COST BENEFIT ANALYSIS OF PROPOSED NEW HAMPSHIRE MAXIMUM CONTAMINANT LEVELS (MCLS) AND AMBIENT GROUND WATER QUALITY STANDARDS (AGQS) FOR PFAS SUBSTANCES

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Cost Benefit Analysis of Proposed New Hampshire PFAS Standards[1]

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Executive Summary

This study estimates the costs and benefits of the 2019 New Hampshire Department of Environmental Services (NHDES) proposed maximum contaminant levels (MCLs) and ambient ground water quality standards (AGQS) for Perfluorooctanoic acid (PFOA), Perfluorooctanesulfonic acid (PFOS), Perfluorononanoic acid (PFNA), and Perfluorohexanesulfonic acid (PFHxS) that are part of a broader class of polyfluoroalkyl substances (PFAS). I compare the difference between the cost of meeting the proposed New Hampshire standards and the cost of meeting less stringent standards, based on levels recommended in the EPA's 2016 Health Advisory, with the additional benefits of the proposed standards.

To estimate the additional costs of the proposed MCLs, I use data provided by the NHDES of the change in capital costs and the change in annual operation and maintenance costs for public water treatment plants that would need to be upgraded. I also use NHDES data on the additional treatment costs that wastewater disposal sites, landfills and hazardous waste sites would be required to incur to satisfy the proposed AGQS . The additional annual cost of the proposed MCLs for public water systems is between $10 million and $20.5 million per year in addition to between $1.5 million and $2.5 million per year to satisfy the groundwater quality standards.

Human studies have found some evidence on the adverse health effects of PFOA, PFOS, PFNA, and PFHxS, but all of these studies have limitations and cannot be used to determine a cause and effect relationship. Human studies have not demonstrated a relationship between PFOA, PFOS, PFNA, or PFHxS and cancer at levels experienced by those whose primary source of exposure is through drinking water. Even the New Hampshire Department of Health and Human Services found no significant difference between the observed and expected number of cancer cases for the town of Merrimack, where residents tested were found to have levels of PFOA in their blood over twice the national average in 2014.

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Importantly, when estimating these potential health impacts based on the scientific literature and recognizing that using target human serum concentrations predicted from laboratory animal serum concentrations addresses the uncertainty when extrapolating from animal studies to humans, this obviates the need for uncertainty factors to account for these differences in the use a toxicokinetic model. Thus, the NHDES and MDH (Minnesota Department of Health) MCLs could be higher by at least a factor of three and still be very health protective.

Reliable quantitative data is not available from human epidemiological studies of health effects of PFAS substances at the low background levels that would have resulted from drinking water from New Hampshire public water systems. I utilized results from two studies to estimate order of magnitudes of possible health effects for subjects with blood serum levels of PFOA and PFOS levels comparable to what has been observed in some New Hampshire communities:

- One of the studies estimated the relationship between PFOA blood serum levels and birthweights.
- The other estimated the effect of PFOS blood serum levels on immune system function and the associated increase in pneumonia cases in pre-school children.

From the study of PFOA on birthweights, I estimate the total benefits of reducing PFOA to levels at which it would be assumed that there would be no adverse effects on birthweights to be between $1.1 million and $6.5 million per year. The estimated total benefits of reducing PFOS low enough at which it would be assumed that there are not adverse effects on immune system function would be less than $1.5 million per year. Comparing the lowest cost estimates to the highest estimated benefits, the costs outweigh the benefits by almost 150%. Since the actual benefits may be much lower, it is not improbable that the costs of implementing DES' MCLs could be many times the health benefits.

While good health and protection from risk is something that everyone values, using animal studies and a series of conservative assumptions can lead to over-estimating the potential risk. In a perfect world, that may be fine, but resources are limited so we need to consider the high economic cost of compliance. This analysis raises serious questions about requiring taxpayers to spend millions to achieve proposed drinking water targets that may not afford any more protection than the higher targets that almost every public water system already satisfies.

Introduction

In 2019 the New Hampshire Department of Environmental Services (NHDES) initiated rulemaking to adopt Maximum Contaminant Levels (MCLs) and ambient groundwater quality standards (AGQS) for four compounds that are part of a broader group of chemicals referred to as per- and polyfluoroalkyl substances (PFAS) (New Hampshire Dept of Environmental Services, 2019a). The chemicals are Perfluorooctanoic acid (PFOA), Perfluorooctanesulfonic acid (PFOS), Perfluorononanoic acid (PFNA), and Perfluorohexanesulfonic acid (PFHxS). The proposed MCLs and AGQS for PFOA and PFOS are lower than the concentration levels the U.S. Environmental Protection Agency (EPA) recommended in its 2016 health advisory (US Environmental Protection Agency, 2016a, 2016b). EPA has not proposed health advisories for PFNA or PFHxS.

This study provides a cost-benefit analysis of these proposed MCLs. More specifically, how do the additional costs of the more stringent standards proposed by NHDES compare with the additional benefits of those standards?

