Which Water to Drink? Costs and Benefits of Alternatives

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Abstract
Public water systems’ infrequent violations of United States Environmental Protection Agency’s (US EPA) health-based water quality standards are highly publicized (and often magnified) by mass media, although waterborne disease outbreaks and deaths have been significantly reduced since the advent of modern public drinking water systems in the U.S. A small number of water systems (e.g. Flint, Michigan) had serious water quality problems in recent years, but all consumers are presented with many alternative products by rapidly growing bottled water and home filtration device industries. We illustrate the problem of consumer decisions regarding drinking water alternatives, in the context of water quality, health, and cost information by investigating and reporting on differences in selected water quality parameters and economics of drinking water alternatives, including public water systems, private wells, bottled water, and home filtration devices. In our historical snapshot dataset, samples were taken from these sources in an Eastern Iowa study area during two different seasons and analyzed for contaminants typically found in highly agricultural areas. In addition to the snapshot data, we also examined the most recent available longitudinal data on study area public water systems and wells. Although there were differences in the numbers and concentrations of contaminants detected, no selected contaminants exceeded US EPA drinking water maximum contaminant levels in any of the drinking water categories. Based on our analysis, public water systems appear to be the most prudent choice for drinking water and therefore deserving of continued investment in associated infrastructure. Water filtration devices are the next best choice, with bottled water by far the most expensive, 280-6,300 times that of public water systems in the study area, without providing additional protection in the context of US drinking water regulations.

Keywords
Drinking Water Quality; Costs And Benefits; Bottled Water; Home Filtration Devices; Well Water; Water Infrastructure; Health-Based Standards; Consumer Risk Perception; Safe Drinking Water Act (SDWA); Public Policy

Introduction
As consumers, citizens, and water quality and health professionals, we are constantly faced with questions such as: What contaminants are found in the nation’s water? Where in the nation are these different contaminants found and at what concentrations? How many people are exposed to these contaminants at different concentration ranges? Are we all consuming water of the same or at least acceptable quality? Given such important consumer and health-related questions and the enormity of the potential investments in water-related infrastructure, we decided to investigate and compare the quality (in the context of health-based standards) and cost of drinking water alternatives in Eastern Iowa.

According to a 2012 Report of the American Water Works Association [1], at least a $1 trillion investment over the next 25 years will be needed to upgrade and revitalize the current water infrastructure to meet the demands of a growing population. As per the report, “the
more we delay the harder the job will be when the day of reckoning comes.” Indeed, such a day did arrive for Flint, Michigan which was recently awarded $100 million from the United States Environmental Protection Agency (US EPA) to replace lead service lines and make other critical infrastructure improvements under the Water Infrastructure Improvements for the Nation Act of 2016 [2].

Federal grants for water infrastructure projects ended in the 1960s, after which federal and state revolving loan programs were established; local rate-payers thus play an increasingly important role in financing water infrastructure projects [3]. For a large segment of the US urban population, drinking water is delivered by over a million miles of pipes, most of which were laid in the early to mid-1900s, with an expected life of 75 to 100 years. With continued deferred maintenance, the symptoms of an ageing water infrastructure will become more noticeable and potentially alarming to the public: issues related to pipeline breaks, corrosion, legacy and emerging contaminants will continue to arise, as illustrated in the case of Flint, Michigan [3, 4].

Increasingly, consumers around the globe are purchasing bottled water as a substitute for drinking water from the tap (Figure 1), buying home filtration devices for further treating tap water, and willing to pay more for infrastructure improvements for better quality. This trend points to a perception that tap water is not fit or adequate for drinking and could be related to several factors including potential health risks, taste, odor, age of the water infrastructure, marketing efforts and others [5-7].

A large body of research has shown that drinking water quality varies significantly over space and time; most drinking water contaminants do not occur in any given location; and the vast majority of community water systems (CWSs) in the US, especially during the last two decades, have had zero or only a few violations of health-based drinking water standards [8, 9]. Bottled water as a drinking water alternative has been available for several decades, and except for the recession years of 2008-09, sales have increased exponentially since the mid-1970s, from little over 1 gallon/person/year in the 1970s to over 39 gallons/person/year in 2016 [10] (Figure 1). Increasing sales of bottled water and home filtration devices has coincided with an overall decrease in the number of public water system violations of drinking water standards and waterborne disease outbreaks, which suggests that consumer decision-making is not consistent with available scientific evidence on drinking water quality conditions. Consumer knowledge of source water quality, the treatment and distribution processes, and finished water quality likely varies considerably. Consumer decision-making in this area may be influenced by sound-bytes and news alerts through mass media, which constantly remind us that at some time, somewhere, someone or an entire community is being exposed to potentially harmful contaminant(s) in their drinking water [2]. And although there are undoubtedly many contaminants (some of which are unregulated) in drinking water, such alerts need not necessarily be translated to an inference that all of us need protection from all contaminants at all places and times.

In this paper, we provide a brief history of the provision of drinking water in the US and of several different types of drinking water: tap water, private well water, filtered tap water, and bottled water. We then describe the water sampling and analysis procedures used to identify the similarities and differences in the chemical quality of such waters in selected locations in Eastern Iowa. Finally, we discuss our findings in two significant consumer contexts: 1) public health and water quality standards; and 2) economics-comparison of the cost of different drinking water alternatives.

**Figure 1: Per Capita Bottled Water Sales in the US (1976-2015)**

![Figure 1](image-url)

**Data Source:** Beverage Marketing Corporation [30]

**Brief History of US Drinking Water**

Prior to the construction of “modern” centralized water treatment and supply systems, drinking water was drawn directly from community wells, creeks, rivers, lakes, and other impoundments with little or no filtration or treatment. During this time, especially in densely populated
areas, outbreaks of waterborne illnesses such as typhoid and cholera were common, arising from the contamination of drinking water by a variety of industrial and domestic waste disposal practices [11, 12]. The Fairmount Waterworks (Philadelphia 1801) is widely recognized as the first public water system to serve an entire city in the US. Despite construction of water supply systems, typhoid and cholera outbreaks remained common (especially in warm months) in large cities until sewage was routed away from drinking water sources (e.g. in Chicago) and water filtration, followed by disinfection, and other types of treatments were deployed [3, 11-13]. Implementation of such measures in the late 19th century was influenced by a growing understanding of the mechanisms of waterborne disease propagation and a health sciences paradigm shift from miasma to bacteriology. These rapid changes were spurred in part by the work of John Snow, Louis Pasteur, and Robert Koch on the transmission and causation of cholera [11-14].

