thus, the proposed rule would not translate into adverse effects on the supply of energy.

The second consideration is whether the proposed rule would adversely affect the distribution of energy. The proposed rule does not regulate any aspect of energy distribution. The water systems that are regulated by the proposed rule already have electrical service. At the proposed MCL, one entry point at one system may require incremental power to operate new treatment processes. The increase in peak electricity demand at water utilities is negligible. Therefore, the EPA estimates that the existing connections are adequate and that the proposed rule has no discernable adverse effect on energy distribution.

The third consideration is whether the proposed rule would adversely affect the use of energy. Because only one system is expected to add treatment technologies that use electrical power, this potential impact on sector demand or overall national demand for power is negligible.

Based on its analysis of these considerations, the EPA has concluded that proposed rule is not likely to have a significant adverse effect on the supply, distribution, or use of energy.

7.11 National Technology Transfer and Advancement Act of 1995

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (NTTAA), Public Law 104–113, 12(d) (15 U.S.C. 272 note) directs the EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (e.g., materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs the EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards. The proposed rulemaking involves technical standards. The proposed rule could involve voluntary consensus standards in that it would require monitoring for perchlorate. The EPA proposed five analytical methods for the identification and quantification of perchlorate in drinking water. EPA methods 314.0, 314.1, 314.2, 331.0, and 332.0 incorporate quality control criteria that allow accurate quantitation of perchlorate.

The EPA's monitoring and sampling protocols generally include voluntary consensus standards developed by agencies such as ASTM International, Standard Methods and other such bodies wherever the EPA deems these methodologies appropriate for compliance monitoring.

7.12 Impacts on Sensitive Subpopulations and Life Stages

Section 1412(b)(3)(C)(i) of the SDWA requires that the EPA evaluate the effects of a contaminant on the general population and on potentially sensitive subpopulations such as infants, children, pregnant women, the elderly, individuals with a history of serious illness, or other sub-populations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population. For the proposed perchlorate rule, the EPA based the proposed MCLG and the benefits analysis in Chapter 4 on a sensitive life stage – the offspring of pregnant women exposed to perchlorate during their first trimester. The Agency determined that an MCLG protective of this sensitive life stage would also be protective of other sensitive life stages. See Chapter 4 for a discussion of the MCLG development method.

7.13 Consultations with the Science Advisory Board, National Drinking Water Advisory Council, and the Secretary of Health and Human Services

In accordance with sections 1412 (d) and 1412 (e) of the SDWA, the Agency consulted with the National Drinking Water Advisory Council (NDWAC or the Council); the Secretary of Health and Human Services (HHS); and with the EPA SAB. The Agency consulted with NDWAC during the Council's October 4-5, 2012 meeting. A summary of the NDWAC recommendations is available in the Fall 2012 Meeting Summary Report (NDWAC, 2012) and the docket for this proposed rule. The EPA carefully considered NDWAC recommendations during development of a proposed drinking water rule for perchlorate.

On May 29, 2012, the EPA sought guidance from the EPA SAB on how best to consider and interpret life stage information, epidemiological and biomonitoring data since the publication of the National Research Council 2005 report, the Agency's PBPK analyses, and the totality of perchlorate health information to derive an MCLG for perchlorate (NRC, 2005; USEPA, 2012). On May 29, 2013, the EPA received significant input from SAB, summarized in the report, *SAB Advice on Approaches to Derive a Maximum Contaminant Level Goal for Perchlorate* (SAB , 2013).

On July 15, 2013, the EPA responded by stating that the Agency would consider all the recommendations from the SAB, as it continued working on the development of the rulemaking process for perchlorate (SAB, 2013). To address SAB recommendations, the EPA collaborated with Food and Drug Administration (FDA) scientists to develop PBPK/PD, or BBDR, models that incorporate all available health-related information on perchlorate to predict changes in thyroid hormones in a sensitive life stages exposed to different dietary iodide and perchlorate levels (USEPA, 2019c). As recommended by SAB, the EPA developed these models based upon perchlorate's MOA (i.e., iodide uptake inhibition by the thyroid; SAB, 2013). Additional details are in the *Health Effects Technical Support Document* (USEPA, 2019a) and described above in chapter 4.

In accordance with SAB recommendations, the EPA developed a two-stage approach to integrate BBDR model results with data on neurodevelopmental outcomes from epidemiological studies, this approach allowed the Agency to link maternal thyroid hormones levels as a result of low iodine intake and perchlorate exposure, to derive an MCLG that directly addresses the most sensitive life stage (SAB, 2013).

On March 25, 2019, the EPA consulted with the HHS. The EPA provided information to HHS officials on the draft proposed perchlorate regulation and considered HHS input.

7.14 Technical, Financial, and Managerial Capacity of Public Water Systems

The EPA considered whether the regulated CWS and NTNCWS would have the technical, financial, and managerial capacity to implement the proposed rule as required by Section 1420(d)(3) of the SDWA. Because the vast majority of the systems would only be required to conduct periodic monitoring for perchlorate, the Agency determined that the affected systems should have the capacity to comply with the rule. Very few systems are expected to require additional treatment to meet the proposed MCL. All of these systems are large systems, which are more likely than small systems to have the capacity to implement treatment.

7.15 National Affordability Determination

The EPA determined that there are several affordable treatment technologies for small systems. The determination, documented in *Best Available Technologies and Small System Compliance Technologies for Perchlorate in Drinking Water* (USEPA, 2019a), compared the estimated incremental treatment costs per household with a baseline expenditure margin that equals 2.5 percent of median household income minus baseline drinking water utility per household. Exhibit 7-4 shows which technologies satisfy the affordability criterion for three small system size categories. For the smallest system size category, ion exchange and point-of-use reverse osmosis are affordable technologies, but biological treatment and centralized reverse osmosis are not.

Exhibit 7-4: Proposed Small System Compliance Technologies for Perchlorate Removal

System Size (population served)	Ion Exchange	Biological Treatment	Reverse Osmosis	Point-of-Use Reverse Osmosis
25–500	Yes	No	No	Yes
501–3,300	Yes	Yes	Yes	Yes
3,301–10,000	Yes	Yes	Yes	Not applicable[a]

a. EPA's WBS cost model for POU treatment does not cover systems larger than 3,300 people (greater than 1 MGD design flow).because implementing and maintaining a large-scale POU program in lieu of central treatment for perchlorate is likely to be impractical.

7.16 The Small System Compliance Technology (SSCT) Listed in National Affordability Determination

The EPA determined that there are several affordable treatment technologies for small systems. The determination, documented in *Best Available Technologies and Small System Compliance Technologies for Perchlorate in Drinking Water* (USEPA, 2019a), compared the estimated incremental treatment costs per household with a baseline expenditure margin that equals 2.5 percent of median household income minus baseline drinking water utility per household. Exhibit 7-5 shows which technologies satisfy the affordability criterion for three small system size categories. For the smallest system size category, ion exchange and point-of-use reverse osmosis are affordable technologies, but biological treatment and centralized reverse osmosis are not.

Exhibit 7-5 include a POU version of reverse osmosis. Although this technology is not a proposed BAT, it can meet the proposed MCL and, therefore, meets the effectiveness requirement for an SSCT. For perchlorate removal, the NSF Joint Committee on Drinking Water Treatment Units added a protocol to NSF/ANSI Standard 58: Reverse Osmosis Drinking Water Treatment Systems that requires a reverse osmosis unit to be able to reduce perchlorate from a challenge level of 130 µg/L to a target level of 4 µg/L (NSF International, 2004). Organizations (e.g., NSF International, Underwriters Laboratories, Water Quality Association) provide third-party testing and certification that POU devices meet drinking water treatment standards. There are no perchlorate certification standards for other types of POU devices such as those using ion exchange media.

The operating principle for POU reverse osmosis devices is the same as centralized reverse osmosis: steric exclusion and electrostatic repulsion of ions from the charged membrane surface. In addition to a reverse osmosis membrane for dissolved ion removal, POU reverse osmosis devices often have a sediment pre-filter and a carbon filter in front of the reverse osmosis membrane, a 3- to 5-gallon treated water storage tank, and a carbon filter between the tank and the tap.

The EPA identified the SSCT using the affordability criteria it developed for drinking water rules (USEPA, 1998). The analysis method is a comparison of estimated incremental household costs for perchlorate treatment to an expenditure margin, which is the difference between baseline household water costs and a threshold equal to 2.5 percent of median household income. Exhibit 7-5 shows the expenditure margins derived for the analysis.

Exhibit 7-5: Expenditure Margins for SSCT Affordability Analysis

System Size (population served)	Median Household Income[a] (a)	Affordability Threshold[b] (b) = 2.5% x a	Baseline Water Cost[c] (c)	Expenditure Margin (d) = b - c
25-500	$52,791	$1,320	$341	$979
501-3,300	$51,093	$1,277	$395	$883
3,301-10,000	$55,975	$1,399	$412	$987

Source: *Best Available Technologies and Small System Compliance Technologies for Perchlorate in Drinking Water* (USEPA, 2019a)

a. Mean household income (MHI) is based on U.S. Census 2010 ACS 5-year estimates (U.S. Census Bureau, 2010) stated in 2010 dollars, adjusted to 2017 dollars using the CPI (for all items) for areas under 50,000 persons (BLS, 2018b).

b. Affordability threshold equals 2.5 percent of MHI.

c. Household water costs derived from 2006 Community Water System Survey (USEPA, 2009b), based on residential revenue per connection within each size category, adjusted to 2017 dollars based on the CPI (for all items) for areas under 50,000 persons.

Exhibit 7-6 shows the estimates of per-household costs by treatment technology and size category generated using the treatment cost method described in Chapter 5 as well as *Best Available Technologies and Small System Compliance Technologies for Perchlorate in Drinking Water* (USEPA, 2019a) and *Technologies and Costs for Treating Perchlorate-Contaminated*

Waters (USEPA, 2018e). Costs in bold font do not exceed the corresponding expenditure margin and, therefore, meet the SSCT affordability criterion.

Exhibit 7-6: Annual Incremental Cost Estimates for SSCT Affordability Analysis

System Size (population served)	Ion Exchange	Biological Treatment	Reverse Osmosis	Point-of-Use Reverse Osmosis
25–500	**$378 to $610**	$2,146 to $3,709	$2,272 to $2,671	**$265 to $271**
501–3,300	**$98 to $148**	**$324 to $566**	**$561 to $688**	**$250 to $251**
3,301–10,000	**$104 to $153**	**$211 to $315**	**$431 to $493**	Not applicable[a]

Source: *Best Available Technologies and Small System Compliance Technologies for Perchlorate in Drinking Water* (USEPA, 2019a); bold font indicates cost estimates that do not exceed the corresponding expenditure margin.
a. EPA's WBS model for POU treatment does not cover systems larger than 3,300 people (greater than 1 MGD design flow), because implementing and maintaining a large-scale POU program is likely to be impractical.