The next section provides some background information on the chemicals of interest and EPA's and the state of New Hampshire's action with respect to these chemicals. Following this is a discussion of the possible health benefits of reducing PFOA, PFOS, PFNA, and PFHxS concentrations in drinking water from current levels to levels below the New Hampshire proposed MCLs. The next section provides some estimates of the possible dollar value of human health benefits of reducing PFAS concentrations to the proposed New Hampshire MCLs. Following is a discussion of the cost of upgrading water treatment plants, and of steps to improve the quality of groundwater migrating from sites where wastewater is discharged, from landfills, and from hazardous waste sites in order to reduce PFAS concentrations in drinking water and groundwater so as to satisfy the proposed MCLs and AGQS. The concluding section compares the benefits with the costs of the standards, using cost estimates from NHDES along with upper bound estimates of possible health benefits based on human epidemiological studies. Although the benefit estimates are somewhat speculative, they are lower than the lower bound estimates of costs, particularly when we compare per capita benefits and per capita costs for smaller water treatment plants that are likely to incur the highest costs.

Background on PFAS Substances

PFOA and PFOS have been used in a variety of consumer products and most people have detectable levels of PFOA and PFOS in their blood. Many people have been exposed to these chemicals through consumer products and food. Drinking water is an additional source of exposure in communities where these chemicals have contaminated water supplies. Exposure to high concentrations of these substances "is typically localized and associated with a specific facility" (US Environmental Protection Agency, 2016c). PFAS were released in and around manufacturing facilities, from wastewater treatment plants and as a result of the use of fire suppression systems, particularly at locations used for firefighter training (US Environmental Protection Agency, 2017).

PFOS was voluntarily phased out by its primary manufacturer and "eight major companies voluntarily agreed to phase out their global production of PFOA and PFOA-related chemicals" in 2006 (US Environmental Protection Agency, 2016c).

The EPA was the first agency to develop screening levels for PFOA and PFOS. They are Health Advisory Levels[3] and are not primary drinking water standards. They serve here as a point of comparison to the values derived by NHDES.

NHDES used fairly standard methods to develop the MCLs proposed in January 2019. NHDES updated the proposed MCLs in June 2019 by using a model developed by the Minnesota Department of Health (MDH), thus the MDH approach to developing drinking water standards for PFAS is also presented here.

EPA Health Advisories

To provide context for the New Hampshire MCLs, the EPA's Health Advisories for PFOA and PFOS are presented here. The health advisories serve as a conservative, and perhaps themselves overly conservative, comparison for the New Hampshire MCLs.

"EPA's health advisory levels were calculated to offer a margin of protection against adverse health effects to the most sensitive populations" (US Environmental Protection Agency, 2016c). The EPA developed lifetime health advisories for PFOA and PFOS in 2016, but not for PFNA and PFHxS. Laboratory studies on animals and human epidemiological studies have identified a number of possible health effects of PFOA and PFOS. These studies find that exposure to PFOA or PFOS above certain levels may result in several different kinds of health effects, including developmental effects to fetuses and to breastfed infants, reproductive effects, liver effects, immune system effects, thyroid effects, and effects on cholesterol levels (US Environmental Protection Agency, 2016c).

The EPA found there is "suggestive evidence" that PFOS and PFOA may cause cancer based on animal and human studies (US Environmental Protection Agency, 2017). The World Health Organization's International Agency for Research on Cancer has found that PFOA is "possibly carcinogenic to humans" (International Agency for Research on Cancer, 2016). Under EPA's Guidelines for Carcinogen Risk Assessment, when there is suggestive evidence for carcinogenic potential for a chemical, a dose-response assessment would generally not be attempted (US Environmental Protection Agency, 2005). In the case of PFOS, EPA determined that the existing evidence does not support a strong correlation between the tumor incidence and dose to

[3] "EPA's health advisories are non-enforceable and non-regulatory and provide technical information to states agencies and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination." See https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos for more information.

justify a quantitative assessment (US Environmental Protection Agency, 2016a, p. 42). Although not enough data were available for PFOA, EPA concluded that a quantitative analysis could be useful by providing a sense of the magnitude of potential carcinogenic risk (US Environmental Protection Agency, 2016b, p. 56). The EPA health advisories were based on peer reviewed studies of the effects of PFOA and PFOS on laboratory animals, including monkeys, rats, and mice, and epidemiological studies of human populations exposed to these two compounds.

The EPA's Lifetime Health Advisory was calculated based on oral Reference Doses (RfDs) developed for PFOA and PFOS. The RfD for PFOA was calculated based on the human equivalent dose for developmental effects from a study in mice to which uncertainty factors were applied, with the end result being based on the assumption that humans are much more sensitive to the effects than animals. EPA notes that this value is the same as the RfD values calculated based on effects on adult body weight and relative liver and kidney weights in male rats, and based on effects on immune system challenges in mice (US Environmental Protection Agency, 2016b). A similar approach was taken for calculating the RfD for PFOS.

Because the RFDs are the same for PFOA and PFOS, the Lifetime Health Advisory Levels are also the same. Using the RfDs for PFOA and PFOS, and assuming that 100% of the dose can come from drinking water, EPA calculated a Drinking Water Equivalent Level (DWEL) of 0.37 micrograms per liter (μg/L). EPA then applied the default Relative Source Contribution (RSC) of 20% to derive a Lifetime Health Advisory of 0.07 μg/L[4].

EPA reports similar effects of PFOS and PFOA in animal studies on the liver, neonate development, and immune system function. Because they have similar developmental effects, the EPA recommends that where the two chemicals occur together in a drinking water source a health protective approach would be to require that the sum of the concentrations be less than 0.07 μg/L (70 parts per trillion) (US Environmental Protection Agency, 2016b, p. 10).