Most existing municipal water supply systems were financed by federal programs and built prior to the 1960s, when point-sources such as industrial and sewage treatment plants were the main pollution sources of concern [3]. Under the Federal Water Pollution Control Act (1948) and numerous subsequent amendments (now known as the Clean Water Act), significant progress has been made in addressing point source pollution. Non-point sources (e.g. runoff from agricultural lands, impervious surfaces, and construction sites) now cause most of our ambient surface water pollution problems [3, 15, 16]. Coupled with reductions in point source pollution, improvements in drinking water treatment have significantly reduced the number and types of waterborne disease outbreaks in the US in the last century, although it is likely that isolated and sub-acute waterborne diseases are likely underreported [17, 18]. Our health concerns have thus largely shifted from acute effects (e.g. gastroenteritis) caused by waterborne pathogens, to chronic effects (e.g. cancer) associated with low concentrations of ubiquitous chemicals such as fertilizers, aromatic hydrocarbons, and pesticides [19].

The past six decades have witnessed significant developments in the context of drinking water regulation. The Public Health Service Act (PHSA, 1944) established national water quality standards known as public health goals, and regulated a total of twenty-two contaminants, but was only legally enforceable for interstate water goals, and regulated a total of twenty-two contaminants, but was only legally enforceable for interstate water...
double its size for nitrate removal at a cost of $15 million [24]. Under certain conditions, contaminants such as trihalomethanes form in the distribution system due to chemical reactions between disinfectants (i.e., chlorine) and residual organic matter in the water. Finally, in some distribution systems and especially in pipes at homes, corrosion byproducts such as lead and copper may enter the water; in breached or stagnant lines, bacteria may also enter and/or multiply.

Privately Owned Wells

Unregulated private wells are the source of drinking water for approximately 42 million in the US who live on farms, or in housing developments or other homes and situations where connection to a public water supply is not possible [25]. In Iowa, approximately 330,000 (11% of the population) are served by private wells [26].

There have been two notable studies of water quality of private wells in Iowa: The Statewide Rural Water Well Survey (late 1980s), and the recent Iowa Statewide Rural Well Water Survey, Phase 2 [27]. These studies sampled approximately 500 wells and indicate that water from many private wells is of excellent quality; however, the proportion of private wells containing contaminants exceeding the SDWA maximum contaminant level (especially in the context of nitrate and coliform bacteria) is much higher than that of wells utilized for public water supply. Well depth is perhaps the most significant physical difference between most public and private wells. Shallow wells (<100 feet) are generally characterized by much higher concentrations of nitrate than “deep” wells (>100 feet) [27, 28]. In Iowa, for example, many public wells tap into aquifers that are between 500 and 2000 feet deep. Because many private wells are relatively shallow and draw from unconfined aquifers they are more vulnerable to contamination from surface activities. Many states’ land grant university extension systems have implemented programs (e.g. Home Asyst, Farm Asyst) to aid private well owners in construction, maintenance, vulnerability assessment, and testing. In Iowa, the state’s Hygienic Laboratory provides assistance and advice to private well owners in dealing with water related issues [29].

Bottled Water

Bottled water is treated and packaged generally for drinking purposes. Sales of bottled water in the US have skyrocketed in the last five decades; more and more Americans rely upon bottled water as their primary source of drinking water (Figure 1) [10, 30]. Individual consumption grew from 16.7 gallons per person in 2000 to 36.7 gallons per person in 2015, an increase of 120% [30].

There are several different types of bottled water, including: artesian, mineral, spring, distilled, and sparkling--different types are distinguished by factors such as mineral content, carbonation, and source [31]. As of the late 1990s, seventy-five percent of bottled water of US origin came from protected or uncontaminated wells and springs; while twenty-five percent originated from municipal water supplies [31]. As of 2010, up to one half of bottled water sold in the US may have originated as municipal tap water [32].

Since 1975, the Food and Drug Administration (FDA) has regulated the processing and bottling of bottled water. FDA specifies good manufacturing practices and processes, plant construction and design, sanitary facilities and operations including packaging and treatment methods, as well as appropriate equipment and procedures, and defines rules for labeling different types of bottled water (i.e., spring, drinking, purified, distilled, etc.). According to the Federal Food, Drug, and Cosmetic Act (FFDCA, 1996), FDA bottled water regulations are required to be as stringent as EPA rules for tap water. Members of the International Bottled Water Association (IBWA) are required not only to meet federal and state regulations, but also subject themselves to unannounced inspections as well as IBWA standards.

In its 1999 study, the Natural Resources Defense Council (NRDC) reported that bottled water may not actually be a pure, safe, or an economical alternative to tap water. Some bottled waters contained contaminants exceeding the maximum contaminant levels; approximately three percent of bottled waters tested by NRDC contracted labs contained coliform bacteria. In addition, bottled water may cost one hundred to ten thousand times more than tap water [33]. The bottled water industry asserts that it adheres to the “model code” of production and is in near perfect compliance with regulations when compared to public water supplies [34, 35]. In 2009, the US General Accountability Office reported that although EPA and FDA water quality standards are similar, the FDA’s enforcement capabilities are much weaker (particularly regarding enforcement of labeling requirements) [36]. One claim that cannot be disputed is that there is a considerable cost range that exists within the category of bottled water: the most expensive brands may be ten or more times as expensive as “no-name” grocery store brands.
Home Filtration Devices

In-home filtration devices (HF) can be separated into point of use (POU) and point of entry (POE) devices, which are respectively designed for use at the tap or at the entry point to a house or other structure. Such devices are most frequently employed as a supplement to public water system treatment but can in some situations serve as a substitute for public water supply treatment (e.g. when only one or a common class of contaminant is of concern, or when operation/construction of a centralized water system is infeasible). The in-home operation and performance of these devices is not subject to regulation under US environmental laws. The National Sanitation Foundation (NSF), a non-governmental entity, has established guidelines and standards for the construction and operation of POU and POE devices. NSF is the overseer of the POU/POE industry and works to ensure that such devices operate in the manner advertised [31, 37]. The Underwriters Laboratory (UL) has also recently begun testing and listing such devices.