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Appendix A. Output from the BBDR Model Summarizing Maternal fT4 Levels Given Increasing Dose of Perchlorate

Perchlorate Dose (µg/kg/day)	Iodine Intake Levels; fT4 (pmol/L)														
	50	55	60	65	70	75	80	85	90	95	100	125	150	170	300
0	8.27	8.47	8.67	8.87	9.06	9.26	9.47	9.67	9.87	10.05	10.18	10.40	10.47	10.50	10.57
0.1	8.27	8.47	8.66	8.86	9.06	9.26	9.46	9.67	9.87	10.04	10.17	10.40	10.47	10.50	10.57
0.2	8.26	8.46	8.66	8.86	9.05	9.25	9.46	9.66	9.86	10.04	10.17	10.40	10.47	10.50	10.57
0.3	8.26	8.46	8.66	8.85	9.05	9.25	9.45	9.65	9.85	10.03	10.17	10.40	10.46	10.50	10.57
0.4	8.26	8.46	8.65	8.85	9.04	9.24	9.45	9.65	9.85	10.03	10.16	10.40	10.46	10.50	10.57
0.5	8.25	8.45	8.65	8.84	9.04	9.24	9.44	9.64	9.84	10.02	10.16	10.40	10.46	10.50	10.57
0.6	8.25	8.45	8.65	8.84	9.04	9.23	9.43	9.64	9.84	10.02	10.15	10.40	10.46	10.50	10.57
0.7	8.25	8.45	8.64	8.84	9.03	9.23	9.43	9.63	9.83	10.01	10.15	10.39	10.46	10.50	10.57
0.8	8.24	8.44	8.64	8.83	9.03	9.22	9.42	9.63	9.82	10.00	10.15	10.39	10.46	10.50	10.57
0.9	8.24	8.44	8.64	8.83	9.02	9.22	9.42	9.62	9.82	10.00	10.14	10.39	10.46	10.50	10.57
1	8.24	8.44	8.63	8.82	9.02	9.21	9.41	9.61	9.81	9.99	10.14	10.39	10.46	10.50	10.57
1.1	8.24	8.43	8.63	8.82	9.01	9.21	9.41	9.61	9.81	9.99	10.13	10.39	10.46	10.49	10.57
1.2	8.23	8.43	8.62	8.82	9.01	9.20	9.40	9.60	9.80	9.98	10.13	10.39	10.46	10.49	10.57
1.3	8.23	8.43	8.62	8.81	9.00	9.20	9.40	9.60	9.79	9.98	10.13	10.39	10.46	10.49	10.57
1.4	8.23	8.42	8.62	8.81	9.00	9.19	9.39	9.59	9.79	9.97	10.12	10.39	10.46	10.49	10.57
1.5	8.22	8.42	8.61	8.80	9.00	9.19	9.39	9.58	9.78	9.97	10.12	10.39	10.46	10.49	10.57
1.6	8.22	8.42	8.61	8.80	8.99	9.18	9.38	9.58	9.78	9.96	10.11	10.39	10.46	10.49	10.57
1.7	8.22	8.42	8.61	8.80	8.99	9.18	9.38	9.57	9.77	9.96	10.11	10.39	10.46	10.49	10.57
1.8	8.22	8.41	8.60	8.79	8.98	9.17	9.37	9.57	9.76	9.95	10.10	10.39	10.46	10.49	10.57
1.9	8.21	8.41	8.60	8.79	8.98	9.17	9.36	9.56	9.76	9.94	10.10	10.38	10.46	10.49	10.57
2	8.21	8.41	8.60	8.79	8.97	9.17	9.36	9.56	9.75	9.94	10.09	10.38	10.46	10.49	10.57
2.1	8.21	8.40	8.59	8.78	8.97	9.16	9.35	9.55	9.75	9.93	10.09	10.38	10.46	10.49	10.57
2.2	8.20	8.40	8.59	8.78	8.97	9.16	9.35	9.55	9.74	9.93	10.08	10.38	10.46	10.49	10.57
2.3	8.20	8.40	8.59	8.77	8.96	9.15	9.34	9.54	9.74	9.92	10.08	10.38	10.46	10.49	10.57
2.4	8.20	8.39	8.58	8.77	8.96	9.15	9.34	9.53	9.73	9.92	10.08	10.38	10.45	10.49	10.57
2.5	8.20	8.39	8.58	8.77	8.95	9.14	9.33	9.53	9.72	9.91	10.07	10.38	10.45	10.49	10.57
2.6	8.19	8.39	8.58	8.76	8.95	9.14	9.33	9.52	9.72	9.90	10.07	10.38	10.45	10.49	10.57
2.7	8.19	8.38	8.57	8.76	8.95	9.13	9.32	9.52	9.71	9.90	10.06	10.38	10.45	10.49	10.57

Perchlorate Dose (µg/kg/day)	Iodine Intake Levels; fT4 (pmol/L)														
	50	55	60	65	70	75	80	85	90	95	100	125	150	170	300
2.8	8.19	8.38	8.57	8.76	8.94	9.13	9.32	9.51	9.71	9.89	10.06	10.38	10.45	10.49	10.57
2.9	8.19	8.38	8.57	8.75	8.94	9.12	9.31	9.51	9.70	9.89	10.05	10.38	10.45	10.49	10.57
3	8.18	8.38	8.56	8.75	8.93	9.12	9.31	9.50	9.70	9.88	10.05	10.37	10.45	10.49	10.57
3.1	8.18	8.37	8.56	8.74	8.93	9.12	9.30	9.50	9.69	9.88	10.04	10.37	10.45	10.49	10.57
3.2	8.18	8.37	8.56	8.74	8.92	9.11	9.30	9.49	9.68	9.87	10.04	10.37	10.45	10.49	10.57
3.3	8.17	8.37	8.55	8.74	8.92	9.11	9.29	9.49	9.68	9.87	10.03	10.37	10.45	10.49	10.57
3.4	8.17	8.36	8.55	8.73	8.92	9.10	9.29	9.48	9.67	9.86	10.03	10.37	10.45	10.49	10.57
3.5	8.17	8.36	8.55	8.73	8.91	9.10	9.29	9.48	9.67	9.85	10.02	10.37	10.45	10.49	10.57
3.6	8.17	8.36	8.54	8.73	8.91	9.09	9.28	9.47	9.66	9.85	10.02	10.37	10.45	10.49	10.57
3.7	8.16	8.35	8.54	8.72	8.90	9.09	9.28	9.47	9.66	9.84	10.01	10.37	10.45	10.49	10.57
3.8	8.16	8.35	8.54	8.72	8.90	9.08	9.27	9.46	9.65	9.84	10.01	10.37	10.45	10.48	10.57
3.9	8.16	8.35	8.53	8.72	8.90	9.08	9.27	9.45	9.64	9.83	10.00	10.37	10.45	10.48	10.57
4	8.16	8.35	8.53	8.71	8.89	9.08	9.26	9.45	9.64	9.83	10.00	10.36	10.45	10.48	10.57
4.1	8.15	8.34	8.53	8.71	8.89	9.07	9.26	9.44	9.63	9.82	9.99	10.36	10.45	10.48	10.57
4.2	8.15	8.34	8.52	8.70	8.89	9.07	9.25	9.44	9.63	9.81	9.99	10.36	10.45	10.48	10.57
4.3	8.15	8.34	8.52	8.70	8.88	9.06	9.25	9.43	9.62	9.81	9.98	10.36	10.45	10.48	10.57
4.4	8.14	8.33	8.52	8.70	8.88	9.06	9.24	9.43	9.62	9.80	9.98	10.36	10.45	10.48	10.57
4.5	8.14	8.33	8.51	8.69	8.87	9.05	9.24	9.42	9.61	9.80	9.97	10.36	10.44	10.48	10.57
4.6	8.14	8.33	8.51	8.69	8.87	9.05	9.23	9.42	9.61	9.79	9.97	10.36	10.44	10.48	10.57
4.7	8.14	8.33	8.51	8.69	8.87	9.05	9.23	9.41	9.60	9.79	9.96	10.36	10.44	10.48	10.57
4.8	8.13	8.32	8.51	8.68	8.86	9.04	9.22	9.41	9.60	9.78	9.95	10.36	10.44	10.48	10.57
4.9	8.13	8.32	8.50	8.68	8.86	9.04	9.22	9.40	9.59	9.78	9.95	10.35	10.44	10.48	10.57
5	8.13	8.32	8.50	8.68	8.86	9.03	9.22	9.40	9.59	9.77	9.94	10.35	10.44	10.48	10.57
5.1	8.13	8.31	8.50	8.67	8.85	9.03	9.21	9.39	9.58	9.76	9.94	10.35	10.44	10.48	10.57
5.2	8.12	8.31	8.49	8.67	8.85	9.03	9.21	9.39	9.57	9.76	9.93	10.35	10.44	10.48	10.57
5.3	8.12	8.31	8.49	8.67	8.84	9.02	9.20	9.38	9.57	9.75	9.93	10.35	10.44	10.48	10.57
5.4	8.12	8.31	8.49	8.66	8.84	9.02	9.20	9.38	9.56	9.75	9.92	10.35	10.44	10.48	10.57
5.5	8.12	8.30	8.48	8.66	8.84	9.01	9.19	9.37	9.56	9.74	9.92	10.35	10.44	10.48	10.57

Perchlorate Dose (µg/kg/day)	Iodine Intake Levels; fT4 (pmol/L)														
	50	55	60	65	70	75	80	85	90	95	100	125	150	170	300
5.6	8.11	8.30	8.48	8.66	8.83	9.01	9.19	9.37	9.55	9.74	9.91	10.35	10.44	10.48	10.57
5.7	8.11	8.30	8.48	8.65	8.83	9.01	9.18	9.36	9.55	9.73	9.91	10.35	10.44	10.48	10.57
5.8	8.11	8.30	8.47	8.65	8.83	9.00	9.18	9.36	9.54	9.73	9.90	10.34	10.44	10.48	10.57
5.9	8.11	8.29	8.47	8.65	8.82	9.00	9.18	9.36	9.54	9.72	9.90	10.34	10.44	10.48	10.57
6	8.10	8.29	8.47	8.64	8.82	8.99	9.17	9.35	9.53	9.72	9.89	10.34	10.44	10.48	10.57
6.1	8.10	8.29	8.47	8.64	8.81	8.99	9.17	9.35	9.53	9.71	9.89	10.34	10.44	10.48	10.57
6.2	8.10	8.28	8.46	8.64	8.81	8.99	9.16	9.34	9.52	9.70	9.88	10.34	10.44	10.48	10.57
6.3	8.10	8.28	8.46	8.63	8.81	8.98	9.16	9.34	9.52	9.70	9.88	10.34	10.44	10.48	10.56
6.4	8.09	8.28	8.46	8.63	8.80	8.98	9.15	9.33	9.51	9.69	9.87	10.34	10.43	10.47	10.56
6.5	8.09	8.28	8.45	8.63	8.80	8.97	9.15	9.33	9.51	9.69	9.86	10.34	10.43	10.47	10.56
6.6	8.09	8.27	8.45	8.62	8.80	8.97	9.15	9.32	9.50	9.68	9.86	10.33	10.43	10.47	10.56
6.7	8.09	8.27	8.45	8.62	8.79	8.97	9.14	9.32	9.50	9.68	9.85	10.33	10.43	10.47	10.56
6.8	8.08	8.27	8.45	8.62	8.79	8.96	9.14	9.31	9.49	9.67	9.85	10.33	10.43	10.47	10.56
6.9	8.08	8.27	8.44	8.62	8.79	8.96	9.13	9.31	9.49	9.67	9.84	10.33	10.43	10.47	10.56
7	8.08	8.26	8.44	8.61	8.78	8.95	9.13	9.30	9.48	9.66	9.84	10.33	10.43	10.47	10.56
7.1	8.08	8.26	8.44	8.61	8.78	8.95	9.12	9.30	9.48	9.66	9.83	10.33	10.43	10.47	10.56
7.2	8.07	8.26	8.43	8.61	8.78	8.95	9.12	9.30	9.47	9.65	9.83	10.33	10.43	10.47	10.56
7.3	8.07	8.26	8.43	8.60	8.77	8.94	9.12	9.29	9.47	9.65	9.82	10.32	10.43	10.47	10.56
7.4	8.07	8.25	8.43	8.60	8.77	8.94	9.11	9.29	9.46	9.64	9.82	10.32	10.43	10.47	10.56
7.5	8.07	8.25	8.43	8.60	8.77	8.94	9.11	9.28	9.46	9.64	9.81	10.32	10.43	10.47	10.56
7.6	8.07	8.25	8.42	8.59	8.76	8.93	9.10	9.28	9.45	9.63	9.81	10.32	10.43	10.47	10.56
7.7	8.06	8.24	8.42	8.59	8.76	8.93	9.10	9.27	9.45	9.63	9.80	10.32	10.43	10.47	10.56
7.8	8.06	8.24	8.42	8.59	8.76	8.93	9.10	9.27	9.44	9.62	9.80	10.32	10.43	10.47	10.56
7.9	8.06	8.24	8.41	8.58	8.75	8.92	9.09	9.26	9.44	9.62	9.79	10.32	10.43	10.47	10.56
8	8.06	8.24	8.41	8.58	8.75	8.92	9.09	9.26	9.43	9.61	9.79	10.31	10.43	10.47	10.56
8.1	8.05	8.23	8.41	8.58	8.75	8.91	9.08	9.26	9.43	9.61	9.78	10.31	10.42	10.47	10.56
8.2	8.05	8.23	8.41	8.58	8.74	8.91	9.08	9.25	9.42	9.60	9.78	10.31	10.42	10.47	10.56
8.3	8.05	8.23	8.40	8.57	8.74	8.91	9.08	9.25	9.42	9.60	9.77	10.31	10.42	10.47	10.56