EPA evaluated the potential carcinogenic effects for PFOA, and determined that the RfD-based Health Advisory was also protective of potential carcinogenic effects.

Development of MCLs for New Hampshire

NHDES first proposed MCLs in January 2019 using a method similar to the EPA method, although different studies were used than those identified by EPA. NHDES revised the MCLs in June 2019, this time using the approach and model developed by MDH. Details of this model are presented in Appendix A.

New Hampshire's proposed standards are based on peer reviewed animal studies and were derived using uncertainty factors to estimate a level of exposure at which human health effects

[4] The RSC is the amount of a total target exposure that is allocated for drinking water. The remainder of the exposure is assumed to come from food and other sources. An RSC of 20% is the default value in a regulatory range of 20% to 80%.

are unlikely to occur. The standard for each substance is derived from what NHDES identified as the most sensitive endpoint, which is defined as the lowest exposure level for which any adverse effect is observed. NHDES identified different endpoints that were derived using different studies and different uncertainty factors than the EPA health advisories or the MDH MCLs.

Thus, although NHDES used the same model as MDH to develop their MCLs, they used different studies and different uncertainty factors to calculate the target human serum concentrations. For PFOA, where the MDH target serum concentration is 0.065 μg/L, the NHDES target serum concentration is 0.0125 μg/L.

Drinking Water Levels Under NH and Other Programs

The proposed EPA health advisory levels, MDH guidance values, and proposed New Hampshire standards are compared in Table 1 below.

Table 1. NHDES Standards Compared to EPA Health Advisory Levels (μg/L)

Constituent/Guideline	PFOA	PFOS	PFNA	PFHxS
EPA Health Advisory Levels[5]	0.07	0.07	NA	NA
MDH Guidance Value	0.035	0.015	NA	0.047
NHDES Proposed MCL and AGQS	0.012	0.015	0.011	0.018

The purpose of this document is not to provide a critique of any of these values, however, it should be noted that all of them are very conservative. For example, using target human serum concentrations predicted from laboratory animal serum concentrations addresses the uncertainty when extrapolating from animal studies to humans, and obviates the need for uncertainty factors to account for these differences, especially with the use of a toxicokinetic model. Thus, the NHDES and MDH MCLs could be higher by at least a factor of three and still be very health protective. There are other factors to consider, including the relevance to humans of the sensitive endpoints selected from animal studies in general, and the relevance to the developing fetus in particular. However, the numbers as proposed are used here as the basis for this economic analysis.

Human Health Effects

Humans and laboratory rodents respond very differently to PFAS. Half-lives and other toxicokinetic parameters are quite different (Pizzurro et al., 2019). Toxicity of many compounds in rat liver depend on a mechanism (PPARα) that is not significant in humans, making the use of toxic endpoints in liver problematic to extrapolate to humans[6] (Corton et al., 2017).

[5] As noted above, the EPA health advisory levels also specify that the combined concentration of PFOA and PFOS not exceed 0.07 μg/L.

[6] https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHEERL&dirEntryId=339414

Human studies have found some evidence on the adverse health effects of PFOA, PFOS, PFNA, PFHxS. Steenland et al., (2018) summarize the results of human studies estimating a relationship between PFOA and birthweights. Their research raises questions about the direction of causality, suggesting that something other than increases in the amount of PFOA ingested may cause both low birthweights and high PFOA blood serum levels. Some evidence from human health studies shows a relationship between PFOA, PFHxS and fecundity (Velez, Arbuckle, & Fraser, 2015). Some human studies also find a relationship between PFOA, PFOS and immune system function (Chang, Adami, Boffetta, Wedner, & Mandel, 2016). However, all of these studies have limitations, and cannot be used to determine a cause and effect relationship.

Human studies have not demonstrated a relationship between PFOA, PFOS, PFNA, or PFHxS and cancer at levels experienced by those whose primary source of exposure is through drinking water. The New Hampshire Department of Health and Human Services found no significant difference between the observed and expected number of cancer cases for the town of Merrimack, where residents tested were found to have levels of PFOA in their blood over twice the national average in 2014 (New Hampshire Dept of Health and Human Services, 2018).

Estimating the Benefits of More Stringent State Standards

The EPA health advisory levels are very conservative. Evidence is limited for answering the question of whether the proposed New Hampshire MCLs will have a measurable impact on health compared to basing the standards on the EPA advisory levels[7].

All of the proposed MCLs and AGQS are based on animal studies. By definition, the reference dose (Rfd) from those studies is that dose below which no adverse health effect is expected to occur. Exposures above the RfD do not mean that an adverse effect will occur, only that the exposure needs to be evaluated in more detail. For example, NHDES makes a point of saying that the serum concentration in humans that equates to the RfD "*is not a clinical or diagnostic value, nor should it be interpreted as such*" (NHDES Attachment 1 – June 28,2019). For the PFOA and PFNA standards, which are based on increased liver weight, the most we can say is that there is the possibility of an adverse effect in humans at levels above the standard. We cannot tell what the probability of an effect is, but it may well be much less than one. First, as noted above, the major liver toxicity mechanism in rodents is not prevalent or relevant in humans. Second, NHDES has used a model that is designed to be used to be protective of a neonate, but NHDES has selected endpoints in adults rather than those that may be relevant to the neonate. Also, as noted above, no matter the target drinking water concentration used, the modeled serum concentrations return to steady state adult levels by 10 to 15 years of age. Similarly, the

[7] According to NH DES (2019-01), only 0.5% of the water sources sampled did not meet the EPA health advisory levels. Since high levels of one PFAS substance are usually associated with high levels of others, upgrading water systems to satisfy standards based on EPA advisory levels for PFOA and PFOS would likely also reduce concentrations of PFNA and PFHxS.