Depending upon their design and filtration media, POU systems are designed to reduce the concentrations of different types of contaminants. Activated alumina cartridges or vessels are often used to remove fluoride; granular activated carbon is employed to address taste and odor concerns as well as remove regulated organic compounds. Finally, air stripping can be used to remove radon and volatile organic compounds [38].

POU systems generally consist of under the sink, countertop, and pitcher devices. There are five different types of point-of-use water purification systems: mechanical filtration (carbon), ion exchange, distillation, reverse osmosis, and ozonation [31]. Experts and the regulatory community generally agree that POU systems should not be permanent replacements for centralized water treatment systems [39]. Most POU devices have been purchased as an additional treatment to improve the chemical quality and/or taste of tap water: the popularity of such devices is growing rapidly; as of 1999, an estimated 20% of US homes owned a water filter-this was expected to increase to 50% by 2004 [40]. The POU water treatment system market has continued to expand rapidly and was valued at over $15 billion in 2015 [41].

Water Quality in the State of Iowa

Despite recent significant improvements in water treatment technologies and processes, the quality of “finished” or treated water still often reflects the quality of the source, or ambient, water. This is especially true in the context of surface water and shallow groundwater, which many private wells and larger communities rely upon for drinking water sources. Of all the states and regions within the US, Iowa’s landscape is perhaps the most altered by human activity: greater than 90% of the land in Iowa is devoted to some type of agricultural practice, with more than two thirds of agricultural lands in some type of row crop cultivation [42]. Additionally, Iowa is the nation’s largest pork producer, with a growing number and density of concentrated animal feeding operations. As evidenced by numerous state, county and other efforts at improving water quality, a significant proportion of Iowans believe that surface and ground water pollution are serious problems in the state. Recognizing the severity of this pervasive public concern, the Iowa Legislature recently approved a voluntary water quality bill redirecting $282 million over 12 years from state revenues to address such concerns [43].

Iowa drinking water systems utilize these same aquifers and surface water bodies as source waters. From 2002-2016, no waterborne diseases or deaths were reported from Iowa PWSs and fewer than 10% of Iowa PWSs violated a health-based standard. Most violations were of the coliform bacteria, nitrate, and disinfection byproduct standards. In eastern Iowa, most violations were by very small water systems serving populations less than 500 [44].

Bordered on the east (Mississippi) and west (Missouri) by two of the largest rivers in the world, Iowa contains a diverse array of surface water resources, including rivers, lakes, reservoirs, and alluvial aquifers. There are more than 71,000 total miles of rivers in the state; lakes and reservoirs occupy 145 and 64 square miles respectively [45]. More than two thirds of the states are drained by tributaries of the Mississippi. Alluvial aquifers serve as a significant source of drinking water for several of Iowa’s larger municipalities as they consistently yield large volumes of water. However, such aquifers are vulnerable to contamination because 1) they are linked to adjacent rivers, and 2) they are quite porous, shallow, and not protected from infiltration from the overlying land. Not surprisingly, water quality in alluvial aquifers tends to be similar to that of adjoining rivers or deeper aquifers to which they are connected [46]. The majority (92%) of Iowa drinking water systems rely upon groundwater only 8% of water systems in Iowa are surface-influenced. However, since many of the surface influenced systems serve large
communities (e.g. Des Moines, Iowa City, Cedar Rapids, Council Bluffs) such systems serve a significant portion (approximately 41%) of Iowa’s population [47].

An extensive body of existing research demonstrates that surface and shallow ground water quality is strongly related to land use in contributing watersheds and/or basins [28, 48-50], and that resultant non-point source pollutants vary widely over space and time [16, 49]. Non-point source contaminants such as herbicides exhibit pronounced fluctuations in concentration associated with a few post-application storms - a phenomenon termed the “spring flush” [51]. Deep groundwater (i.e., greater than 100 feet) in Iowa tends to be characterized by less agriculture-related (i.e., nitrate and herbicides) pollution [28, 48].

To provide a comprehensive comparison of the quality of available drinking water choices specific to Eastern Iowa, we collected water samples from several different types of drinking water in seven different communities during two seasons. Our aim was to address research questions regarding potential quantitative differences in water quality and to discuss these differences in the context of the cost and availability of alternative sources of drinking water. We compared the quality of several different categories of drinking water (i.e., PWSs, private farm wells, bottled water, and home filtration devices), and several sources or types within each category. Since the PWSs in our study area are all located in highly agricultural areas, we focus on contaminants typically related to agricultural activities.

Study Design and Methods

Rationale

As noted before, both ambient and drinking water quality vary widely by geographic location, and are influenced by a host of factors, including local land use. The health, economic, and justice issues associated with drinking water alternatives manifest themselves at local scales (i.e., the radii within which we conduct our daily lives). Numerous drinking water studies and reports have quantified and compared water quality within categories (e.g. bottled water, private wells, bottled water, and home filtration devices) over large areas (e.g. a state or the entire US); however, there is a dearth of empirical studies that compare locally available water quality between drinking water categories.

The problem of consumers’ decision-making process with reference to drinking water alternatives, in the face of imprecise and uncertain water quality, health, and cost information, is illustrated with the use of historical research data collected during 2003-04. We specifically address the following questions:

1. Are any contaminants detected in drinking water (PWSs, farm wells, bottled water, and home treatment devices) in the study area?
2. Are any contaminants detected at significant concentrations (>20% of the maximum contaminant level, a standard set under the SDWA) in the study area?
3. Does water quality vary between the four specified drinking water alternatives?
4. Does water quality vary within drinking water alternatives?
5. What are the economic costs and health benefits of different drinking water alternatives?

Study Area

To address our research questions on a local scale, we chose a relatively small area within which to conduct an empirical comparison of the quality of available drinking water alternatives. We focused on six communities located in a three-county area in Eastern Iowa. Selected communities ranged in size from less than 1,000 to greater than 120,000 inhabitants; PWSs in these communities rely upon source waters which include surface water, shallow groundwater, and deep well water. Some PWSs draw water from only one source (e.g. Cedar Rapids), whereas others such as Iowa City utilize multiple sources-the majority of Iowa City’s water, however, is drawn from shallow collector wells located adjacent to the Iowa River (See Figure 2 and Table 1).