Perchlorate Dose (μg/kg/day)	Iodine Intake Levels; fT4 (pmol/L)														
	50	55	60	65	70	75	80	85	90	95	100	125	150	170	300
8.4	8.05	8.23	8.40	8.57	8.74	8.90	9.07	9.24	9.42	9.59	9.76	10.31	10.42	10.47	10.56
8.5	8.04	8.22	8.40	8.57	8.73	8.90	9.07	9.24	9.41	9.59	9.76	10.31	10.42	10.47	10.56
8.6	8.04	8.22	8.39	8.56	8.73	8.90	9.06	9.23	9.41	9.58	9.75	10.30	10.42	10.47	10.56
8.7	8.04	8.22	8.39	8.56	8.73	8.89	9.06	9.23	9.40	9.58	9.75	10.30	10.42	10.47	10.56
8.8	8.04	8.22	8.39	8.56	8.72	8.89	9.06	9.23	9.40	9.57	9.74	10.30	10.42	10.46	10.56
8.9	8.04	8.21	8.39	8.55	8.72	8.89	9.05	9.22	9.39	9.57	9.74	10.30	10.42	10.46	10.56
9	8.03	8.21	8.38	8.55	8.72	8.88	9.05	9.22	9.39	9.56	9.73	10.30	10.42	10.46	10.56
9.1	8.03	8.21	8.38	8.55	8.71	8.88	9.04	9.21	9.38	9.56	9.73	10.30	10.42	10.46	10.56
9.2	8.03	8.21	8.38	8.55	8.71	8.87	9.04	9.21	9.38	9.55	9.72	10.29	10.42	10.46	10.56
9.3	8.03	8.20	8.38	8.54	8.71	8.87	9.04	9.20	9.37	9.55	9.72	10.29	10.42	10.46	10.56
9.4	8.02	8.20	8.37	8.54	8.70	8.87	9.03	9.20	9.37	9.54	9.71	10.29	10.42	10.46	10.56
9.5	8.02	8.20	8.37	8.54	8.70	8.86	9.03	9.20	9.37	9.54	9.71	10.29	10.42	10.46	10.56
9.6	8.02	8.20	8.37	8.53	8.70	8.86	9.03	9.19	9.36	9.53	9.70	10.29	10.42	10.46	10.56
9.7	8.02	8.19	8.37	8.53	8.69	8.86	9.02	9.19	9.36	9.53	9.70	10.29	10.42	10.46	10.56
9.8	8.01	8.19	8.36	8.53	8.69	8.85	9.02	9.18	9.35	9.52	9.69	10.28	10.41	10.46	10.56
9.9	8.01	8.19	8.36	8.53	8.69	8.85	9.01	9.18	9.35	9.52	9.69	10.28	10.41	10.46	10.56
10	8.01	8.19	8.36	8.52	8.69	8.85	9.01	9.18	9.34	9.51	9.68	10.28	10.41	10.46	10.56

Appendix B. Estimated Value of an IQ Point

The benefits of the proposed rule are the monetary value of the avoided IQ decrements attributable to baseline perchlorate exposure greater than the MCL. The EPA's approach to valuation relies on studies that link changes in IQ to effects on lifetime earnings. The economics literature provides a robust basis for estimating the relationship between IQ and lifetime earnings. Because the literature relies on large datasets that are representative of the US population, it is appropriate to use the results to infer subpopulation-level impacts (though not individual-level impacts) from changes in environmental policy, even when average impacts are very small in magnitude. The estimated effects of IQ on lifetime earnings are not predicated on a particular type or pathway of chemical exposure. Rather, they are broadly applicable to evaluating any type of policy intended to improve children's cognitive development (Lin et al. 2018).

This appendix describes the EPA's method for estimating an average value per IQ point. Section B.1 provides a summary of the economics literature estimating the relationship between IQ and earnings. Section B.2 Describes EPA's reanalysis approach that follows Salkever (1995). Section B.3 provides a critical review of the Salkever approach. Section B.4 describes how the EPA estimated lifetime earnings, and Section B.5 describes the EPA's method for estimating educational costs and summarizes the IQ value results. Section B.6 discusses limitations to the methods described in this appendix.

Exhibit B-1 summarizes this appendix's estimates of the IQ point dollar values produced in 2017 dollars. The values can be used to estimate the benefits of avoiding IQ decrements.

Exhibit B-1: Summary of IQ Point Dollar Values (2017$)

Estimate Parameter	Discount Rate			
	3%, Male	3%, Female	7%, Male	7%, Female
Present value of lifetime earnings	$1,069,129	$695,243	$244,738	$164,427
IQ value	$20,008	$23,700	$4,580	$5,605
Additional education costs and lost earnings	$1,352	$1,372	$625	$624
Net value of an IQ point (IQ value less additional education costs and lost earnings) discounted to the third year of life	$18,656	$22,328	$3,955	$4,981
Net value of an IQ point, weighted average	**$20,419**		**$4,448**	
Net value of an IQ point, discounted to birth	**$18,686**		**$3,631**	

B.1 Literature Review

Neurotoxins such as lead have well-known adverse effects on cognitive development (e.g., USEPA, 2013). Salkever (1995) and Schwartz (1994) proposed conceptual frameworks to describe the relationships between IQ, education, labor participation, and earnings in the context of valuing neurotoxin impacts. IQ can directly affect both participation in the labor force and wages conditional on labor participation. IQ can also indirectly affect these outcomes via effects on educational attainment. Some chemicals can also lead to other adverse neurological effects. Some of these effects, such as reduced executive function, also affect wages and labor participation, either directly, or indirectly through educational attainment (Heckman et al., 2006; Gensowski, 2018). Some studies found that non-cognitive personality traits are at least as predictive of life outcomes as IQ (Cawley et al., 2001; Heckman et al., 2006; Heckman and Kautz, 2012; Borghans et al., 2016).

Most studies linking cognitive function to earnings have used data from the National Longitudinal Survey of Youth 1979 cohort (NLSY79) (BLS, 1979). NLSY79 is a nationally representative survey of over twelve thousand Americans born from 1957 to 1964 that tracked participant information about schooling, employment, and earnings for almost four decades. It also includes detailed information about participants' family backgrounds, such as parents' education and income, which allows researchers to isolate the effect of IQ on earnings by controlling for these other potential determinants of earnings.

Studies typically use performance on the Armed Forces Qualifying Test (AFQT), administered to NLSY79 participants in 1980, as a proxy for IQ. The AFQT includes tests of verbal and mathematics skills. It has been widely used as a measure of cognitive ability. While AFQT scores are an imperfect measure of cognitive ability and suffer from test-retest variability, the large sample size in the AFQT allows for relatively precise estimates of the effect of IQ on earnings across the sample.

Salkever (1995) estimated the relationships between IQ, educational attainment, labor participation, and log wages for males and females using data from the NLSY79 for 1990 earnings, when participants were roughly 30 years old. Salkever's analysis included race/ethnicity, region, family income in 1979, and parents' education to control for socioeconomic factors that may be correlated with both IQ and earnings. Salkever found that each 1-point increase in IQ score was associated with an average total gain in earnings of 1.93 percent for males and 3.23 percent for females. While the effect of IQ on schooling and the direct effect of IQ on earnings (after conditioning on schooling) were similar across males and females, the effects of schooling on wages and labor participation were larger for females, resulting in a larger total effect. While Salkever was motivated by the desire to estimate the benefits of reductions in lead exposure, the empirical analysis focused only on the IQ to earnings link. The analysis did not include information on lead. The variations in IQ across the study cohort were not linked to lead exposure.

Since Salkever (1995), other studies in the labor economics literature have used the NLSY79 dataset to examine different aspects of the relationship between IQ and earnings. Neal and Johnson (1996) and Johnson and Neal (1998) examined the wage gap between blacks and whites. Heckman et al. (2006) compared the roles of cognitive and non-cognitive factors in determining earnings, finding that both had statistically significant effects. Ganzach (2011) used more recent data from the NLSY79 to examine the effects of socioeconomic background and IQ on wages over the lifecycle to age 40 for respondents with exactly 12 years of schooling. Zax and Rees (2002) used a different dataset—the Wisconsin Longitudinal Survey—to examine the relationship between IQ, academic performance, and earnings for white male high school graduates, contrasting effects at age 35 (in 1974) and 53 (in 1992). Both Zax and Rees (2002) and Ganzach (2011) found that the importance of IQ grows with age, but the effects of socioeconomic background variables on wages are stable over time.

The results of these studies are qualitatively consistent with Salkever (1995) in finding a statistically significant positive relationship between IQ and wages. Nevertheless, estimates from these studies are not directly comparable to Salkever (1995) because they excluded data from participants with zero earnings. Thus, their findings did not incorporate the effect of IQ on labor participation (Salkever, David S 2014). In addition, Zax and Rees limited their analysis to a subpopulation (white males) in which estimated earnings effects of IQ have been found to be smaller compared to effects for other demographic groups (Salkever, David S 2014). The studies also varied in the extent to which they controlled for educational attainment. Controlling for planned or actual educational attainment without accounting for the endogenous effect of IQ on education will bias the effect of IQ on earnings downward, because higher IQ individuals are likely to attend more years of school and to generate higher earnings (Heckman et al. 2006). This bias is a concern in Zax and Rees (2002), who limited their sample to high school graduates and included educational aspiration variables in some specifications, as well as Ganzach (2011), who limited the sample size to participants with exactly 12 years of schooling. The Salkever (1995) approach addressed this potential source of bias by estimating the impact of IQ on schooling in addition to the direct impacts of IQ on labor participation and wages when schooling is held constant and summing the relevant effects together when estimating the total effect of IQ on earnings.