PFNA standard is based on liver function in pregnant women, which is not a mechanism that would function in the neonate.

A more detailed assessment of the proposed MCLs and AGQS is included in appendix B

Valuing the Health Benefits to Compare with Costs of Implementing NHDES Standards

This study estimates the additional costs and additional benefits of standards that are more stringent than the EPA health advisory levels. Thus, we do not count the costs or benefits to those water systems with PFOA or PFOS concentrations higher than the EPA health advisory levels, because those systems would have upgraded even if those levels were used as the standard. According to Clark Freise, the cost of upgrading a water treatment plant to meet the proposed NHDES standard would not be much more than the cost of upgrading to meet standards consistent with the EPA advisory levels (Freise, 2020). So, the relevant costs and benefits for this study are those that apply to water systems and the population served by those water systems that would not have to make any changes to provide water with PFOA and PFOS concentration less than 70 ppt as recommended by the EPA but have concentration of one or more PFAS substances in their drinking water that exceeds the proposed NHDES standards.

The animal studies that were used to identify the most sensitive endpoint in deriving the standards for each of the PFAS substances do not provide enough information to estimate the monetary value of the benefits of the proposed standards. As noted in our evaluation of each of the proposed MCLs in appendix B, there is good reason to think that they are lower than needed to be health protective. Nevertheless, it is helpful for illustrative purposes to estimate some possible benefits of upgrading drinking water systems to satisfy the standards proposed by NHDES. Each health effect used to estimate the benefits discussed below is based on the results of one human epidemiological study.

<u>Estimating the Benefits of Avoiding Low Birthweights Attributed to PFOA Exposure</u>

Several studies show an association between PFOA and low birthweights in human subjects[8]. Although the proposed New Hampshire standards were not derived with low birthweights in mind as a sensitive endpoint, there is some evidence that higher PFOA blood serum levels are associated with lower birthweights, and at least one human epidemiological study has measured the size of the effect (Malits, Blustein, Trasande, & Attina, 2018). I use estimates from this nationwide study of the effect of PFOA on the number of low birthweight babies to estimate the benefits of reducing PFOA to the levels in the proposed standards.

A number of studies have been conducted to estimate the effect of PFOA on birthweight in humans. The NHDES estimated the benefits of lowering PFOA levels to the point where they

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[8] For a recent review of the literature see Steenland et al (2018).

have no effect on birthweights (New Hampshire Dept of Environmental Services, 2019b)[9]. This calculation is based on results from Malits et al (2018). Data on the distribution of blood serum levels is from a representative sample of women of childbearing age in the US population during each two-year period between 2003-04 and 2013-2014 taken from the National Health and Nutrition Examination Survey (NHANES) administered by the National Center for Health Statistics of the Centers for Disease Control and Prevention as cited in Malits et al (2018).

PFOA blood serum levels were falling for women of child bearing age in the US population between 2003 and 2014 time according to the NHANES (Malits, Blustein, Trasande, & Attina, 2018). The number of low birth weights due to PFOA exposures estimated by Malits et al. (2018) is a function of the assumed distribution of blood serum PFOA levels. The NHDES (2019) argues that since national averages for PFOA serum levels for 2013-14 were half what has been measured in some impacted New Hampshire communities, benefits of reducing PFOA should be calculated using years when the US population had similar blood serum levels as New Hampshire impacted communities. But even though residents of impacted communities in New Hampshire have higher blood serum levels than the US population as a whole, that does not mean that the distribution of blood serum levels in New Hampshire is any different than the distribution in the US as a whole. The population of impacted communities is a small share of the state population so that the distribution of blood serum levels in New Hampshire may not be much different than that for the US as a whole in 2013-2014.

The Malits et al. (2018) study calculates the cost of each low birthweight baby in terms of the cost of a lower IQ and expected hospitalization costs for medical problems associated with low birth weight. They estimated that on average low birth weight resulting from PFOA exposure lowers IQ by 4.98 points and results in over $12,000 of extra hospital costs. Those with lower IQs are less productive and earn lower incomes over their lifetimes. The foregone cost of a low birth weight includes the sum of estimated hospitalization costs during the first year of life plus the reduced productivity associated with a lower IQ. For each reduction of IQ by 1 point, lifetime income was estimated to fall by $19,269 in 2014. The estimated hospitalization costs are for the first year of life.

NHDES arrives at an estimate of the cost of low birthweights due to PFOA exposure by assuming that the distribution of PFOA exposure in the New Hampshire population is comparable to the distribution of PFOA exposure in the US population in 2007-2008, when it was about twice as high as it was in 2013-2014[10]. This is an upper bound estimate. If one assumes that these correlations reflect causation, then using the Malits et al. counterfactual model of the estimated number of low birthweight babies born as a function of the distribution of PFOA exposure results in an estimate of 17,501 low birthweight births per year in 2007-2008 in the US that could have been prevented with reduced PFOA exposure. I also estimated a

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[9] The documents provided to me by NHDES do not claim that their standards were derived using birthweight data. This data is presented in their summary document as suggestive of how the benefits of their PFOA standard may be estimated.