Sample Collection Procedures

A total of 44 water samples were collected on December 16, 2003, and on May 12, 2004 (see Table 2 for a breakdown); 21 (+ 3 QA/QC) samples were collected from seven different PWSs (Table 2) on both sampling runs. PWS samples were collected directly from the tap after running the tap for 5 seconds. Four (+ 1 QA/QC) home filtration device samples (HF) were collected on each sampling run: one each from a Brita pitcher filter, Pur Ultimate faucet mounted filter, Kinetico VX reverse osmosis unit, Culligan FXRC refrigerator filter, and one
QA/QC sample. HF samples were collected directly from the filter tap and were collected only in Iowa City. Five (+1 QA/QC) samples from private wells were collected directly from the tap or the well hydrant. Eight (+1 QA/QC) bottled water samples were collected. To obtain the necessary volume, apart from the grocery store brand, bottled water samples were collected by thoroughly mixing the contents of multiple bottles (three in the case of Perrier, a six-pack in the case of Evian, Dasani, and Aquafina) in a sterilized vessel and then transferring to the appropriate sample bottles for submission to the laboratory. Samples from the grocery store brand were collected from one of the gallon-size plastic jugs provided at the store. Two samples were collected for each type of bottled water (except for Evian and Perrier) during each sampling run.

Using bottles and supplies provided by the State Hygienic Laboratory (SHL), samples were collected during the morning on each collection date and delivered to the SHL the same afternoon for processing, and analysis. The SHL is the state certified laboratory for chemical and microbiological analyses of air, water, soil, effluent, and clinical samples, and is certified by the AIHA, USEPA, NELAC, NVLAP, CLIA, NIST (asbestos), and OSHA (blood lead).

**Figure 2:** Geographic Setting of the Study Area in Central Eastern Iowa, USA

Table 1: Selected Eastern Iowa Water Systems’ Source Water

<table>
<thead>
<tr>
<th>PWS Name</th>
<th>Type</th>
<th>Source/Influence</th>
<th>Well Depth</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceder Rapids</td>
<td>Shallow GW</td>
<td>alluvium/Cedar River</td>
<td>~65 ft</td>
<td>120,758</td>
</tr>
<tr>
<td>Coralville</td>
<td>GW</td>
<td>Silurian-Devonian &amp; Cambrian-Ordovician (65%), drift (35%) aquifers</td>
<td>~500 ft (Silurian/devonian), 1700 ft (Cambro-Ordovician) 85 ft (drift)</td>
<td>15,123</td>
</tr>
<tr>
<td>Iowa City</td>
<td>ShallowGW</td>
<td>alluvium/Iowa River</td>
<td>~40 ft (alluvium); ~400 ft (Silurian), ~1600 ft (Jordan)</td>
<td>62,220</td>
</tr>
<tr>
<td>Mount Vernon</td>
<td>GW</td>
<td>Silurian-Devonian (67%) &amp; Cambrian Ordovician (33%) aquifers</td>
<td>~40 ft (SD); ~1560 ft (CO)</td>
<td>3,390</td>
</tr>
<tr>
<td>North Liberty</td>
<td>GW</td>
<td>Silurian-Devonian aquifers</td>
<td>~460 ft</td>
<td>5,367</td>
</tr>
<tr>
<td>Riverside</td>
<td>GW</td>
<td>Drift Aquifer</td>
<td>~250 ft</td>
<td>928</td>
</tr>
<tr>
<td>University of Iowa</td>
<td>River</td>
<td>Iowa River</td>
<td>N/A (Surface Source)</td>
<td>29,745^1</td>
</tr>
</tbody>
</table>

^1This figure only includes the number of students enrolled at The University of Iowa, which also has approximately 10,000 employees

Table 2: Distribution of Samples Taken in Fall 2003 and Spring 2004 Sampling Runs

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Water Systems</td>
<td></td>
</tr>
<tr>
<td>Cedar Rapids</td>
<td>3 + 1</td>
</tr>
<tr>
<td>Coralville</td>
<td>4</td>
</tr>
<tr>
<td>Iowa City</td>
<td>5 + 1</td>
</tr>
<tr>
<td>Mount Vernon</td>
<td>3</td>
</tr>
<tr>
<td>North Liberty</td>
<td>2 + 1</td>
</tr>
<tr>
<td>Riverside</td>
<td>2</td>
</tr>
<tr>
<td>University of Iowa</td>
<td>2</td>
</tr>
<tr>
<td>PWS Total</td>
<td>24</td>
</tr>
<tr>
<td>Private Wells</td>
<td>5 + 1</td>
</tr>
<tr>
<td>Bottled Water</td>
<td></td>
</tr>
<tr>
<td>Aquafina</td>
<td>2</td>
</tr>
<tr>
<td>Dasani</td>
<td>2</td>
</tr>
<tr>
<td>Evian</td>
<td>1</td>
</tr>
<tr>
<td>Grocery Store</td>
<td>2 + 1</td>
</tr>
<tr>
<td>Perrier</td>
<td>1</td>
</tr>
<tr>
<td>BW Total</td>
<td>9</td>
</tr>
<tr>
<td>Brita</td>
<td>1</td>
</tr>
<tr>
<td>Pur</td>
<td>1</td>
</tr>
<tr>
<td>Refrigerator Filter</td>
<td>1 + 1</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>1</td>
</tr>
<tr>
<td>HF Total</td>
<td>5</td>
</tr>
<tr>
<td>Total Number of Samples</td>
<td>44</td>
</tr>
</tbody>
</table>

Note: "+1" denotes a quality assurance/quality control (QA/QC) sample
### Table 3: Contaminants Analyzed for Drinking Water Study

