PUBLIC PERCEPTION TRENDS OF DRINKING WATER QUALITY OVER A 32-YEAR PERIOD IN THE PACIFIC NORTHWEST, USA

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ABSTRACT

The public in the Pacific Northwest considers the quality of their drinking water the most important aspect of water resources. Consequently, the purpose of this paper is to examine public perceptions of drinking water quality over a 32-year period between 1988 and 2019 in the states of Alaska, Idaho, Oregon and Washington. Mail-based surveys were used to collect data in 1988, 1993, 1998, 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2019. In each survey year, the minimum sample size was 400 adult residents. Residents were asked about their perceptions of: (1) drinking water safety and satisfaction, (2) use of in-home water filters, (3) use of bottled water, (4) water testing, and (5) water pollutants. Over 10,400 residents completed surveys over this 32-year period. Over 80% of the residents obtained their tap water from a city or community water system that was nationally regulated. Over this 32-year period, more than 78% of residents considered their drinking water safe; however, trends show that the perceived safety of drinking water has declined from 92.8% in 1998 to less than 79% in 2019. The use of secondary in-home water filters has increased from 18.2% in 1998 to 35.4% in 2019. The use of bottled water peaked at 34.9% in 2007 but has declined since and dropped to less than 17% of the public by 2019. In the last 32 years only about 15% of residents have had their drinking water tested at least once every 5 years. As far as contaminants in drinking water quality is concerned the major complaint over the last 32 years was hard water. Survey respondents over the age of 50 were more likely than residents younger than 35 to consider their drinking water safe and pollution-free, while younger residents were more likely to use bottled water and a secondary in-home water filter. Respondents that were male, older than 70, college educated, from Idaho or Alaska and from communities of more than 7,000 residents were most likely to consider drinking water safe. From a trend standpoint, more residents have thought that their drinking water has become less safe and fewer people are using bottled water compared to 32 years go. Conversely, the use of secondary in-home filters has substantially increased in the last 32 years.

Keywords: bottled water, drinking water quality, in-home water filters, public opinion, urban water quality.

1 BACKGROUND

The public in the four Pacific Northwestern States (Alaska, Idaho, Oregon, Washington) considers drinking water quality the most important aspect of water resources management [1]. Over 80% of the public in this region obtains their drinking water from city water systems that are regulated by states through the authority of the United States Environmental Protection Agency (USEPA). Several public drinking water surveys have been conducted in this region over the last 25 years; however, long-term trends about water safety, the use of in-home water filters, the use of bottled water, water testing, and public identification of water contaminants is lacking [2,3,4].

2 INTRODUCTION

The history of drinking water treatment can be broken into the ancient (pre-1880), progressive (1880–1960) and contradictive (post-1960) periods. Despite the lack of knowledge about drinking water at the molecular level the ancient Mesopotamians and Romans developed techniques to improve the quality of drinking water [5]. Through advances in microbiology

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and organic chemistry chemicals were developed to kill microbial pathogens in drinking water during the progressive period. By the 1960s drinking water samples were evaluated for inorganic and organic chemicals, radionuclides and turbidity [5,6]. Since the 1970s urban water supplies in highly developed countries have been routinely screened and treated for microbial pathogens, inorganic chemicals, organic chemicals, radionuclides and turbidity [7]. Despite this technology, other issues have contributed to the acceptance of treated drinking water by the public.

Several studies have been conducted to evaluate the public perception of drinking water quality in addition to the traditional scientific metrics [7]. These aesthetic factors have included: (1) trust in water suppliers, (2) water flavour, (3) past problems attributed to water quality, (4) risk perception, (5) attitudes toward chemicals put into the water to enhance its safety, (6) familiarity with specific water properties, and (7) information provided by the media and friends and neighbours [8,9,10,11]. Studies in the United States have shown that many households perceive drinking water as unsafe despite successfully meeting national regulations [12]. In less developed countries water quality is even of more suspect by the local population.

Public surveys about drinking water conducted in France, South Africa, Canada, Japan and the United Kingdom have shown that the majority of consumers are satisfied with the quality of their water; however, there continues to be concern about taste and emerging contaminants such as pharmaceuticals. The purpose of this paper is to examine public perceptions of drinking water quality over a 32-year period between 1988 and 2019 in the states of Alaska, Idaho, Oregon and Washington. Eleven regional, mail-based surveys were used to develop long-term trends toward drinking water.