Lin et al. (2018) is a recent addition to the labor economics literature using the NLSY79 to examine how the effect of IQ on earnings varies over the lifecycle to age 50. Lin et al. (2018) generated estimates that are comparable to Salkever (1995) because they included participants with zero earnings in the analysis to capture effects related to labor participation. In contrast, Lin et al. (2018) modeled a reduced form relationship by including IQ in the earnings equation without controlling for education due its endogeneity. Therefore, the coefficient on IQ captures both the direct effect on earnings and the indirect effect resulting from increased educational attainment. Lin et al. (2018) included a similar but not identical set of socioeconomic background variables as Salkever (1995). In addition, Lin et al. (2018) included three non-cognitive personality traits—sociability, self-esteem, and perceived level of control over one's life. Lin et al. (2018) also compared the results to estimates using a more recent survey—the NLSY 1997 cohort (NLSY97), a survey of roughly 9,000 Americans born from 1980 to 1984 (BLS, 2015). They found that the effect of IQ on earnings at age 30 was not significantly different across the two cohorts. Lin et al. (2018) noted that, after adjusting for years worked, reference age, and IQ scale, their central estimate of the effect of IQ on lifetime earnings is within two percent of EPA (2008) range of estimates. Because the Lin et al. (2018) estimates of the IQ-earnings effect increase with age, their estimate of the IQ-earnings effect at age 30 is smaller than Salkever (1995) found. According to Lin et al. (2018), their estimates are generally applicable to policies aimed at improving cognitive performance including reduced exposure to neurotoxins

Salkever (1995) and Lin et al. (2018) both incorporated features that make them useful for regulatory analysis. Salkever (1995) explicitly modeled the role of education in the IQ-earnings relationship, which sheds light on the mechanism by which cognitive skills affect earnings and also allows the EPA to account for educational costs when calculating the change in net lifetime earnings from a change in IQ. Extrapolating the Salkever (1995) IQ-earnings effect at age 30 will generate an estimate of lifetime earnings that is biased downward if the effect of IQ on earnings grows over the lifecycle, a result found in Zax and Rees (2002), Ganzach (2011), and Lin et al. (2018). Salkever (1995) relied on older data from the NLSY79 cohort, but EPA's reanalysis uses more recent data from the NLSY97 cohort. Lin et al. (2018) also used both the NLSY79 and NLSY97 data, and examined data that extend throughout the lifecycle, including earnings at age 50 and beyond. However, their analysis lacked some control variables included in Salkever (1995), and the use of estimates from a model that includes non-cognitive traits in the regression is problematic if the effect of neurotoxin exposure on these characteristics is not quantifiable. Because these variables are correlated with IQ, their inclusion may attenuate the effect of IQ on earnings, leading to a downward bias on the EPA's estimate of the total earnings effects of reduced neurotoxin exposure.

The labor economics literature confirms that there is a measurable link between cognitive skills and earnings (as well as a link between non-cognitive skills and earnings). The role education plays as a potential pathway from cognitive skills to earnings is challenging to estimate quantitatively. Cognitive skills and level of schooling are highly correlated, and cognitive ability is endogenous with years of education at the time of the test, making it difficult to separately identify these effects on lifetime earnings. Some researchers have made assumptions about the functional form of the earnings function in an attempt to separate out the two effects. However, these assumptions are problematic because not every ability-education combination is observed in the data (Cawley et al., 2001). For a portion of the sample, there is no observable counterfactual: there are not many observations for individuals with high cognitive ability and low levels of education or individuals with low cognitive ability and high levels of education. Nevertheless, studies that examined the effect of IQ on wages or earnings found statistically significant effects even after fully or partially controlling for educational attainment (Salkever ,1995; Zax and Rees, 2002; Heckman et al., 2006; Ganzach, 2011), suggesting that education is not the only pathway by which cognitive skills affect earnings.

Researchers have observed a growing wage premium (adjusted for the average share of total hours worked by gender-education-experience) associated with completing a four-year college degree.[16] In 2008, the earnings of an average college graduate exceeded those of an average high school graduate by 97 percent.[17] The wage premium between skilled (college) and unskilled (high school) workers has been mainly driven by rising wages for individuals with post-college degrees and large decreases in wages for the less educated (high school or less) (Acemoglu and Autor, 2010). Consistent with Acemoglu and Autor (2010), Cunha et al. (2011) found that shifts in supply and demand for high school and college workers were the main drivers of the change

[16] Accounting for non-wage benefits does not alter these trends and in fact widens the gap. If part-time workers are incorporated, the downward trend for less-educated workers is more pronounced.
[17] Card (1999) noted that the measure of earnings matters. Since more educated people also tend to work greater hours, the measured return to schooling will be higher when weekly or annual earnings are used instead of the hourly wage. Using annual earnings data from the mid-1990s, he found that about two-thirds of the measured return to education was explained by differences in the per-hour wage while the remaining one-third was driven by the amount of time spent working.

in the wage premium. The increase in the wage premium for college graduation has been mainly due to an increase in the return to cognitive skills.[18]

There is uncertainty about whether a degree showing the completion of a stage of schooling—high school or college—matters more than years of schooling. Studies that allowed for nonlinearities found some support with respect to college graduation (Hungerford and Solon, 1987; Belman and Heywood, 1991). Others, however, observed that the relationship between earnings and years of schooling is largely linear (Park, 1994), except at the highest levels of education (MDs and PhDs) (Card, 1999). Recent work by Heckman et al. (2018) found that high school and college graduation have important effects on earnings even after controlling for years of schooling, but that attending some college had a positive causal effect on earnings relative to high school graduation only. Returns to education also vary by cognitive ability; Heckman et al. (2018) found that low-ability individuals gained the most in lifetime earnings from high school completion, but found fewer additional returns from more schooling. They also found that cognitive and non-cognitive skills were important predictors of educational attainment and, therefore, lifetime earnings.

B.2 Reanalysis of the IQ Effect on Lifetime Earnings

The value of an IQ point as a percentage of lifetime earnings is a reanalysis of Salkever (1995), which estimated the effect of IQ on earnings, accounting for both labor participation and intermediate effects on educational attainment. The method begins with an identity relationship between income (I), probability of employment (P), and earnings from employment (E):

$$I = P \times E.$$

A change in income depends on changes in employment and earnings:

$$\Delta I = \Delta P \times E + P \times \Delta E + \Delta P \times \Delta E.$$

Assuming the last term in negligible and rearranging terms, the equation becomes

$$\Delta I = I \times \left(\frac{\Delta P}{P} + \frac{\Delta E}{E}\right).$$

Thus, a change in income equals baseline income multiplied by the sum of a percent change in probability of employment and a percent change in earnings.

The reanalysis followed the same approach as the original analysis, but used more recent 1997 NLSY data instead of the original 1979 NLSY data. This analysis indicates that a one point change in IQ results in a 1.865 percent and 3.397 percent change in lifetime earnings for males and females, respectively. The estimates incorporate the direct and indirect effects that changes in IQ have on earnings. Direct effects include the effect of IQ test scores on participation in employment and earnings with the years of schooling held constant. Indirect effects include the

[18] Returns to cognitive ability for high school graduates and non-cognitive skills for high school and college graduates have remained fairly constant over time.

effect of IQ test scores on years of schooling attained, and the subsequent effect on participation and earnings.

Salkever (1995) also produced adjusted estimates that incorporate non-IQ related effects caused by lead exposure on schooling from Schwartz (1994), yielding a 2.094 percent and 3.631 percent change in lifetime earnings for males and females, respectively. Non-IQ effects on schooling caused by lead exposure include effects on hearing, balance, hyperactivity, and perceptual and attention disorders (Schwartz 1994). Schwartz (1994) estimates lead exposure on schooling to be 0.131 years per IQ point,[19] whereas Salkever (1995) estimates the effect to be 0.1007 years per IQ point−the former estimate unsurprisingly larger given that it captures IQ and non-IQ effects of lead exposure.

In his meta-analysis, however, Salkever (2014) only defended his unadjusted results, implying a belief that his unadjusted results are the most defensible. For this reason, Salkever's (1995) adjusted estimates incorporating Schwartz's (1994) effect on schooling were not updated and are not used to measure the effect of lead exposure on earnings in this analysis, despite the fact that omitting non-IQ effects on schooling may underestimate the actual IQ point dollar value associated with reducing lead exposure.

Because the EPA's reanalysis omits the non-IQ effects on schooling, the valuation results may be applied more generally to value IQ decrements resulting from exposure to any toxin.

B.3 Reanalysis of Salkever (1995) Using NLSY 1997 Data

The variables available in the 1997 NLSY are generally very similar to those available in the 1979 NLSY used by Salkever. Therefore, the EPA was able to use the more recent data in their reanalysis without making many changes to the variable definitions or approach that Salkever (1995) used for his estimates. However, some changes were necessary, and the discussion below details the variable definitions used, the assumptions made, and compares the EPA reanalysis results with Salkever's (1995) analysis.

- Salkever appears to have dropped a set of the individuals not in the labor force from his 1995 analysis (as evidenced by the "participation" rates (rates of individuals with positive earnings) he reports). Although detailed specifics for which individuals were excluded were not included in his paper, based on the high "participation" rate reported it appears that anyone not in the labor force was excluded, except for respondents that reported their employment status as "keeping house." However, "keeping house" is not a labor force variable available in the 1997 data. Thus, there was no way to use the 1997 data while excluding those not in the labor force, except for those "keeping house" or in school. Therefore, the reanalysis includes individuals not in the labor force, excluding only those enrolled in school and 17 observations with missing or unknown employment status. The final analysis included 8,984 respondents. The EPA excluded the following respondents because of missing data: 1,843 respondents did not participate in the 2012 survey (the reanalysis uses the income and schooling level reported in the 2012 survey, so the reanalysis can only include respondents that participated in the 2012 survey)

[19] Exposure sufficient to cause a 1-point decrement in IQ.

- 1,371 respondents did not have the Armed Services Vocational Aptitude Battery (ASVAB) Math and Verbal combined score percentile
- 67 respondents did not report highest grade completed
- 36 respondents did not report race/ethnicity
- 128 respondents who were active duty military (excluded from the participation and income regressions, which include (2012 employment status variable by week)
- 17 respondents had incomplete employment status for at least one week (excluded from the participation and income regressions)
- 759 respondents enrolled in college during 2012 (excluded from the participation and income regressions.

Whether or not excluding respondents with missing data results in any bias is not known because it is not clear how the various types of missing data result in systematic differences in the effect of IQ, schooling, and family history on earnings. Final respondent counts are as follows:

  - The schooling data includes 2,869 females and 2,798 males
  - The participation data includes 2,378 females and 2,385 males
  - The income data include 1,663 females and 1,886 males.

Exhibit B-2 includes detailed descriptions of the variables used in the EPA reanalysis and summarizes the differences between the reanalysis variables and the variables used in Salkever's (1995) analysis.

Exhibit B-2: Map Between Variables in Salkever (1995) Analysis and the EPA's Reanalysis Estimates Using the 1997 NLSY Data

Salkever 1995 Variable	Updated Reanalysis Variable	Notes
Highest Grade	Highest Grade	The variable EPA used appears equivalent to what was used in Salkever's 1995 analysis. EPA used respondent's highest grade completed as of the date of the survey in 2013. The variable name is T8128900.
Participation	Participation (2012)	
Log 1990 Earnings	Log 2012 earnings	The variables EPA used appear equivalent to what was used in Salkever's 1995 analysis. EPA used total income from wages and salary in the past year from the 2013 survey. The variable name is T8976700. If the value is positive, then the participation variable is 1; otherwise it is zero.
Family Income Unknown	Family Income Unknown	
Family Income (in 1979) x 10^{-3}	Family Income (in 1997) x 10^{-3}	The variable EPA used appears equivalent to what was used in Salkever's 1995 analysis. EPA used variable R1302500,

Salkever 1995 Variable	Updated Reanalysis Variable	Notes
Race/Ethnicity Variables: African American Hispanic	Race Variables: White (omitted from regressions) African American American Indian, Eskimo or Aleut Asian or Pacific Islander Other Ethnicity Variable: Hispanic Non-Hispanic (omitted from regressions)	EPA used the more detailed race (R0538700) and ethnicity (R0538600) variables that were available in the 1997 data. They are not available in the 1979 data.
Binary Geographic: Urban Rural nonfarm Nonsouth	Binary Geographic: Urban Rural Nonsouth	EPA used variable R1217500 to define binary variables for urban and rural. Unknown is the omitted dummy variable in the regression. EPA used R1200300 to define the binary variable for nonsouth. These indicate the respondent's location in 1997.
Age (in 1987)	Age (on December 31, 2002)	The variable EPA used appears equivalent to what was used in Salkever's 1995 analysis. Variable R0538700 (age in 1981) plus 6.
IQ (AFQT)	IQ (ASVAB)	Estimated with variable R0538700, which indicates the ASVAB Math and Verbal combined score percentile. This was converted to IQ by assuming IQ is normally distributed with mean 100 and standard deviation 15. Salkever 1995 estimates IQ the same way, using the score percentile for the Armed Forces Qualification Test (AFQT).
Mother's Highest Grade Father's Highest Grade	Mother's Highest Grade Father's Highest Grade	The variable EPA used appears equivalent to what was used in Salkever's 1995 analysis. R1302500 is the variable for mothers and R1302400 is the variable for fathers.