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Detection Limit</th>
<th>Maximum Contaminant Level</th>
<th>Highest Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia Nitrogen as N</td>
<td>0.05 mg/L</td>
<td>None</td>
<td>5.6 mg/L (Farm Well #1)</td>
</tr>
<tr>
<td>Nitrate + Nitrite as N</td>
<td>0.1 mg/L</td>
<td>Nitrate: 10 mg/L; Nitrite: 1 mg/L</td>
<td>9.0 mg/L (University of Iowa)</td>
</tr>
<tr>
<td>Ortho Phosphate as P</td>
<td>0.05 mg/L</td>
<td>None</td>
<td>0.39 mg/L (Riverside)</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>0.05 mg/L</td>
<td>None</td>
<td>7.1 mg/L (Farm Well #1)</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>0.5 mg/L</td>
<td>None</td>
<td>5.1 mg/L (Farm Well #1)</td>
</tr>
<tr>
<td>Total Phosphate as P</td>
<td>0.02 mg/L</td>
<td>None</td>
<td>0.75 mg/L (Farm Well #2)</td>
</tr>
<tr>
<td>Acetochlor</td>
<td>0.05 ug/L</td>
<td>None</td>
<td>0.14 ug/L (Cedar Rapids)</td>
</tr>
<tr>
<td>Atrazine</td>
<td>0.05 ug/L</td>
<td>3 ug/L</td>
<td>0.17 ug/L (University of Iowa)</td>
</tr>
<tr>
<td>Butylate</td>
<td>0.05 ug/L</td>
<td>None</td>
<td>0.09 ug/L (Cedar Rapids)</td>
</tr>
<tr>
<td>Dimethanamid</td>
<td>0.05 ug/L</td>
<td>None</td>
<td>0.08 ug/L (Farm Well #2)</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>0.05 ug/L</td>
<td>None</td>
<td>0.12 ug/L (University of Iowa)</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>0.05 ug/L</td>
<td>None</td>
<td>0.3 ug/L (Farm Well #2)</td>
</tr>
</tbody>
</table>

mg/L = milligrams per liter or parts per million

ug/L = micrograms per liter or parts per billion
Box 1: Health Effects of Nitrate and Atrazine

There are two major categories of health effects associated with nitrates: 1) methemoglobinemia, and 2) cancer, although a recent study found positive relationships between high nitrate concentrations and body mass index, low recreational activity, and perceived susceptibility to a variety of illnesses [52]. Water quality standards for nitrates were originally established in order to reduce the incidence of methemoglobinemia or “blue baby” syndrome. Presence of nitrates in the blood causes oxidation of hemoglobin to methemoglobin, which is unable to transport oxygen. The skin of babies with high concentrations of methemoglobin often appears grey or blue [53]. Recent reported incidences of methemoglobinemia are rare: five cases attributable to nitrates in water were reported between 1991 and 1999 in the US [54].

With regard to cancer causation, experimental studies have shown that ingested nitrates are absorbed by the small intestine, transformed to nitrite, and secreted in saliva. Nitrite from saliva may interact with amines and amides in the stomach and convert to n-nitroso compounds, which have been shown to be powerful carcinogens [55]. Epidemiologic studies of associations between cancer and nitrate exposure via drinking water have had mixed findings. For example, there are findings of positive associations between exposure to elevated nitrate concentrations and bladder, colorectal, stomach cancers, as well as non-Hodgkin’s lymphoma [55-58]. Other studies report no association between elevated nitrates and stomach, esophageal, kidney, and bladder cancers [55, 59].

Atrazine was classified as a possible carcinogen; however, in 1999 EPA scientific advisory groups determined that atrazine was “not likely to be carcinogenic to humans” [60]. Atrazine exposure is believed to be linked to other health effects including disruption of the endocrine system (interference with the hypothalamus and pituitary glands), which can result in a variety of different health endpoints such as reproductive and developmental abnormalities including demasculinization; these effects have been demonstrated in animal models including mammals, fish, reptiles, and amphibians [61]. In laboratory experiments, chemical castration by exposure to atrazine has been demonstrated in amphibians at concentrations as low as 0.1 parts per billion, or 30 times less than the current drinking water standard [62]. In humans, it appears that atrazine and related compounds may be associated with pre-term deliveries and may impact brain development in children and adolescents [63, 64]. Health effects of atrazine’s two persistent breakdown products, desethyl atrazine and deisopropylatrazine, are believed to be similar to atrazine [60].

Rationale for Contaminant Selection

Along with nutrients (nitrogen and phosphorus species), samples were analyzed for a total of thirty-seven herbicides and herbicide metabolites. These herbicide compounds are routinely analyzed by the Water Monitoring Section of the Iowa Department of Natural Resources in its various ambient monitoring programs, which selects these compounds based on current and past herbicide use and detection patterns in Iowa. Atrazine and nitrate are two of the most frequently detected contaminants in agricultural communities; health impacts associated with exposure to these contaminants are detailed in Box 1. Water samples were also analyzed for two other general indicators of water quality: fecal coliform (MFC) and total organic carbon (TOC). Table 3 provides a complete list of contaminants analyzed in this study; Table 4 provides a list of the contaminants detected in the study, along with the applicable EPA maximum contaminant level, if any.

Results

Overall Findings

On examining the sample measurements obtained for this research, several observations are evident (See Table 5 and Figure 3). No sample measurement exceeded the water quality standard set as part of the SDWA; however, many detected measurements were below the standards. Only two detected contaminants (nitrate/nitrite and atrazine) are regulated under the SDWA. Some herbicides were detected in two PWSs and one private well. Fecal coliform bacteria were not detected in any sample. All non-herbicide compounds (nitrogen, phosphorus, and organic carbon) were detected at least once. Only seven of 37 measured herbicide compounds were detected in one or more sample. Total phosphate was detected in most samples. At least one species of nitrogen (i.e., nitrate, ammonia) was detected in nearly all samples. Findings related to occurrence, distribution, and standard violations
of drinking water quality contaminants within and between the four categories of drinking water sources are discussed, analyzed, and evaluated below.

Public Water Systems

Eleven contaminants were detected in PWS samples; nitrogen and phosphorus species and total organic carbon were detected at varying concentrations in all seven PWSs (Table 5). The University of Iowa (UI) and the Cedar Rapids PWSs were the only two to have detectable levels of any of the thirty-seven herbicides and herbicide metabolites. Acetochlor and atrazine were found in both; whereas, butylate was only found at Cedar Rapids, and desethyl atrazine and metolachlor were detected only at the UI. Given that these two PWSs rely upon surface-influenced supplies, the results are not unexpected. In terms of detected contaminants, there were few differences between the December and May sampling runs.