[10] A recent estimate for Merrimack, which has some of the highest PFOA exposure levels in the state showed those levels were higher than the average for the US in 2007-08.

lower bound cost assuming the distribution of PFOA levels in New Hampshire was closer to that of the US as a whole in 2011-2012. To be conservative I took the Malits et al (2018) estimate of the number of low birthweights in the US in 2011-2012 and multiplied it by 2. The lower bound estimate was 2800 babies with low birthweight for the US as a whole.

Using estimates from Malits et al. (2018), multiplying this by the upper bound value of the number of low birthweight births attributable to PFOA and adding the expected hospitalization cost results in a total cost in 2014 dollars of about $1.9 billion per year. Multiplying this number by the percentage of US babies born in New Hampshire results in an upper bound estimated benefit of just under $6 million per year from reducing PFOA exposure to a "safe" level in New Hampshire. The lower bound estimated benefit for the entire US is more than $300 million, which equates to an estimated benefit for New Hampshire of just under one million dollars per year. If we adjust these estimated benefits for inflation between 2014 and 2019, the result is an upper bound of about $6.5 million and a lower bound estimate of less than $1.1 million (Table 2).

Table 2. Benefits of Reducing Preventable Low Birthweights

	No. of low birthweights that are preventable	Cost per low birthweight	Total Benefit
Low Estimate	9	$ 117,960	$ 1,042,019
High Estimate	55	$ 117,960	$ 6,512,992

Source: Malits et al. (2018) and author's calculations

Malits et al. (2018) note several limitations regarding their valuation of the direct and indirect costs of low birthweights that can be attributed to PFOA. First, having a low IQ may reduce welfare in ways not fully accounted for by reduced lifetime income and hospitalization costs. There may be additional medical costs and health consequences experienced by those with low birth weights beyond those incurred during the first year of life. But the IQ loss decrements associated with low birth weights as reported by Kormos et al (2014) may be an overestimate of the actual reduction in IQ and thus of lost lifetime earnings. This is because the average low birthweight infant in the Kormos et al study weighed 1300 grams (2.9 lbs.), while the mean low birth weight in the Malits et al study was above 2000 grams (4.4 lbs.) in each year of the study. The combined effect of these two sources of error implies that the above estimates of foregone costs could over or underestimate the beneficial effects of reducing PFOA exposure on birthweights.

Although the benefit associated with any given reduction in the number of low birthweight babies could be over or underestimated, the reduction in the number of low birthweight babies is likely overestimated. First, there are questions about the direction of causality between birthweights and PFOA blood serum levels. In a recent meta-analysis of 24 studies that estimate the relationship between PFOA and low birthweights, those studies with statistically significant results sampled mothers in the second or third trimester (Steenland, Vaughn, & Savitz, 2018). But increases in blood volume or in the glomerular filtration rate (GFR) later in pregnancy could cause a reduction in maternal serum PFOA concentration. The magnitude of maternal blood volume expansion is related to fetal growth (Vricella, 2017). GFR also affects both birthweight and the amount of serum PFOA, with a positive effect of GFR on birthweight and a negative effect on serum PFOA. This effect should be more evident later in pregnancy when GFR has increased by 40-50%. Steenland et al. (2018) find that none of the studies of blood serum levels during the first trimester of pregnancy finds a statistically significant relationship between PFOA and birthweight, although almost every study finds a negative effect, but one that is small enough that it could be caused by chance. All of the studies from late in pregnancy with statistically significant effects had relatively modest variation in PFOA levels in the sample populations studied.

A second reason why the reduction of PFOA levels resulting from the standards would not reduce the number of low birthweight babies as much as calculated is because the estimated benefits assume that all state residents would have access to drinking water with a PFOA level low enough so it does not affect birthweights. But the benefits of the regulation only affect those who get their water from public water systems. Approximately 250,000 households in New Hampshire get their water from wells. Although the regulations could have some beneficial effect on well water because the state requires actions to be taken by landfills and hazardous wastes sites, from which PFOA may leach into ground water, owners of wells will not be required to comply with the regulations. To do so would be quite costly for owners of wells where PFOA levels are now high.

In addition to the effect on birthweights, benefits should include other harmful health effects that could be avoided by implementing the proposed New Hampshire standards. Sufficient information is not available to demonstrate other health effects at doses below the EPA advisory levels, but they might exist. Some research has been done concerning immune system function in humans. The evidence for specific immune system responses is inconclusive[11]. Although highly speculative, I estimated ballpark figures for the possible cost of immunosuppression resulting from PFOS ingestion, since the standard for PFOS is based on reduced immune system function. The estimates are based on the author’s calculations from one human epidemiological study. See the appendix for additional details.

In addition to the possible health benefit listed above, upgrading of water treatment systems might also result in ancillary benefits from removing new emerging chemicals and other PFAS compounds that have not been well studied (New Hampshire Dept of Environmental Services, 2019). There is no way to estimate the order of magnitude of such effects.

[11] According to Chang et al. (2016) there is insufficient epidemiological evidence to conclude that a causal relationship exists between PFOA and PFOS and any immune-related health condition in humans.