Exhibit B-3 presents the estimated parameters from Salkever's 1995 model and the updated model using Salkever's approach and 1997 NLSY data (2012 earnings are used here). As noted above, there are differences in labor force participation rates. This difference explains why the participation effect parameters are larger for the EPA reanalysis estimates compared to Salkever's 1995 analysis. However, as the overall participation rate is lower for the EPA reanalysis estimates, the total effect on earnings ends up being similar in both analyses. The direct IQ effect on earnings is very similar for females comparing the original and updated analyses, but decreased for males. At the same time, for males, the schooling effect on earnings increased in the updated analysis compared to the original. This variation might be due to multicollinearity between schooling level and IQ. However, if schooling is picking up some of the effects of IQ on earnings or vice versa, the two effects appear to cancel each other out given that the total effects on earnings are very similar when comparing the original and updated analyses for both males and females.

Exhibit B-3: Parameters from Salkever 1995 and EPA's Reanalysis Estimate Using Salkever's Approach and 1997 NLSY Data

Parameter Name	Male		Female	
	Parameter Value	Standard Error	Parameter Value	Standard Error
Salkever (1995)				
IQ Effect on Schooling	0.1007	0.0022	0.1007	0.0025
IQ Effect on Participation	0.0016	Not Presented	0.0037	Not Presented
Schooling Effect on Participation	0.0035	Not Presented	0.0282	Not Presented
Schooling Effect on Earnings	0.0476	0.0071	0.0960	0.0100
IQ Effect on Earnings	0.0124	0.0013	0.0140	0.0021
Total Effect on Earnings[1]	**1.931%**	**not applicable**	**3.225%**	**not applicable**
EPA Reanalysis Estimate using Salkever Approach and 1997 NLSY Data				
IQ Effect on Schooling	0.0811	0.0031	0.0916	0.0034
IQ Effect on Participation	0.0036	0.0007	0.0053	0.0009
Schooling Effect on Participation	0.0186	0.0039	0.0297	0.0042
Schooling Effect on Earnings	0.0818	0.0088	0.1089	0.0092
IQ Effect on Earnings	0.0052	0.0016	0.0120	0.0018
Total Effect on Earnings[1]	**1.865%**	**not applicable**	**3.397%**	**not applicable**

1. Following Salkever (1995), the total effect on earnings is calculated as ((IQ Effect on Schooling)*(exp(Schooling Effect on Earnings)-1)+exp(IQ Effect on Earnings)-1)+(((IQ Effect on Schooling)*(Schooling Effect on Participation)+(IQ Effect on Participation))/(Labor Force Participation Rate)). The labor force participation rate was 79% for males and 70% for females for the EPA reanalysis. Labor force participation rates from Salkever (1995) were higher, 96% and 81% for males and females, respectively.

EPA used a bootstrap approach to estimate the model parameters and their underlying uncertainty. To implement this approach, EPA drew 10,000 random samples of observations from the schooling data sets (samples of 2,869 and 2,798 for females and males, respectively), using random sampling with replacement, and estimated the model parameters for each of the 10,000 replicates.[20] Exhibit B-4 presents the mean, median, 5th and 95th percentiles for the

[20] To check whether a sufficient number of replicates were used, the estimates from the 5 sets of 2,000 replicates that make up the total of 10,000 replicates were compared. The following ranges represent the results: (1) male/mean: 1.866%-1.877%, (2) male/median: 1.864%-1.871%, (3) male/5th: 1.556%-1.578%, (4) male/95th: 2.167%-2.207%, (5) female/mean: 3.403%-3.411%, (6) female/median: 3.393%-3.409%, (7) female/5th: 3.001%-3.020%, and (8) female/95th: 3.803%-3.830%. The similar results for these five sets indicate that the estimates would not be very sensitive to including additional replicates.

resulting estimates. The range between the 5th and 95th percentiles represents the 95 percent confidence interval for the parameter.

Note that the value of an IQ point used in the benefits analysis relies on the bootstrap model mean parameter results shown in Exhibit B-4.

Exhibit B-4: EPA Reanalysis Mean, Median, 5th and 95th Percentile Parameter Estimates from Bootstrap Model

Parameter Name	Mean	Median	5th Percentile	95th Percentile
Males				
IQ Effect on Schooling	0.08125	0.08119	0.07512	0.08761
IQ Effect on Participation	0.00362	0.00363	0.00239	0.00485
Schooling Effect on Participation	0.01859	0.01864	0.01222	0.02492
Schooling Effect on Earnings	0.08168	0.08181	0.06752	0.09577
IQ Effect on Earnings	0.00529	0.00528	0.00266	0.00801
Total Effect on Earnings	**1.871%**	**1.867%**	**1.571%**	**2.184%**
Females				
IQ Effect on Schooling	0.09170	0.09164	0.08398	0.09965
IQ Effect on Participation	0.00529	0.00528	0.00380	0.00680
Schooling Effect on Participation	0.02983	0.02981	0.02296	0.03688
Schooling Effect on Earnings	0.10899	0.10896	0.09484	0.12326
IQ Effect on Earnings	0.01198	0.01193	0.00900	0.01516
Total Effect on Earnings	**3.409%**	**3.402%**	**3.010%**	**3.820%**

1. Following Salkever (1995), the total effect on earnings is calculated as ((IQ Effect on Schooling)*(exp(Schooling Effect on Earnings)-1)+exp(IQ Effect on Earnings)-1)+(((IQ Effect on Schooling)*(Schooling Effect on Participation)+(IQ Effect on Participation))/(Labor Force Participation Rate)). The labor force participation rate was 79% for males and 70% for females for the EPA reanalysis. Labor force participation rates from Salkever (1995) were higher, 96% and 81% for males and females respectively.

B.4 Critical Review of Salkever's Estimates

Salkever's estimates of the impacts of IQ decrements on future earnings are greater than those of other authors, which has led to claims that they overstate the true impacts. Most notably, Grosse (2007) and Robinson (2013) present critical reviews of Salkever's estimates. Their concerns fall into two categories:

1. Measurement and statistical issues, and
2. Comparability of earnings impact results with recent findings in the labor economics literature.

Salkever (2014) addresses the concerns of Grosse (2007) and Robinson (2013) by providing a meta-analysis of related studies. Salkever (2014) provides convincing evidence in support of his original estimates. For example, the author found that many of the studies only included males and/or considered hourly wages instead of annual earnings with a participation effect. Because impacts are lower for males (Salkever 2014), Salkever indicates that results from studies that only consider the impact of IQ decrements on male wages will be biased downward. In reference to the latter observation, Salkever (2014) concludes that studies examining impacts on hourly wages omit the impact that IQ decrements have on workforce participation, again biasing the results downward. In fact, Salkever (1995) is the only analysis that separately estimates the IQ effect derived from average annual earnings and the participation effect for both males and females. For a full discussion of Salkever's response to critical review articles see Salkever (2014).

B.5 Method for Estimating Lifetime Earnings Stream

This section describes the methods used to estimate the average present value of the earnings stream of the affected birth cohort from age 16 to age 80. The universe of individuals from which annual earnings and enrollment are estimated includes the civilian population only, excluding individuals living in institutional and non-institutional group quarters and unpaid workers.[21] Estimates are presented in 2017 dollars and are discounted using both a rate of 3 percent and of 7 percent.

Section B.5.1 describes the method used to estimate the distribution of educational attainment associated with each age in the age profile. Section B.5.2 describes the method used to estimate the annual earnings associated with each level of educational attainment for each age in the age profile. Section B.5.3 describes the life tables used in the lifetime earnings estimation and the derivation of male-female population ratios from the life tables. Section B.5.4 summarizes the lifetime earnings estimates. Section B.6 describes the effect changes in IQ have on lifetime earnings. Section B.7 presents a discussion of the limitations of this method.

B.5.1 Educational Attainment

Increases in educational attainment also increase education costs and diminish short-term earnings by reducing hours worked while in school. To accurately portray the benefits of a population with a higher average IQ, the average value of an IQ point must include an offset to reflect the cost of additional education and the opportunity cost of foregone income while in school. The EPA used two methods to estimate the distribution of educational attainment over the age profile of the target birth cohort. One method is to estimate primary and secondary school attainment, with the exception of grade 12; and a second method is to estimate postsecondary school attainment. Section B.5.1.1 describes primary and secondary school attainment, and Section B.5.1.2 describes postsecondary school attainment.

[21] According to the Census Bureau, people not living housing units (e.g., house, apartment, mobile home, rented room) are classified as living in group quarters. As of 2006, the ACS sample includes both institutional group quarters (e.g., correctional facilities, nursing homes, and mental hospitals) and non-institutional group quarters (e.g., college dormitories, military barracks, group homes, missions, and shelters) (U.S. Census Bureau, 2016a).

B.5.1.1 Primary and Secondary School Attainment

Primary and secondary school attainment is estimated for ages 1 to 19 by estimating the average proportion of the population that has completed grades 1 to 11 for each age. Primary and secondary school attainment is estimated for ages 20 and older by estimating the average proportion of 20 to 25 year olds that have completed grades 1 to 11. ACS single-year PUMS from 2008 to 2017 are used to produce ten-year average primary and secondary school attainment estimates (U.S. Census Bureau 2017c).

B.5.1.2 Postsecondary School Attainment

Postsecondary educational attainment is estimated first by determining the age-sex distribution of degrees conferred and then by applying this distribution to the total number of degrees conferred. The age-sex distribution of enrollment in college and graduate school is used as a proxy for the age-sex distribution of degrees conferred. Lag times are used to stagger enrollment because of the length of time it takes to earn a degree. A lag time of one year is assigned to Associate's and Master's degrees, two years to Bachelor's degrees, and three years to doctoral degrees. For example, if 20 percent of males enrolled as undergraduates in college are 20 years old then it is assumed that 20 percent of Bachelor's degrees are awarded to 22 year old males.

The proportion of an age group receiving a degree is then calculated by dividing the number of degrees awarded at a particular age by the total number of people of the same age. To account for individuals receiving successive degrees from postsecondary institutions the proportion of individuals with a bachelor's degree that previously received an associate's degree (21 percent) is subtracted from the proportion of individuals with an associate's degree[22] (U.S. Department of Education 2009); the proportion of individuals receiving a master's degree or receiving a doctoral degree without previously receiving a master's degree (25 percent; U.S. Department of Education, 2003) is subtracted from the proportion of individuals receiving a Bachelor's degree; and the proportion of individuals receiving a doctoral degree that previously received a Master's degree is subtracted from the proportion of individuals with a Master's degree (75 percent; U.S. Department of Education, 2003).[23, 24] The cumulative proportion of degrees conferred at a particular age represents the proportion of the population for whom the corresponding degree is the highest level of education attained.

Enrollment statistics are estimated from 2008 to 2017 using ACS single-year PUMS data. Data describing Associate's, Bachelor's, Master's, and doctoral degrees conferred are taken from the 2016 Digest of Education Statistics, published by the National Center for Education Statistics (NCES) (Snyder and Dillow, 2018). Data describing degrees conferred in the years 2016 and 2017 are projected by the NCES.

[22] Estimate based on the 2003-04 Beginning Postsecondary Students Longitudinal Study (U.S. Department of Education, 2009).

[23] Estimate based on the 1993 Baccalaureate and Beyond Longitudinal Study (U.S. Department of Education, 2003). The actual figure is 74.3.

[24] Educational attainment does not account for individuals receiving a second degree within the same attainment group later in life. For example, a second master's degree is treated as two individuals with a master's degree.