3 METHODOLOGY

A survey instrument was developed to access public attitudes, priorities and concerns about drinking water issues in the Pacific Northwest, USA. Within this survey instrument was a set of questions that asked recipients about their perceptions of: (1) drinking water safety and satisfaction, (2) use of in-home water filters, (3) use of bottled water, (4) water testing, and (5) water pollutants. In 2002, 2007, 2012 and 2017 these questions were embedded into a 60-question surveys that were sent to over 2,500 residents of the region. The same questions were embedded into smaller 30-question surveys that were sent to 1,200 residents in 1988, 1993, 1998, 2002, 2005, 2010, 2015 and 2019. Consequently, answers to each of the survey questions were obtained in 1988, 1993, 1998, 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2019.

The survey target audience was a representative sample of the 9,500,000 adult residents of Idaho, Oregon and Washington that live within the four PNW states. In addition, demographic information, including state of residence, community size, length of time residing in the region, gender, age, and educational level were also collected. Community size data were translated into urban, suburban and rural based on the county of residence. Residents were considered urban if they resided in a county (borough in Alaska) with more than 100,000 people. They were considered suburban if they resided in a country with between 30,000 and 100,000 residents. Residents residing in counties with less than 30,000 people were considered rural. Based on census estimates in 2020 there were 28, 34 and 74 counties in the Pacific Northwest classified as urban, suburban and rural, respectively.

Each survey was developed using the Diliman methodology and was delivered to clientele via the United States Postal Service [13,14]. A sufficient number of completed surveys was the goal to result in a sampling error of 3–5% [15]. The survey process was also designed to receive a completed survey return rate more than 50%. Addresses were obtained from a professional social sciences survey company (SSI, Norwich, CT). Four mailings were planned to achieve the 50% return rate. The mailing strategy used was identical in all 11 surveys that had been conducted in the region since 1988 [1,2,3,4]. It only took three mailings to achieve the target return rate of 50% in 2002, 2005, 2007, 2012, and 2015. Conversely it took four mailing to achieve the 50% return rate in 1988, 1993, 1998, 2010, 2017 and 2019.

Survey answers were coded and entered into Microsoft Excel. Missing data were excluded from the analysis. The data were analysed at two levels using SAS [15]. The first level of analysis generated frequencies, while the second level evaluated the impacts of demographic factors. Significance ($P < 0.05$) to demographic factors was tested using a chi-square distribution [14,15]. Since similar response rates were observed in all survey years, data analysis procedures were identical for each sampling.

4 RESULTS AND DISCUSSION

The survey methodology was not designed to be unique, but rather to be able to compare resident responses over time so that useful information could be obtained. Using the mail based Dillman survey methodology, response rates of over 50% were achieved for all 11 surveys with three or four mailings. This high response rate resulted in a sampling error of less than 5%.

When this survey was first initiated in 1988 the population of the four Pacific Northwest states was 8,696,000 [16]. However, by 2019 the region's population had grown to 14,516,000 [17]. This 16% population increase resulted in the region becoming more urban over the 32-year study period. On a numerical basis in 2019 based on county classification, the urban, suburban and rural populations of the four Pacific Northwest states were 11,612,000, 2,322,000 and 584,000 people, respectively.

When the 1988 and 2019 survey data were compared the primary source of in-home tap water changed over the 32-year survey period (Table 1). In 1988, 76.5% of the public

Table 1: The source of drinking water in the home tap in 1988 and 2019 based on Pacific Northwest surveys conducted in Alaska, Idaho, Oregon and Washington.

Source of tap water	1988	2019	Significance (between columns)
	----------%----------		
City water system	76.5	83.9	****
Private well	12.3	8.6	***
Use bottled water	22.4	27.9	****
Other private sources (surface water)	1.4	1.2	NS
Do not know	9.5	6.3	**
Significance (within columns)	****	****	

, * **** = significant at 0.05, 0.01 and 0.001 levels of probability. NS = not significant.

received their tap water from a city water system. This number statistically increased to 83.9% by 2019. The increase in urban population within the region is the likely explanation for this increase. Private wells were the second largest source of tap water in both 1988 and 2019. Less than 20% of the public had a different private water source (surface water) in both 1988 and 2019. Less than 10% of survey respondents did not know their source of tap water. Fewer people did not know their tap water source in 2019 compared to 1988.