Multiple samples collected from individual PWSs showed very little variability in concentrations, and hence averages are used for discussion and shown in Figures 1 and 3. None of the measurements in the study exceeded any SDWA standard. The closest measurement to a health standard was that of \((\text{NO}_3+\text{NO}_2)\) at 8.1 mg/L from the May sample at the UI; 2) surface influenced supplies had higher concentrations of \((\text{NO}_3+\text{NO}_2)\) and TOC, with the exception of a sample from Riverside; 3) in the case of \((\text{NO}_3+\text{NO}_2)\), there were remarkable differences (2-3 mg/L) between December and May concentrations in the samples from the UI and Iowa City (IC) water supplies, which directly and indirectly draw water from the Iowa River; 4) other than \((\text{NO}_3+\text{NO}_2)\), there were no major differences between May and December measurements at PWSs; and 5) Riverside was the only PWS with a significant concentration of ammonia (~4 mg/L) in December and May.

Private Wells

All private wells in the study were in Johnson and Linn counties of Iowa and were less than 200 feet deep and some were as shallow as 60 feet. For confidentiality

Table 5: Detections of Selected Contaminants in Eastern Iowa Drinking Water

<table>
<thead>
<tr>
<th>Contaminants Tested</th>
<th>Public Water Systems</th>
<th>Bottled Water</th>
<th>Home Filtration</th>
<th>Farm Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CR</td>
<td>CV</td>
<td>IC</td>
<td>MV</td>
</tr>
<tr>
<td>Non-Herbicides</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia Nitrogen as N</td>
<td>B</td>
<td>D</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Membrane Fecal Coliform</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Nitrate + Nitrite as N</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Ortho Phosphate as P</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>B</td>
<td>B</td>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Total Phosphate as P</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Herbicides</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling Runs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D December</td>
<td>f1 (farm well 1)</td>
<td>CR</td>
<td>Cedar Rapids</td>
<td>Aq</td>
</tr>
<tr>
<td>M May</td>
<td>f2 (farm well 2)</td>
<td>CV</td>
<td>Coralville</td>
<td>Da</td>
</tr>
<tr>
<td>B Both</td>
<td>f3 (farm well 3)</td>
<td>IC</td>
<td>Iowa City</td>
<td>Ev</td>
</tr>
<tr>
<td></td>
<td>f4 (farm well 4)</td>
<td>MV</td>
<td>Mount Vernon</td>
<td>GS</td>
</tr>
<tr>
<td></td>
<td>f5 (farm well 5)</td>
<td>NL</td>
<td>North Liberty</td>
<td>Pe</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>Riverside</td>
<td>Br</td>
<td>Berta</td>
</tr>
<tr>
<td></td>
<td>UI</td>
<td>University of Iowa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Interpretation: This table depicts which contaminants were detected in which supplies, and during which sampling runs. Representative observations include; herbicides (the last contaminant category) were only detected in the Cedar Rapids (M = May) and University of Iowa (B = both) water supplies, and one farm well (M = May); only two contaminants (nitrate + nitrite and total phosphate) were detected in bottled water samples; and the most contaminants were detected in Cedar Rapids water supply (7), UI water supply (6), and farm wells (5). This table only provides information about whether contaminants were detected and not whether water quality standards were exceeded.
Figure 3: Comparison of Test Results for Selected Contaminants in Four Types of Drinking Water

Note: See Table 5 legend for explanation
reasons, exact locations of wells are not included. Six contaminants were detected in private wells: all nitrogen and phosphorus species as well as total organic carbon. Herbicides were detected in only one of the five farm wells. Except for herbicides, all detected contaminants were found in both December and May sampling runs (Table 5).

There were significant differences between well f1 and the other wells sampled in this study (Figure 3). Well f1 had much greater ammonia (>5mg/L) and total organic carbon (~5mg/L); 5 and 2.5 times that of wells with the next highest concentrations. Ammonia and TOC concentrations in the other wells were less than 2 mg/L. This pattern was evident in both winter and spring samples. Well f1 also had the highest concentrations of orthophosphate as P (not reported in Figure 3), of 0.23 and 0.25 in spring and winter respectively. Wells f2 and f3 had the highest total phosphate concentrations, but were still less than 1 mg/L. Well f2 was the only well in which herbicides (Dimethenamid and Pendimethalin) were detected.

**Bottled Water**

Only two contaminants were detected in the five different types of bottled water included in the study: nitrate + nitrite, and total phosphate. Nitrate + nitrite was detected in Evian, grocery store, and Perrier in both samples, and only in the May sample of Aquafina. Total phosphate was detected in all five bottled waters, but only in December samples (Table 5).

As noted earlier, two samples were collected on each run of Aquafina, Dasani, and grocery store brand bottled water. Since no significant differences in concentrations were noted between samples, all discussions in this section and reported in Figure 3 are based on averages. Although total phosphate was detected in all five brands, no concentration exceeded 0.06 mg/L. Nitrate + nitrite concentrations were highest in the grocery store brand (0.2 mg/L) in May, Perrier (1.2 and 0.8 mg/L) in May and December respectively, and Evian (0.79 and 0.7 mg/L) in May and December respectively. Nitrate + nitrite concentration (0.07) in Aquafina narrowly exceeded the detection limit of 0.05 mg/L. The SDWA standard for NO₃⁻N is 10 mg/L.

**Home Filtration**

Home filtration (HF) samples were collected only in Iowa City; the effectiveness of these devices in other communities would depend upon the tap water quality in those communities and the specifications of each individual device. Nitrate + nitrite was detected in all HF samples. The reverse osmosis system reduced all other Iowa City PWS contaminants to below detectable levels. The Pur and Refrigerator samples reduced TKN to below detectable level in May and December; whereas in terms of detections, the Brita pitcher was only able to reduce TKN to below detectable level in May. No herbicides were detected in any HF sample (Table 5).

In both May and December samples collected from the Brita, Pur, and refrigerator filters, (NO3+NO2) concentrations were comparable to Iowa City PWS water, with the Brita pitcher performing slightly better than the other two filters (Figure 3). The reverse osmosis system reduced May and December nitrate concentrations to near the detection limit of 0.1 mg/L. In the context of total phosphorus and total organic carbon, the Pur, Brita, and refrigerator filters provided some small but insignificant reductions in concentration compared to Iowa City PWS water.