B.5.2 Average Annual Earnings

Annual earnings for males and females are estimated from ACS single-year PUMS for each of the levels of educational attainment previously described for ages ranging from 16 to 80, for each year from 2008 to 2017. Average annual earnings for males and females are equal to the sum of annual earnings associated with each level of educational attainment weighted by the distribution of educational attainment for each year in the age profile of the target birth cohort. Earnings consist of pre-tax wages and salary.

B.5.2.1 Topcodes

For confidentiality reasons, the Census Bureau topcodes reported income components if it falls below or above a predetermined threshold before making the data publicly available. Amounts above or below the threshold are replaced with the state mean value above or below the threshold (U.S. Census Bureau, 2013).

B.5.2.2 Real Earnings Growth Rate

Real earnings fluctuate from one year to the next in response to trends in the economy-wide productivity growth rate (Thornton et al., 1997). An annual growth rate of 1 percent is incorporated into the annual earnings estimates. Grosse et al. (2002) and Schwartz (1994) calculate lifetime earnings using a 1 percent growth rate in similar analyses. This rate is also consistent with long term historical averages; for example, the average percent change in real annual earnings from the year 1967 to 2016 as derived from Historical Income Tables published by the U.S. Census Bureau (U.S. Census Bureau, 2017).

B.5.3 Life Tables

Life tables present the survival rate or the probability that an individual will survive from age N to age N+1 (e.g. a 60 year old living to 61). Because some individuals die before retirement, the survival rate represents the probability of receiving earnings each year. As an individual ages, the probability declines. Future birth cohorts are expected to live longer, increasing the probability of living to age N+1, thereby increasing the average lifetime earnings for the cohort.

This analysis relies on the *Life tables underlying the SSA Trustees' 2015 annual report*, which are published on the website of Value Economics LLC (SSA, 2015).[25] The SSA develops projected life tables for future birth cohorts. In this analysis, the life tables associated with the 2015 birth cohort are incorporated to represent a recent cohort.

B.5.4 Present Value of Lifetime Earnings

Age-earnings profiles are estimated for the years 2008 through 2017. Average earnings are calculated for each year, Step 1, and then the ten averages are averaged to produce the grand mean earnings estimates presented in this report, Step 2:

[25] Value Economics LLC requested the life tables from the SSA. The SSA does not publish the tables on their website.

Step 1

$$NPV_{yr} = \sum_{N=3}^{80}[\frac{Y_N P_N R_N (1+X)^{N-A+0.5}}{(1+r)^{(N-A+1)}}]$$

where:

NPV = the net present value of earnings between ages A and 80;
yr= survey year from 2008 to 2017
A = current age, which is 3 in this analysis;
N = ages in the future (3, ..., 80);
Y = average annual earnings among earners for a particular age (N);
P = survival rate for a particular age (N);
R = percent of population with earnings;
X = productivity rate assumed at the midpoint of age N; and
r = discount rate for the beginning of age N.

Step 2

$$NPV_{average} = \frac{1}{10}\sum_{yr=2008}^{2017} NPV_{yr}$$

where:

NPV = the net present value of earnings between ages A and 80; and
yr = survey year;

Lifetime earnings are discounted at both 3 percent and 7 percent, and the model assumes that real earnings will increase by 1 percent per year. Earnings are assumed to be zero for individuals under the age of 16 and over the age of 80. Exhibit B-5 presents average lifetime earnings for males and females from 2006 to 2017.

Exhibit B-5: Lifetime Earnings (2017$)

Earnings Group	3% Discount Rate	7% Discount Rate
Male	$1,069,129	$244,738
Female	$695,243	$164,27

B.6 Effects on Earnings from Changes in IQ

The value of an IQ point is estimated by considering the direct and indirect effects of changes in IQ on earnings, as well as the costs associated with additional years of education. The cost of additional education is comprised of the direct cost of education and forgone earnings while in school.

Section B.6.1 describes the parameter used to estimate the total value of an IQ point, Section B.6.2 describes the methods used to estimate the components of costs associated with additional education, and Section B.6.3 presents the estimate for the net value of an IQ point.

B.6.1 Total Value of an IQ Point

The EPA's updated analysis based on Salkever (1995) yields a value of an IQ point equal to 1.865 percent and 3.397 percent of earnings for males and females, respectively. The average value of an IQ point is $23,269 and $5,398 discounted at a rate of 3 percent and 7 percent, respectively.

B.6.2 Additional Education: Costs and Lost Earnings

The effect of lead exposure on schooling is estimated to be 0.0811 years per IQ point for males and 0.0916 years per IQ point for females in the EPA's reanalysis of Salkever (1995). Increases in educational attainment signify analogous increases in education costs and diminished earnings resulting from working fewer hours while in school. To accurately portray the benefits of a population with a higher average IQ, the average value of an IQ point is adjusted to reflect the cost of additional education and the opportunity cost of being in school.

ACS PUMS data on enrollment were used to estimate both: (1) the ages at which the marginal increases in educational attainment due to higher IQ would be realized, and (2) the levels of additional educational attainment that would be achieved.

The distribution of ages at which the last year of education was obtained was estimated based on changes in the percentages of the population enrolled in school by age. For example, if 95 percent of 16 year olds are enrolled in school and 90 percent of 17 year olds are enrolled in school, it was estimated that 5 percent (95 percent minus 90 percent) of the population attained their last year of education at age 16. Thus, the analysis assumes that for 5 percent of the population, the marginal increase in educational attainment would be realized at age 17 – one year after they achieved their highest level of education in the baseline.

The level of additional education attained is estimated based on the enrollment for the ages at which the additional education is realized. For example, if 30 percent of enrolled 18 year olds are enrolled in 12th grade and 70 percent of enrolled 18 year olds are enrolled in university, the analysis estimates that additional education attained at age 18 is 30 percent 12th grade and 70 percent university.

B.6.2.1 Education Costs

Education costs associated with pursuing additional education are determined by the level of education being pursued. Three categories of education are considered in estimating costs:

- Public elementary and secondary schools (expenditures per pupil enrolled);
- Average undergraduate tuition (including fees, room, and board); and
- Average graduate tuition (including required fees).

Data describing the cost of education are taken from the 2016 version of the Digest of Education Statistics (Snyder and Dillow 2018-).

For each age in the age profile an individual has a likelihood of pursuing additional education in one of the three categories listed above, and therefore of incurring corresponding education costs. Enrollment is used to determine each category's relative likelihood thereby allowing costs to be apportioned appropriately with respect to each age in the age profile. For example, at age 17, most individuals will be enrolled in secondary schools causing the cost of education to primarily reflect the costs associated with the first category of education.

The total cost of education for the target cohort is estimated by calculating the sum of education costs corresponding to each level of attainment, weighted by enrollment and the probability of pursuing additional education at age N. For example, suppose that 100 percent of the target cohort's females attain additional education at age 18 or age 19. Twenty-five percent of the target cohort females attain additional education at age 18 and 75 percent of the target cohort females attain additional education at age 19. At age 18, 30 percent of the target cohort currently enrolled in school is enrolled in 12th grade and 70 percent is enrolled in an undergraduate university. At age 19, 10 percent of the target cohort females currently enrolled in school are enrolled in 12th grade and 90 percent are enrolled in an undergraduate university. The annual cost of a secondary school and an undergraduate university is $12,000 and $20,000, respectively. As shown in Exhibit B-6, the weighted cost of education per IQ point (assuming 0.0916 additional years of education) for the target cohort females is $1,722, $403 and $1,319 for 18 and 19 year olds, respectively.

Exhibit B-6: Example of Education Cost Calculation

Age	Enrollment		Annual Cost of Ed.		Additional Ed. Weight *e*	Weighted Costs *f=((a·c)+(b·d))·e*	Cost per IQ Point *f ·.0916*
	12th Grade *a*	University *b*	12th Grade *c*	University *d*			
18	30%	70%	$12,000	$20,000	25%	$4,400	$403
19	10%	90%	$12,000	$20,000	75%	$14,400	$1,319
Total						**$18,800**	**$1,722**

B.6.2.2 Lost Earnings

Lost earnings are calculated by separately estimating annual earnings for individuals enrolled in school and not enrolled in school according to the method detailed in Section B.5.2, and taking the difference of the two estimates. The difference in earnings is assumed to be zero for a given age and sex combination if enrolled and/or not enrolled earnings estimates rely on fewer than 150 observations. As with education costs, the differences in annual earnings are weighted by the probability that an individual will pursue additional education at their current age, N, as described at the beginning of this section. Lost earnings associated with an additional IQ point are generated by applying the EPA's IQ effect on schooling to the difference in annual earnings between the enrolled and not enrolled populations.

B.6.2.3 Summary of Additional Education Costs

The average estimated costs for additional education (tuition plus lost earnings) are $1,592 and $691, discounted at a rate of 3 percent and 7 percent, respectively.

B.6.3 Net Value of an IQ Point

The net value of an IQ point is equal to the total value minus the costs of attaining additional education. The estimates presented in Exhibit B-7 are averages produced from ten years of ACS single-year PUMS covering the years 2008 through 2017. The overall estimate for males and females combined is estimated assuming a population that is 52 percent male based on the male:female ratio of births (CDC, 2017).

Exhibit B-7: Effects of a One Point Change in IQ on Earnings (2017$)

Estimate Parameter	3% Discount Rate			7% Discount Rate		
	Male	Female	Overall	Male	Female	Overall
1. IQ Value	$20,008	$23,700	$21,780	$4,580	$5,605	$5,072
2. Additional education costs	$1,013	$1,147	$1,077	$473	$524	$497
3. Forgone earnings	$339	$255	$284	$152	$100	$127
4. Additional education costs and forgone earnings [2 + 3]	$1,352	$1,372	$1,361	$625	$624	$624
5. IQ value without education costs and lost earnings [1 – 4]	$18,656	$22,328	20,419	$3,955	$4,981	$4,448

B.7 Limitations

B.7.1 Nonmarket Work

The use of earnings is an incomplete measure of an individual's value to society. This is particularly true for individuals who choose to not participate in the labor force for all of their working years. If the opportunity cost of non-wage compensated work is assumed to be the average wage earned by persons of the same sex, age, and education, the average lifetime earnings estimates for these people would be significantly higher.

B.7.2 Multiple Degrees

Individuals receiving a second degree within the same attainment group later in life are not taken into account. For example, a second Master's degree is treated as two individuals with a Master's degree. This would increase the proportion of individuals with degrees from postsecondary schooling institutions. Given that a minority of individuals would fall into this attainment category, the lifetime earnings estimate is not expected to be substantially impacted.

B.7.3 Earnings Growth Rate

The earnings growth rate for females is substantially higher than the rate for males. A portion of the difference is likely due to females approaching equal pay to males over time. However, a portion of the difference is likely an artifact of rising female labor force participation, hours worked per year, and educational attainment. These trends have tapered off overtime and in all likelihood will continue to do so. Therefore, the average growth rate of real wages for the 2017 birth cohort may be closer to the earnings growth rate for males compared to older cohorts.

B.7.4 Income vs. Earnings

Although earnings is a significant component of income for the middle quintiles of the distribution of income, Barth et al. (1984) indicates that income may be substantially different from earnings for the tails of the income distribution. Therefore, earnings are assumed to be a good proxy for income in accordance with Salkever (1995).

B.7.5 Benefits

Because benefits have become a greater portion of income, their exclusion could result in lifetime earnings to be underestimated.

B.7.6 Impact of Ability on Earnings

Barth et al. (1984) found that many studies concluded that the impact of ability on earnings increases with age. Therefore, estimates of the impact of IQ on earnings derived from younger individuals may be smaller than if estimates were derived from individuals over the age of 30 (Barth et al. 1984). The EPA reanalysis of Salkever (1995) relies on data where respondents range in age from 27 to 32. Thus, the estimate of the impact of IQ on earnings may underestimate the true impact of ability on earnings.