Cost of Achieving Lower Standards

The NHDES estimated the additional capital costs and annual maintenance costs of reducing PFOS, PFOA, PFNA, and PFHxS concentrations from the EPA health advisory levels, to satisfy the MCLs in the final proposal. These estimates apply to public water systems, hazardous waste sites, municipal landfills, and wastewater discharges to groundwater. Table 3 lists the estimated costs of upgrading public water systems, wastewater disposal, landfill sites, and hazardous wastes sites to filter out PFAS compounds using data provided by the New Hampshire Department of Environmental Services (2019).[12] As noted above, the additional cost of meeting the NHDES proposed standard compared to the EPA health advisory levels is the cost of upgrading water treatment plants where PFOA and PFOS are already low enough to meet the EPA health advisory levels, but where concentration of one or more substances in treated water exceeds the proposed New Hampshire standards.

The cost estimates listed in Table 3 are based on two technologies commonly used for removal of PFAS substances: granular activated carbon (GAC) and resin (Underwood Engineers, 2018). Resin is the more expensive of the two. GAC may not be as successful as resin in removing short chain compounds, which are not currently included in the proposed state standards. For removing higher concentration compounds like PFOA, the most cost-effective option seems to be GAC (Underwood Engineers, 2018).

Levels of PFOA are above the proposed standard MCLs in 10 -11 percent of public water systems sampled in the state according to data reported by the NHDES (New Hampshire Dept of Environmental Services, 2019b). Early estimates were that only about 7- 9 percent of water systems in the state would need to be upgraded (Freise, 2020). Levels of PFOS, PFNA, and PFHxS each exceed the proposed standards in less than 5 percent of public water systems (New Hampshire Dept of Environmental Services, 2019b). Those water systems with high levels of PFOS, PFNA, and PFHxS are the ones that also have levels of PFOA above standards. The estimated costs for public water systems apply only to those public water systems where concentrations of one of the four substances in drinking water exceeds the proposed standards. If we assume that the water systems that will need to be upgraded serve about 11 percent of the state's population then the average total annual cost per capita of upgrading public water systems in those communities will be between $68 and $139[13].

[12] Capital costs were converted to annual values by calculating the payment required to amortize them over a 30-year period at 3 percent interest. The assumption is that water treatment plants will fully depreciate over 30 years. Even if the new equipment is still operational by that time, without new industrial sources it is likely that after 30 years, concentrations in water would decline enough so that PFAS substances no longer need to be filtered out of the water. If a lower interest rate is used, the estimated annual costs will be somewhat lower.

[13] According to Clark Freise, Assistant Commissioner of the NHDES, about 7-9 percent of public water systems in the state would have satisfied the EPA advisory levels for PFOA and PFOA but had concentrations of one or more PFAS substances exceeding the proposed New Hampshire standards. The percentage of the population served by these water systems could be larger or smaller than the percentage of systems, so our estimate of 11 percent is conservative. If the population we are assuming these water systems serve is less than that, then we have underestimated the per capita costs. If we use a lower discount rate of 1 percent, the range of costs declines to between $63 and $127 per capita.

Table 3. Change in Costs In order to Meet Proposed Standards

Category	Low Estimate	High Estimate
Additional Capital Costs- Public Water Systems	$ 63,195,633	$ 137,651,262
Annual payment for capital costs amortized for 30 years at 3 percent- public water systems	$ 3,224,194	$ 7,022,865
Annual Sampling Costs- Public Water Systems	$ 101,202	$ 259,584
Additional Treatment Costs- Public Water Systems	$ 6,799,640	$ 13,221,524
Total Annual Cost- public water systems	**$ 10,125,036**	**$ 20,503,973**
Total Cost per capita- public water systems	**$ 68**	**$ 139**
Wastewater Disposal to Groundwater (Capital Cost)	$ 3,900,000	$ 3,900,000
Landfill Sites (Capital Cost)	$ 555,000	$ 1,000,000
Hazardous Waste (Capital Cost)	$ 965,000	$ 2,130,000
Wastewater Disposal to Groundwater (Operation & Maintenance)	$ 649,000	$ 1,200,000
Landfill Sites (Operation & Maintenance)	$ 205,000	$ 310,000
Hazardous Waste Sites (Operation & Maintenance)	$ 410,000	$ 775,000
Subtotal- Capital Costs to meet AGQS	$ 5,420,000	$ 7,030,000
Subtotal- Amortized Capital Costs- AGQS	$ 276,524	$ 358,665
Subtotal- Operation & Maintenance- AGQS	$ 1,264,000	$ 2,285,000
Total Annual Cost- AGQS	$ 1,540,524	$ 2,643,665
Total Annual payment for capital costs amortized for 30 years at 3 percent	$ 3,500,719	$ 7,381,531
Total Operation and Maintenance Costs	$ 8,164,842	$ 15,766,108
Total Annual Cost- public water systems & groundwater	**$ 11,665,561**	**$ 23,147,639**

Source: New Hampshire Dept of Environmental Services (2019a)

Water treatment plants have economies of scale--the larger the population served, the lower the cost per capita. This is likely true of the additional costs associated with upgrading water treatment plants to reduce concentrations of specific contaminants. One study found that to satisfy the EPA MCL for arsenic would cost more than twice as much per capita for a water system serving a population under 1000 as for a system serving a population between 10,000 and 50,000 (Raucher, Rubin, Crawford-Brown, & Lawson, 2011).