**Between-Category Comparisons**

Six contaminants (maximum) were detected in 11 PWSs, followed by 6 private wells, 5 from water out of home filtration devices, and 2 bottled water brands (Table 5). The reverse osmosis system was able to reduce contaminant levels to near bottled water levels. This is not surprising since many of the bottled water products on the market (e.g. Dasani and Aquafina) are actually PWS water that is further purified via reverse osmosis. The single highest detection (with respect to the maximum contaminant level) was 8.1 mg/L of nitrate (81% of the standard) was found in a PWS sample taken from the UI. High nitrate concentrations were only found in the two PWSs reliant upon the Iowa River; neither bottled water nor private wells had a nitrate concentration greater than 2mg/L. Ammonia concentrations higher than 2 mg/L were only found in one PWS (Riverside) and one private well (R1). Whereas the total organic carbon was not detected at all in bottled water, there were several detections above 1 mg/L in PWSs, and two in private wells. Farm wells and PWSs had in general much higher concentrations of total phosphate.

**Validity of Historical Data**

To verify whether the water quality measurements of 2003-04 used in this study (Table 3) for the PWSs and
Wells (Tables 1 and 2), and the conclusions drawn are still valid under current conditions, we obtained three additional datasets and reviewed their content in the context of contaminants analyzed for the sites of interest.

Safe Drinking Water Act (SDWA) data from Iowa PWSs (Table 1) during 2005-16

The Center for Health Effects of Environmental Contamination [65] is a repository of several environmental datasets, including Iowa’s SDWA data from PWSs. We obtained data on 137,858 measurements covering the public water supplies of Iowa for the period 2005-2016. Six of the seven PWS listed in Table 1, use a combination of surface and groundwater sources, whereas, the University of Iowa Water Treatment Facility is the only one that draws exclusively from surface source of Iowa River.

• For Cedar Rapids PWS, 4,635 measurements were available. Seven out of 200 available Acetachlor measurements were found above the detection limit, and ranged from 0.16 to 1.5 ppb, and all the rest were below the detection limit. All 402 measurements for Alachlor were below the detection limit. 119 of 402 Atrazine measurements were in the range of 0.11 and 1.9 ppb, and the remaining were below the detection limit. The health-based standard for Atrazine in drinking water is 3 ppb. 31 of 400 Metolachlor measurements were detected in the range of 0.11 and 1.1 ppb, the rest were below the detection limit. All of 44 Nitrite-N measurements were below detection limit and the health-based standard for Nitrite-N in drinking water is 1 ppm. Nine of 875 Nitrate-N measurements were found in the range of 0.05 and 8.23 ppm. The health-based drinking water standard for Nitrate-N is 10 ppm. Total Organic Carbon was detected in all 474 measurements and were in the range of 0.88 and 8.18 ppm.

• For Coralville PWS, 54 measurements were available and only Ammonia-N was detected twice at 1.4 and 1.7 ppm and the remaining measurements were all below the detection limit.

• For Iowa City PWS, 464 measurements were available. Out of 213 available Nitrate-N measurements, 14 were below detection limit and the remaining 199 measurements were detected in the range of 0.5 and 7.3 ppm. The 238 Total Organic Measurements were found in the range of 0.8 and 4.7 ppm. All herbicides and their degradates were not detected.

• For Mount Vernon PWS none of the 52 reported measurements were above the detection limit.

• For North Liberty PWS, 10 of 28 measurements had detectable levels of Nitrate-N in the range of 1.1 and 1.4 ppm and the remaining were below detection.

• For Riverside PWS, out of 33 available measurements, 2 had Ammonia-N detected at 3.1 and 3.2 ppb during 2005 and 2006 and the remaining measurements were all below detection levels.

• For the University of Iowa Water Treatment Facility, which uses the surface waters of Iowa River, the latest Consumer Confidence Report [66] reported Nitrate-N in the range of 5.1 and 9.0, and Total Organic Carbon in the range of 1.07 and 4.38 ppm.

Farm Wells

To get an additional perspective of drinking water quality, samples from rural farm wells (that draw water from aquifers similar to those shown in Table 2) were also evaluated using the data available from the Iowa Statewide Rural Well Water Survey Phase 2 (SWRL2) [27]. The wells reported in Table 2 are from Linn, Johnson, and Washington counties of Iowa. SWRL2 was conducted from May 2006 through December 2008. As part of this survey, 473 wells from 89 counties were surveyed during 2006-08.

A total of 626 measurements of interest on Metolachlor, Nitrate-N, and Total Organic Carbon were available for analysis from samples taken from 2 wells in Johnson County, 3 in Linn, and 4 in Washington. They in turn, fetched 2 detections of Total Coliform (1 and 5 MPN/100ML) in Johnson County, 2 Nitrate-N detections of 1.1 and 5 ppm, and 2 Metolachlor detections of 0.2 and 0.9 ppb in Linn County, and 3 Nitrate-N detections of 2, 3.2, and 21 ppm, 2 Metolachlor detections of 0.07 and 0.1 ppb, and 4 Total Coliform detections of 1, 6, 9, and 310 MPN/100ML.

The data presented above from multiple sources for the period 2005-2016 clearly reveal the paucity of detections, low concentrations of detected contaminants of interest (Table 3), and no violations of health-based standards. These observations reflect and are consistent with what was found based on the data of 2003-04 used in this study.
Discussion

Of the four types of drinking water, only bottled water exhibited non-detections or negligible (i.e., less than 1/5th of the MCL) concentrations of all contaminants included in the study. It is important to note that no contaminant exceeded the health standard in any of the four types of drinking water alternatives. In one sample, NO₃ as N was detected at 8.1 mg/L, which is at 81% of the maximum contaminant level of 10 mg/L. These observations bring to light an intriguing question: is reducing measurable concentrations of contaminants “worth” spending additional funds? As shown in Table 6, there is a wide range (which we have conservatively underestimated) of costs associated with each type of drinking water. Overall, the cost of one year of drinking water for one person (2 quarts per day (1/2 gallon) or approximately 182.5 gallons per year) ranges from less than $0.30 in some PWSs, to approximately $1,100 or more in others, if one of the more expensive brands of bottled water is chosen.