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Appendix C. Detailed Cost Calculations and Methods

This appendix provides detailed calculations for the cost analysis described in Section 5. Section C.1 provides detailed cost curves and the blending equation used to estimate control costs. Section C.2 describes the sources and methods used to estimate PWS wage rates. Section C.3 provides detailed calculations of the household-level control costs. Section c.4 provides annual estimates of monitoring and waiver activity.

C.1 Capital and O&M Control Cost Details

To generate costs for the treatment technologies discussed in Section 5.1, the EPA used its WBS cost-estimating models. The WBS models are spreadsheet-based engineering models for individual treatment technologies that are linked to a central database of component unit costs.

For each scenario modeled and separately for total capital and for O&M costs, the EPA fit up to three curves: one covering small systems (less than 1 MGD design flow), one covering medium systems (1 MGD to less than 10 MGD design flow), and one covering large systems (10 MGD design flow and greater). For each curve fit, the EPA selected from among several possible equation forms: linear, quadratic, cubic, power, exponential, and logarithmic. The EPA chose the form that resulted in the best correlation coefficient (R^2), subject to the requirement that the equation must be monotonically increasing over the appropriate range of flow rates (i.e., within the flow rate category, the equation must always result in higher estimated costs for higher flow systems than for lower flow systems).

For the selected technology (medium-cost perchlorate-selective 170,000 BV), the costs are calculated based on the following equation:

$$Cost = C7 \times Q^3 + C8 \times Q^2 + C9 \times Q + C10$$

where Q is treatment process design flow (MGD) for total capital costs or treatment process average flow (MGD) for annual O&M costs. Exhibit C-1 shows the values for C7 through C10 for the selected technology based on the water source (ground water or surface water) and system size.

Exhibit C-1: Capital and O&M Control Cost Curve Parameters

Source	Size	Cost Type	C7	C8	C9	C10	Useful Life
GW	Small	O&M	56351.5	-50187.5	122627.1	4364.815	17.69411765
GW	Medium	O&M	0	0	133861.3	29816.62	31.74
GW	Large	O&M	0	0	122526.4	48879.59	33.95882353
SW	Small	O&M	0	-18636.8	118095.4	4401.098	17.69411765
SW	Medium	O&M	0	0	136673.8	28097.73	31.74
SW	Large	O&M	0	0	123719.9	66316.38	33.97058824
GW	Small	Total capital	111665.4	-213210	435508.3	125329.7	17.69411765
GW	Medium	Total capital	802.1603	-17543.4	455922.7	687296.4	31.74
GW	Large	Total capital	0	0	287995.3	1130876	33.95882353
SW	Small	Total capital	111750.5	-213364	435584.9	125332.8	17.69411765
SW	Medium	Total capital	830.5377	-17999.3	457555.7	685792.9	31.74
SW	Large	Total capital	0	0	287250.1	1144962	33.97058824

Additionally, given the high perchlorate removal efficiencies achieved by the treatment technology, the EPA assumes that systems can blend treated water and untreated water to meet the MCL. As such, the EPA applied the above equations using treatment process flows that account for the blending rate, which is the proportion of influent water that must be treated. For example, a blending rate of 0.6 means 60 percent of the water is treated and then blended with 40 percent untreated water. This rate depends on baseline perchlorate concentration, the treatment target concentration, and the removal efficiency of the treatment process (i.e., the percent of baseline perchlorate removed during treatment). For a treatment efficiency of 95 percent (or 0.95), the following equation defines the treatment target concentration of perchlorate (P_t) as a weighted average of the baseline concentration (P_b) and the treated water concentration [P_b x (1-0.95)] where the weights – based on the blending rate (B) – are (1-B) for the untreated water and B for the treated water:

$$P_t = (1 - B) \times P_b + B \times (P_b \times (1 - 0.95)).$$

Rearranging terms to solve for B (the blending rate) shows that the blending rate increases when the baseline concentration increases or the treatment target concentration decreases.

$$B = \frac{(P_b - P_t)}{P_b \times 0.95}$$

In turn, the equation presented above uses treatment process flow as the independent variable. Treatment process flow can be calculated from entry point flow by incorporating the blending rate as follows:

$$\text{Treatment Process Flow} = \text{B} \times \text{Entry Point Flow}$$

C.2 PWS Labor Rate Calculations

Section 5.2.1 summarizes the PWS labor rate used to estimate the administrative and reporting burden. This section describes the calculation of the labor rate in more detail. First, the EPA identified the labor rates in the WBS models for technical staff (i.e., a full-time treatment plant operators) and managerial staff (i.e., utility managers for smaller systems and environmental managers for larger systems). Then, EPA calculated a weighted wage rate for each system size range based on these labor rates and assumed division of labor among technical and managerial staff. Exhibit C-2 summarizes this calculation for each size range category; the weighted wage rate is calculated as follows:

$$Weighted = \sum_{i=1}^{7} [CWS_i\,(R_{t,i} \times W_{t,i} + R_{m,i} \times W_{m,i})] \,/\, \sum_{i=1}^{7} CWS_i$$

Where:

Weighted = Overall system wage rate for labor associated with the proposed rule
R = hourly loaded wage rate
W = assigned weight for labor category
t = indicator for technical labor category
m = indicator for managerial labor category

s = indicator for size stratum
CWS = number of CWS by size stratum.

Exhibit C-2: PWS Wage Rate Assumptions (2017$)

System Size (Population)	Technical Wage Rate[a]	Managerial Wage Rate[a]	Technical Weight	Managerial Weight	Weighted[b]	Number of Systems[c]
0-100	$31.91	$45.24	90%	10%	$33.24	10,838
101-500	$31.91	$45.24	90%	10%	$33.24	14,166
501-1,000	$31.91	$45.24	90%	10%	$33.24	5,117
1,001-3,300	$31.91	$45.24	90%	10%	$33.24	7,697
3,301-10,000	$34.05	$51.74	70%	30%	$39.36	4,663
10,001-50,000	$35.94	$57.64	70%	30%	$42.45	2,937
50,001-100,000	$37.52	$67.25	70%	30%	$46.44	445
> 100,000	$43.84	$71.85	70%	30%	$52.24	339

a. Source: Based on EPA WBS models. For more information, see USEPA (2018e).
b. Calculated as technical wage rate times technical weight plus managerial wage rate times managerial weight.
c. Source: USEPA (2018c). Includes community water systems.

For the systems serving more than 3,300, the EPA based the weight for technical and managerial labor on labor force data reported in (USEPA, 2009b). Comparing the managerial and treatment plant operator labor hours for all employment classes indicates that operator labor accounts for 70 percent of aggregate manager and operator labor hours while managerial hours account for 30 percent. Although the implied labor hour split was similar for smaller systems, the number of smaller systems reporting managerial hours was approximately one-third of those reporting treatment plant operator hours. Assuming one-third of systems serving up to 3,300 people have managers account for 30 percent of labor time, but the other two-thirds have no managerial labor time, the overall average is 10 percent managerial time.

The EPA calculated an overall weighted average wage rate across CWS based on the number of CWS in each size range. This yields an overall wage rate of $34.71 for PWSs. The EPA does not have wage rate data for NTNCWS. In the absence of data, the EPA used the CWS average wage rate as a proxy value for NTNCWS systems.

C.3 Household-Level Control Cost Calculations

This section shows how the EPA calculated household-level annual costs based on total annualized treatment costs. The analysis focuses on treatment costs because the cost of initial and follow-up monitoring will have a negligible impact on households.

First, the EPA estimated the number of households served by dividing PWS population by the median persons per household (PPH) for the service area associated with the PWS based on U.S. Census Bureau data. Then, the EPA summed treatment costs across all of a system's entry points and divided the total cost by the number of households. Exhibit C-3 shows this calculation. The values in the table are per-system values that do not take into account the implementation timeline (e.g., large CWS incur capital costs in year 6 and O&M costs thereafter through year 35 while small CWS incur capital costs in year 9 and O&M costs thereafter through year 35).

Therefore, the sum of the annualized costs below is greater than the treatment costs reported in Sections 5 and 6 because the sum does not take into account the effect of delayed implementation on total costs.

Exhibit C-3: Calculation of Household-Level Annual Control Costs

Entry Point	PWS	PWS Pop[a]	PPH[b]	PWS Households[c]	Total Entry Point Annualized Cost[d]		Total PWS Annualized Cost[e]		Household Annual Cost[f]	
					3%	7%	3%	7%	3%	7%
MCL = 56 µg/L										
FL6280250_004_08004	FL6280250	38,761	2.67	14,517	$157,776	$200,214	$157,776	$200,214	$11	$14
PR0002702_2702004_00004	PR0002702	25,972	2.77	9,376	$644,017	$751,577	$644,017	$751,577	$69	$80
MCL = 18 µg/L										
FL6280250_001_08001	FL6280250	38,761	2.67	14,517	$197,908	$246,137	$630,485	$780,477	$43	$54
FL6280250_002_08002	FL6280250	38,761	2.67	14,517	$208,039	$257,730	$630,485	$780,477	$43	$54
FL6280250_004_08004	FL6280250	38,761	2.67	14,517	$224,539	$276,611	$630,485	$780,477	$43	$54
FL6411132_POE1_08001	FL6411132	198,500	2.67	74,345	$2,385,945	$2,710,362	$2,385,945	$2,710,362	$32	$36
GA2190000_323_15152	GA2190000	15,231	2.72	5,600	$142,776	$181,117	$142,776	$181,117	$25	$32
LA1089001_3CAA-6_00001T	LA1089001	24,081	2.62	9,191	$338,089	$403,270	$338,089	$403,270	$37	$44
MD0120001_0100000_00001	MD0120001	13,800	2.68	5,149	$199,068	$245,137	$199,068	$245,137	$39	$48
MD0120002_0100000_00001	MD0120002	12,002	2.68	4,478	$196,194	$241,914	$196,194	$241,914	$44	$54
MS0750005_7500502_00004T	MS0750005	4,309	2.65	1,626	$79,736	$103,513	$79,736	$103,513	$49	$64
NM3528616_003_00003	NM3528616	16,500	2.66	6,203	$111,127	$146,997	$111,127	$146,997	$18	$24
NV0000076_EP04_00206	NV0000076	220,000	2.70	81,481	$1,923,507	$2,187,850	$1,923,507	$2,187,850	$24	$27
OH0900715_EP001_00008	OH0900715	42,097	2.43	17,324	$347,464	$414,047	$347,464	$414,047	$20	$24
OH4401612_EP001_00006	OH4401612	25,091	2.43	10,326	$450,128	$529,521	$450,128	$529,521	$44	$51
OK2002412_UCM0001_11032	OK2002412	35,031	2.60	13,473	$563,740	$656,196	$563,740	$656,196	$42	$49
PA6200036_00101E_00100	PA6200036	16,000	2.47	6,478	$322,605	$386,584	$322,605	$386,584	$50	$60
PR0002702_2702004_00004	PR0002702	25,972	2.77	9,376	$677,224	$789,394	$677,224	$789,394	$72	$84
TX1100002_04003_04003	TX1100002	13,805	2.88	4,793	$179,074	$222,667	$179,074	$222,667	$37	$46

a. PWS population based on USEPA (2019c).
b. Persons per household (PPH) is state-specific average household size from U.S. Census Bureau (2017c).
c. Calculated as PWS population divided by PPH.
d. Calculated based on method described in Section 5.1.
e. Calculated as the sum of all entry point costs for the PWS; in cases where only one entry point incurs control costs, PWS costs equal entry point costs.
f. Calculated as total PWS annualized costs divided by PWS households.