The cost estimates listed in Table 3 are based on the cost of upgrading 7-9 percent of the water treatment systems in the state. More recent estimates suggest that only about 5 percent of public water systems in New Hampshire, with concentrations of PFOA and PFOS low enough to satisfy the EPA advisory levels, will need to spend substantial money to upgrade their treatment plants to meet the proposed New Hampshire standards (Freise, 2020). This is because some water systems that do not meet the new standards have found alternative sources for their drinking water or other ways to upgrade their treatment plants that involve little or no additional cost. The water systems that can make changes to meet the standards at little or no cost tend to be the larger water systems.

It is thus possible that the total capital costs of all New Hampshire water systems meeting the proposed standard might not be much more than half of the costs estimated in Table 3. If this is the case, it would not lower the per capita cost of meeting the standards, which would need to be recalculated with both lower total costs and a lower population affected. Since it is larger water systems that might be able to avoid all or most of the costs of upgrading their systems, and those systems tend to have lower costs per capita, the per capita annual costs of upgrading the remaining 5 percent of water systems, which serve smaller populations than average, may well be greater than the $68 -$139 per capita range of estimates listed above.

A considerable percentage of the state population does not get their water from public water systems. There are an estimated 250,000 private wells in the state. The additional costs incurred by the public water systems will not benefit these residents, some of whom likely get their water from wells with PFAS contamination.

Those who get their water from private wells as well as some public water systems will benefit from expenditures to reduce PFAS contamination at hazardous waste sites and landfills to meet AGQS. This study does not compare the benefits with the costs of the AGQS. As shown in Table 3, those standards cost an additional $1.5 to $2.5 million. Those standards may provide some benefits to those who get their water from wells, but it is not likely that the additional benefits would be very large.

Comparing Benefits and Costs

As discussed above, if the observed correlation between PFOA and birthweights reflects causation, then the benefits of fewer low birth weight babies by eliminating maternal exposure to high PFOA levels may be between $1.1 million and $6.5 million per year. There is also the possibility of a benefit from improved immune system function, which could be almost $1.5 million per year.

The relevant benefits and costs to be compared are the marginal costs and marginal benefits, not the average costs and benefits[14]. So even if the average costs per capita are lower than $68 because the total cost estimates are too high, which might be the case if some public water systems can find lower cost alternative ways to upgrade, the marginal costs per capita are likely $68 or higher. There is no reason to expect the marginal benefits per capita to be any higher in the towns that must bear the full cost of upgrading to meet the new standards. Although the new standards might pass a cost benefit test for those towns and cities that can find a low-cost

[14] Marginal cost is the additional cost per additional resident who drinks the water and marginal benefit is the additional benefit per additional resident.

way to upgrade their water systems, what limited evidence we have about the health effects of PFAS substances suggests that the new standards do not provide sufficient benefits to justify the high costs likely to be incurred by some of the smaller public water systems in the state.

If we divide by 11 percent of the population whose drinking water does not satisfy the proposed standards, just as we did in calculating costs, the estimated marginal benefit per capita from reduced low birthweights is between $7 and $44.[15] If we add in the possible benefits associated with improved immune system function, total benefits would be between $17 and $54 per capita, which is less than the lower bound estimate of the costs per capita. Thus, when we use quantitative estimates from human epidemiological studies, which have not been replicated, we get an estimate of benefits per capita that is less than the cost per capita. And each of these benefit estimates should be reduced because the probability of PFAS substances causing the large harmful health effects that is the basis of these estimates is considerably less than one.[16]

Good health and protection from risk is something that everyone values. But using animal studies and a series of conservative assumptions can lead to over-estimating the potential risk. In a perfect world, that may be fine, but resources are limited so we need to consider the high economic cost of compliance, which raises serious questions about requiring taxpayers to spend millions to achieve proposed drinking water targets that may not afford any more protection than the higher targets that almost every public water system already satisfies.

At this point, the state of New Hampshire has relatively accurate estimates of the costs of reducing the concentration of PFAS substances in drinking water from current levels to levels required to meet the proposed standards. We can be confident that many public water systems that do not now satisfy the standards will need to incur costs between $68 and $139 per capita and possibly more for very small water systems. Much less information is available on the benefits of doing so, and what estimates we can arrive at are quite speculative. Even by calculating upper bound estimates for two health effects for which evidence is inconclusive at best, benefits would not be large enough to cover costs.

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[15] If I have overestimated the percentage of the population that currently drinks treated water that exceeds the proposed MCLs, then both benefits and costs per capita will be underestimated by the same percentage. Total benefits are also likely to be lower if the population exposed to PFOA or PFOS levels above the proposed standards is lower.

[16] The expected value of each benefit is the probability of it occurring multiplied by the size of the benefit.