Of course, cost is not the only consideration when comparing different drinking water alternatives, there are also matters of convenience, taste, quality, health concerns, maintenance requirements (i.e., in the case of regularly changing filters on home filtration devices), and support (or lack thereof) of federal legislation and regulations (Table 6). PWS water is generally cheap, is tested regularly as required by the SDWA, and is conveniently delivered to the tap in most urban areas. However, PWS water can be expected to contain measurable concentrations (as opposed to exceeding a standard) of one or more contaminants.

Private wells, except for rural water associations in some areas, are generally the only way to provide a regular source of running water in rural areas. Unlike PWS water, private wells require a sizeable initial outlay for drilling a well; after the well is installed, however, the main cost associated with obtaining water is the electricity required to run the pump. Unless the owner takes the initiative to have water samples tested, no “official” entity is required to perform water quality testing, and even though we did not find this in our study, many private wells in agricultural areas have been demonstrated to contain contaminants (e.g., nitrates, bacteria, and herbicides in some cases) at or above MCLs.

Bottled water and home filtration devices are increasingly viewed as a means of escape from the taste and measurable concentrations of contaminants in PWS or farm well water. Especially in transit, bottled water is a convenient, packaged form of refreshment, can generally be expected to contain negligible contaminant concentrations (except in the case of mineral water, which often has high concentrations of mineral solids), and is regulated by the Food and Drug Administration and overseen by the International Bottled Water Association; though EPA and FDA water standards are similar, FDA enforcement capabilities are far weaker [36]. As mentioned above, however, relative benefits associated with bottled water are delivered at a rather high cost when compared with PWS water. It should be noted that bottled water may be an essential source of drinking water in emergencies or natural disasters or other instances in which the public drinking water supply is interrupted or contaminated.

The effectiveness of home filtration devices depends on three major factors: 1) the specifications of the device (does the device reduce the concentration of only some or many contaminants), 2) the quality of the tap water (i.e., does the tap water contain only contaminants whose concentration the HF device is designed to reduce, or does it contain others?), and 3) the regular performance of required maintenance by the owner(s) of the system. HF devices may also be affected by the hardness of the tap water, as some filters may become plugged by calcium or other mineral deposits. These issues aside, some HF devices, most notably the reverse osmosis system, may achieve similar or better quality than bottled water at a fraction of the cost.

The quality of the four types of drinking water examined in this study was equal in one respect: none of the samples exceeded any MCL. However, beyond this basic observation, there were important differences in the number of contaminants detected, and the concentrations at which such contaminants were detected. Which type of water is ‘best’ for each individual? This depends on many factors, such as personal and family disease history, perception, socio-economic status, the “actual” (as determined by epidemiologic or toxicological studies) risk posed by such contaminants, convenience, information (media, government, public water system, and other sources) and location (home, work, in transit). Although taste is often thought of as a secondary characteristic when it comes to health standards, taste is also an important determining factor when it comes to beverage choice. For example, a small investment in household filtration that improves taste and leads to increased consumption of tap water versus other beverages (e.g., sugary sodas) may pay a long-term health dividend.

While water from public water systems is
Table 6: Comparison of Drinking Water Alternatives

<table>
<thead>
<tr>
<th>Option and Sources</th>
<th>Cost/1000 gal</th>
<th>Cost/person/year</th>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Water Supply [67]</td>
<td>$1.42-$15.20</td>
<td>$0.26-$2.80</td>
<td>Supported by federal legislation (SDWA); “clean” and “safe” water, cheap (especially for subscribers of large water supplies)</td>
<td>Treats all water to drink water standards, regardless of its ultimate use; can be more expensive for small communities</td>
</tr>
<tr>
<td>Private Well</td>
<td>$1-$10²</td>
<td>$0.18-$1.80²</td>
<td>Incremental cost is low for each additional gallon pumped</td>
<td>Not regulated or supported by federal or state regulations; owner must take initiative with maintenance and testing schedules and activities; initial drilling and set-up is expensive</td>
</tr>
<tr>
<td>Point-of-Use as Supplement [68-70, +retail price research]</td>
<td>$50-$210³</td>
<td>$9-$38³</td>
<td>Provides additional protection from contaminants not addressed by PWS/CWS; generally improves taste</td>
<td>Requires homeowner maintenance and regular cartridge replacements.</td>
</tr>
<tr>
<td>Bottled Water prices from local grocery stores</td>
<td>$400-$9000</td>
<td>$73-$1635</td>
<td>Convenience: packaged, ready to consume. Generally contains fewer/lower concentrations of contaminants than other types of drinking water; regulated as food product by FDA</td>
<td>Expensive, regulation less stringent than public water supply, significant use of plastic (packaging, bottles)</td>
</tr>
</tbody>
</table>

¹Assumes consumption of 2 quarts of drinking water per person per day, or 182.5 gallons per person per year
²The costs of drilling, maintaining, operating, and testing a private well in any given location varies widely depending on local drilling rates, depth to sufficient aquifer(s), substrate (sand, clay, bedrock, etc.), cost of electricity, and other factors.
³The initial and operating costs of lower end POU devices have not changed significantly in the past 15-20 years since the reports cited here were published. More sophisticated (and expensive) devices are available, however.

Currently as healthy as other options, at much lower cost, it is important to note that the developed nation privilege of having safe water flow reliably through pipes and taps can only be maintained if appropriate and timely investments are made in our drinking water infrastructure. Funds for such investments are apparently readily available as we in the US spend nearly as much on bottled water as on maintaining our drinking water infrastructure [67-71]. Failure to make such investments may have significant impacts on the ability of local utilities to deliver water that is not only vital for public health, but also for economic vitality and public safety (e.g. fire protection).

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the University of Minnesota, Morris. The findings and conclusions reported in the paper are of the authors and do not necessarily reflect the views of the sponsoring organizations, and no official endorsement should be inferred.

References
27. Center for Health Effects of Environmental Contamination. Iowa Statewide Rural Well Survey Phase 2. Results and Analysis.


44. Iowa Department of Natural Resources (2017) State of Iowa Public Drinking Water Program 2017 Annual Compliance Report.

45. Iowa Department of Natural Resources. State Nonpoint Source Management Program—Iowa. Chapter 1: Iowa’s Water Resources.


60. US EPA. Atrazine- Background and Updates.


65. Center for Health Effects of Environmental Contamination, Historical community water supply and treatment data for the State of Iowa. Iowa City, IA.