C.4 Monitoring and Waiver Schedule for Cost Analysis

As noted in Section 5, the EPA estimated the number of monitoring samples across all entry points from years 4 to 35 of the analysis period. The aggregate samples shown in Exhibit 5-5 reflect the following phases:

- 1. Initial monitoring; four quarterly samples at every CWS and NTNCWS entry point;
- 2. Preliminary regular monitoring before waiver application: three regular monitoring samples for every CWS and NTNCWS entry point (collected annually at surface water system entry points and triennially at ground water system entry points); and
- 3. Long-term monitoring at either (a) regular monitoring frequency for entry points at systems not granted waivers (60% of surface water system and 10% of ground water systems), or (b) reduced monitoring frequency for entry points at systems receiving waivers from primacy agencies (40% of surface water systems and 90% of ground water systems), which is one sample during every nine-year compliance monitoring cycle.

In this appendix section, the EPA provides more detailed estimates of monitoring and waiver impacts. Exhibit C-4 provides the annual estimates of the entry points affected by monitoring requirements per year and the number of systems submitting by applications for entry point monitoring waivers by year. Exhibit C-5 shows corresponding annual samples and waivers.

Exhibit C-4: Counts of Entry Points Conducting Monitoring and Systems Applying for a Monitoring Waiver by Analysis Year (4 to 35) and Source Water

Year	Total Number of Monitoring Samples					Number of Waiver Applications	
	Below MCL, Waiver, SW[a]	Below MCL, Waiver, GW[b]	Below MCL, No Waiver, SW[c]	Below MCL, No Waiver, GW[d]	Above MCL[e]	SW, Waiver[f]	GW, Waiver[g]
4	739	2,039	1,108	227	0.67	0	0
5	739	2,039	1,108	227	0.67	0	0
6	739	2,039	1,108	227	0.67	0	0
7	3,564	21,063	5,345	2,340	2	0	0
8	3,564	21,063	5,345	2,340	2	0	0
9	3,564	27,180	5,345	3,020	2	938	0
10	4,043	0	9,388	0	2	0	0
11	4,043	0	9,388	0	2	0	0

Year	Total Number of Monitoring Samples					Number of Waiver Applications	
	Below MCL, Waiver, SW[a]	Below MCL, Waiver, GW[b]	Below MCL, No Waiver, SW[c]	Below MCL, No Waiver, GW[d]	Above MCL[e]	SW, Waiver[f]	GW, Waiver[g]
12	4,043	69,306	9,388	7,701	2	3,576	0
13	0	0	9,388	0	2	0	0
14	0	0	9,388	0	2	0	0
15	0	69,306	9,388	7,701	2	0	1236
16	0	0	9,388	0	2	0	0
17	0	0	9,388	0	2	0	0
18	2,216	63,189	9,388	7,701	2	938	44,473
19	0	0	9,388	0	2	0	0
20	0	0	9,388	0	2	0	0
21	4,043	0	9,388	7,701	2	3,576	0
22	0	0	9,388	0	2	0	0
23	0	0	9,388	0	2	0	0
24	0	6,117	9,388	7,701	2	0	1,236
25	0	0	9,388	0	2	0	0
26	0	0	9,388	0	2	0	0
27	2,216	63,189	9,388	7,701	2	938	44,473
28	0	0	9,388	0	2	0	0
29	0	0	9,388	0	2	0	0
30	4,043	0	9,388	7,701	2	3,576	0
31	0	0	9,388	0	2	0	0
32	0	0	9,388	0	2	0	0
33	0	6,117	9,388	7,701	2	0	1,236
34	0	0	9,388	0	2	0	0
35	0	0	9,388	0	2	0	0

a. For entry points at SW systems that eventually qualify for waivers (40% of entry points):

- years 4-6 include initial monitoring for 1/3 of large CWS entry points each year;
- years 7-9 include annual monitoring for all large CWS entry points and initial monitoring for 1/3 of small CWS and all NTNCWS each year;

- years 10-12 include annual monitoring for small CWS and large/small NTNCWS;
- years 18 and 27 include repeat monitoring for large CWS re-applying for waivers; and
- years 21 and 30 include repeat monitoring for small CWS and large/small NTNCWS re-applying for waivers.

b. For entry points at GW systems that eventually qualify for waivers (90% of entry points):
- years 4-6 include initial monitoring for 1/3 of large CWS entry points each year;
- years 7-8 include initial monitoring for 1/3 of small CWS and large/small NTNCWS each year;
- year 9 includes triennial monitoring for all large CWS entry points and initial monitoring for 1/3 of small CWS and all NTNCWS;
- years 12 and 15 include triennial monitoring for all systems (the 2^{nd} and 3^{rd} cycle for large CWS and the 1^{st} and 2^{nd} cycle for small CWS and large/small NTNCWS);
- year 18 includes 3^{rd} cycle triennial monitoring for small CWS and all NTNCWS;
- years 24 and 33 include monitoring for large CWS re-applying for waivers; and
- year 27 includes monitoring for small CWS and all NTNCWS re-applying for waivers.

c. For 2 large CWS entry points that exceed the MCL of 56 µg/L:
- years 4-6 include initial monitoring for 1/3 of entry points; and
- years 7-35 include annual sampling; we assume the increased schedule (quarterly) monitoring throughout the analysis period instead of returning to the regular schedule. Primacy agencies may, however, eventually allow those systems monitor at the regular schedule, thus the assumption may overstate the monitoring impact.

d. For entry points at SW systems that will not receive waivers:
- years 4-6 include initial monitoring for 1/3 of large CWS entry points each year;
- years 7-8 include annual monitoring for all large CWS entry points and initial monitoring for 1/3 of small CWS and all NTNCWS each year; and
- year 9-35 include annual monitoring for all systems.

e. For entry points at GW systems that will not receive waivers:
- years 4-6 include initial monitoring for 1/3 of large CWS entry points;
- years 7-8 include initial monitoring for 1/3 of small CWS and all NTNCWS;
- year 9 includes triennial monitoring for all large CWS entry points and initial monitoring for 1/3 of small CWS and all NTNCWS; and
- years 12, 15, 18, 21, 24, 27, 30, and 33 include triennial monitoring for all systems

f. For SW systems that eventually qualify for waivers for entry point monitoring:
- years 9, 18, and 27 include waiver requests for large CWS systems; and
- years 12, 21, and 30 include waiver requests for small CWS and all NTNCWS.

g. For GW systems that eventually qualify for waivers for entry point monitoring:
- years 15, 24, and 33 include waiver requests for large CWS systems; and
- years 18 and 27 include waiver requests for small CWS and all NTNCWS.

Exhibit C-5: Counts of Monitoring Samples and Waiver Applications by Analysis Year (4 to 35) and Source Water

Year	Total Number of Monitoring Samples					Number of Waiver Applications	
	Below MCL, Waiver, SW[a]	Below MCL, Waiver, GW[b]	Below MCL, No Waiver, SW[c]	Below MCL, No Waiver, GW[d]	Above MCL[e]	SW, Waiver[f]	GW, Waiver[g]
4	2,955	8,156	4,432	906	3	0	0
5	2,955	8,156	4,432	906	3	0	0
6	2,955	8,156	4,432	906	3	0	0
7	7,606	84,252	11,410	9,361	8	0	0
8	7,606	84,252	11,410	9,361	8	0	0
9	7,606	90,369	11,410	10,041	8	938	0
10	4,043	0	9,388	0	8	0	0
11	4,043	0	9,388	0	8	0	0
12	4,043	69,306	9,388	7,701	8	3,576	0
13	0	0	9,388	0	8	0	0
14	0	0	9,388	0	8	0	0
15	0	69,306	9,388	7,701	8	0	1,236
16	0	0	9,388	0	8	0	0
17	0	0	9,388	0	8	0	0
18	2,216	63,189	9,388	7,701	8	938	44,473
19	0	0	9,388	0	8	0	0
20	0	0	9,388	0	8	0	0
21	4,043	0	9,388	7,701	8	3,576	0
22	0	0	9,388	0	8	0	0
23	0	0	9,388	0	8	0	0
24	0	6,117	9,388	7,701	8	0	1,236
25	0	0	9,388	0	8	0	0
26	0	0	9,388	0	8	0	0
27	2,216	63,189	9,388	7,701	8	938	44,473
28	0	0	9,388	0	8	0	0
29	0	0	9,388	0	8	0	0

Year	Total Number of Monitoring Samples					Number of Waiver Applications	
	Below MCL, Waiver, SW[a]	Below MCL, Waiver, GW[b]	Below MCL, No Waiver, SW[c]	Below MCL, No Waiver, GW[d]	Above MCL[e]	SW, Waiver[f]	GW, Waiver[g]
30	4,043	0	9,388	7,701	8	3,576	0
31	0	0	9,388	0	8	0	0
32	0	0	9,388	0	8	0	0
33	0	6,117	9,388	7,701	8	0	1,236
34	0	0	9,388	0	8	0	0
35	0	0	9,388	0	8	0	0

a. For entry points at SW systems that eventually qualify for waivers (40% of entry points):

- years 4-6 include 4 quarterly initial monitoring samples for 1/3 of large CWS entry points each year;
- years 7-9 include annual monitoring for all large CWS entry points and 4 quarterly initial monitoring samples for 1/3 of small CWS and all NTNCWS each year;
- years 10-12 include annual monitoring samples for small CWS and all NTNCWS;
- years 18 and 27 include monitoring samples for large CWS re-applying for waiver; and
- years 21 and 30 include monitoring samples for small CWS and all NTNCWS re-applying for waiver.

b. For entry points at GW systems that eventually qualify for waivers (90% of entry points):

- years 4-6 include 4 quarterly initial monitoring samples for 1/3 of large CWS entry points each year;
- years 7-8 include 4 quarterly initial monitoring samples for 1/3 of small CWS and all NTNCWS each year;
- year 9 includes triennial monitoring samples for all large CWS entry points and 4 quarterly initial monitoring samples for 1/3 of small CWS and all NTNCWS;
- years 12 and 15 include triennial monitoring samples for all systems (the 2nd and 3rd cycle for large CWS and the 1st and 2nd cycle for small CWS and all NTNCWS);
- year 18 includes 3rd cycle triennial monitoring samples for small CWS and all NTNCWS;
- years 24 and 33 include monitoring samples for large CWS re-applying for waivers; and
- year 27 includes monitoring samples for small CWS and all NTNCWS re-applying for waivers.

c. For 2 large CWS entry points that exceed the MCL of 56 µg/L:

- years 4-6 include 4 quarterly initial monitoring samples and a replicate sample for 1/3 of entry points; and
- years 7-35 include 4 quarterly samples per year; we assume the increased schedule (quarterly) monitoring throughout the analysis period instead of returning to the regular schedule. Primacy agencies may, however, eventually allow those systems monitor at the regular schedule, thus the assumption may overstate the monitoring impact.

d. For entry points at SW systems that will not receive waivers:

- years 4-6 include 4 quarterly initial monitoring samples for 1/3 of large CWS entry points each year;

- years 7-8 include annual monitoring samples for all large CWS entry points and 4 quarterly initial monitoring samples for 1/3 of small CWS and all NTNCWS each year; and
- year 9-35 include annual monitoring samples for all systems.

e. For entry points at GW systems that will not receive waivers:

- years 4-6 include 4 quarterly initial monitoring samples for 1/3 of large CWS entry points each year;
- years 7-8 include 4 quarterly initial monitoring samples for 1/3 of small CWS and all NTNCWS each year;
- year 9 includes triennial monitoring samples for all large CWS entry points and initial monitoring for 1/3 of small CWS and all NTNCWS; and
- years 12, 15, 18, 21, 24, 27, 30, and 33 include triennial monitoring samples for all systems

f. For SW systems that eventually qualify for waivers for entry point monitoring:

- years 9, 18, and 27 include waiver requests for large CWS systems; and
- years 12, 21, and 30 include waiver requests for small CWS and all NTNCWS.

g. For GW systems that eventually qualify for waivers for entry point monitoring:

- years 15, 24, and 33 include waiver requests for large CWS systems; and
- years 18 and 27 include waiver requests for small CWS and all NTNCWS.