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Appendix A: Development of MCLs in Minnesota

The Minnesota Department of Health (MDH) came up with a lower MCL for PFOA than the EPA health advisory level because it used a different approach. The MCL is based on a toxicokinetic model that the MDH developed, and the MDH calculated a reference or target serum concentration to use in the model. The target serum concentration is based on a mouse developmental study to which Minnesota applied an uncertainty factor of 300 to derive the lower target PFOA serum concentration in humans. Minnesota further reduced the target by using an RSC of 50% to develop the target PFOA serum concentration for the drinking water scenario. The model predicts PFOA serum concentrations throughout a lifetime, starting from the newborn, based on a specific drinking water concentration. The model evaluates an infant as the critical receptor, and includes a woman's drinking water exposure to PFOA, transfer of PFOA across the placenta in a pregnant mother, and lifetime exposure by the offspring who is either formula fed or breast fed. Because of the conservative assumptions used in the breastfeeding scenario (95th percentile breastmilk intake and 95th percentile breastfeeding duration (1 year)), the model estimates a drinking water concentration that is protective of a breastfed infant that is ¼ the drinking water concentration that would be protective for formula-fed infants (Goeden, Greene, & Jacobus, 2019). The MDH model predicted that a lifetime drinking water concentration of PFOA of 0.035 µg/L is protective of breastfed infants. Note that each model run produces a graph of PFOA serum concentrations over a lifetime. Based on this model, serum concentrations peak in the first year of life, and then decrease to serum levels predicted for adults from drinking water between 10 and 15 years of age. To identify the final drinking water concentration, MDH iteratively ran the model for a range of input drinking water concentrations until one was identified where the maximum serum concentration over a lifetime of exposure, including the peak concentration in early childhood, was below the target serum concentration.

MDH also used the target serum concentration they developed to calculate an RfD; however, it is the target serum concentration that is used in the model, not the RfD.

Appendix B: Assessment of New Hampshire Proposed MCLs

To conclude that the benefits of the proposed NHDES standards are significant, more detailed data would be needed to confirm that there are any adverse health effects demonstrated in humans at levels below the EPA health advisory levels. Below we evaluate the MCLs and how they were derived for each of the four substances.[17]

- PFOA – the cited critical endpoint, increased liver weight, is not necessarily an adverse effect, is likely due to functional differences between rodents and humans, and is not necessarily an effect that would occur in the neonate. The calculated MCL results in serum PFOA in adults well below the target identified by NHDES. Although NHDES cites studies that have reported some instances of association between liver enzyme changes in humans and PFOA serum concentrations, these are not necessarily adverse effects, nor are they necessarily consistent with the rodent assay outcomes. The uncertainty factor of 3 for interspecies differences is not applicable based on the use of a toxicokinetic model, and the uncertainty factor for database limitations is also not necessary. Thus, just based on the uncertainty factors, the proposed MCL of 12 ng/L could be 3 to 10-fold higher, or 36 to 120 ng/L.
- PFOS – the cited critical endpoint, decreased Immunoglobulin M (IgM) production in rodents is of questionable biological significance in humans. The calculated MCL results in serum PFOS in adults well below the target identified by NHDES. The uncertainty factor of 3 for interspecies differences is not applicable based on the use of a toxicokinetic model, and the uncertainty factor for database limitations is also not necessary. Thus, just based on the uncertainty factors, the proposed MCL of 15 ng/L could be 3 to 10-fold higher, or 45 to 150 ng/L.
- PFNA – the cited critical endpoint is increased relative liver weight in pregnant mice. This is an effect in the mother, and not in the neonate. The calculated MCL results in serum PFNA in adults well below the target identified by NHDES. As above, the uncertainty factor of 3 for interspecies differences is not applicable based on the use of a toxicokinetic model, and the uncertainty factor for database limitations is also not necessary. Thus, just based on the uncertainty factors, the proposed MCL of 11 ng/L could be 3 to 10-fold higher, or 33 to 110 ng/L.
- PFHxS – the cited critical endpoint is decreased litter size. This is an effect in the mother, and not necessarily in the neonate, and the calculated MCL results in serum PFHxS in adults well below the target identified by NHDES. As above, the uncertainty factor of 3 for interspecies differences is not applicable based on the use of a toxicokinetic model, and the uncertainty factor for database limitations is also not necessary. Moreover, although all four of the studies (this and the three above) are of short-term duration, it was only for PFHxS that NHDES applied an extra uncertainty factor for “duration of exposure.” Thus, just based on the uncertainty factors, the proposed MCL of 18 ng/L could be 3- or 10 to 30-fold higher, or 54 or 180 to 540 ng/L.

[17] Lisa Bradley completed this analysis.

Appendix C - Estimating the Benefits in Terms of Foregone Costs of Reduced Immune-System Function

An effect found in some human studies of PFOS is immunosuppression. With a weaker immune system, incidence of pneumonia and other communicable diseases may increase (Goudarzi, et al., 2017). The Minnesota Dept of Health (2019), however, notes that "consistent association between serum PFOS and rates of infectious diseases have not been reported." Using data from a Japanese study on the effect of PFOS on the immune system (the study calculates the effect of PFOS on the incidence of pneumonia and other diseases in pre-school children), I estimated a cost of reduced immune system function of about $1.4 million per year (Goudarzi, et al., 2017). This is based on an estimated 117 additional pneumonia cases in affected communities and a cost of $12,181 to treat each pneumonia case (Sulley & Ndanga, 2019). Per capita, this comes to less than $10 per year. This cost might be somewhat higher if other diseases were included, but the other diseases considered rarely require hospitalization.

Table A1. Estimating the Cost of Reduced Immune System Function from PFOS Exposure

NH Births per year	% of population drinking water with PFOS above standard	Population incidence of child pneumonia cases due to reduced immunity	# of additional cases due to PFOS above standard	Avg. hospital cost of child pneumonia	Total Cost of Additional Pneumonia Cases
12372	11%	8.6%	117	$ 12,181	$ 1,425,800