4.1 Safety of drinking water

Drinking water was considered safe to by over 78% of residents in all 11 surveys conducted over this 32-year study (Fig. 1). Basically, two trends were evident. First, over three quarters of survey respondents felt that water at their tap was safe to drink in each of the 11 surveys. Second, there was a trend that fewer people considered their drinking water safe over time. Even though this trend was statistically significant ($p = 0.0001$) the vast majority of the public felt that their drinking water was safe. Reasons for this decline in drinking water safety may be tied to the media, advertising and the water crisis in Flint, Michigan in 2015 [18].

The collected survey data from this 32-year study was pooled to identify the impacts of the demographic factors of gender, age, formal education level, state of residence and community size on drinking water safety. Males were more likely to consider their home tap water safe for drinking than females (Table 2). Even though this difference in gender was highly statistically significant the vast majority of both genders considered their tap water safe to drink.

Age of survey respondent also impacted the answer about drinking water safety. Respondents older than 70 were more likely to consider tap water safe to drink that respondents younger than 30 years old (Table 3). Age had a stair-step impact on drinking water safety as

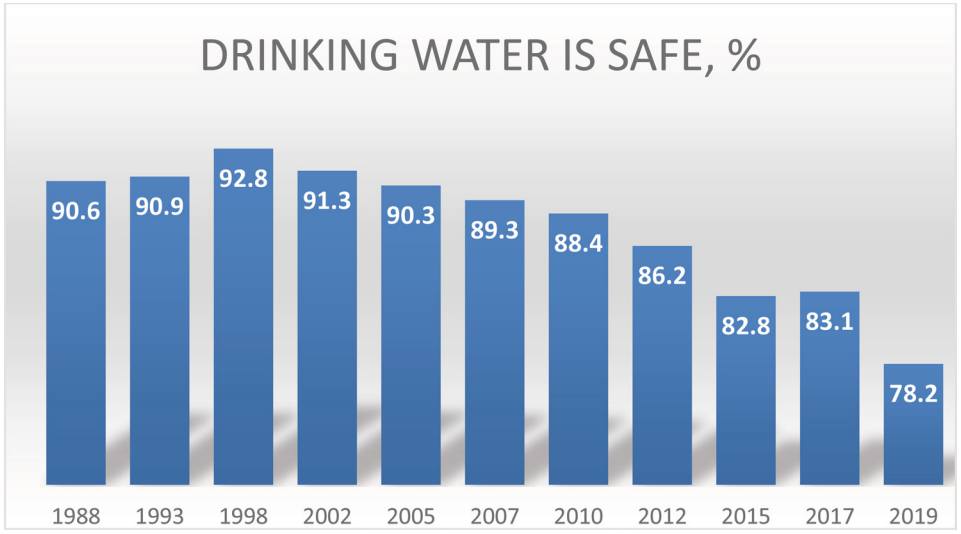

Figure 1: The percentage of survey respondents that said their drinking water was safe between 1988 and 2019 based on 11 surveys conducted in the four Pacific Northwestern states.

Table 2: The influence of gender on the safety of tap water, presence of water contaminants and the use of water filters, bottled water and testing drinking water based on surveys conducted between 1988 and 2019 in the Pacific Northwest.

Issue/answer	Male	Female	Significance
	----------%----------		
Tap water is safe to drink	90.3	81.8	****
Use in-home water filters	19.8	27.6	****
Use bottled water	22.4	27.9	****
Have water tested once in 5 years	17.1	17.6	NS
Identified at least one major contaminant	7.2	11.9	***

, * = significant at 0.001 and 0.0001 levels of probability. NS = not significant.

Table 3: The influence of age on the safety of tap water, presence of water contaminants and the use of water filters, bottled water and testing drinking water based on surveys conducted between 1988 and 2019 in the Pacific Northwest. Answers are pooled for the 11 conducted surveys. Over 10,210 surveys were completed by the public.

Issue/answer	Age				Significance
	<30	30–50	50–70	>70	
	---------- % ----------				
Tap water is safe to drink	85.2	86.9	88.9	91.3	***
Use in-home water filters	36.4	30.2	23.2	16.4	****
Use bottled water	35.3	31.6	22.4	18.6	****
Have water tested once in 5 years	9.3	18.2	22.4	21.0	****
Identified at least one major contaminant	13.8	12.9	8.1	7.2	****

, * = significant at 0.001 and 0.0001 levels of probability. NS = not significant.

85.2%, 86.9%, 88.9% and 91.3% of the residents less than 30, between 30 and 50, between 50 and 70 and over 70 years. old felt that their home tap water was safe to drink. The highest level of educational achievement also impacted feeling toward the safety of tap water in the home (Table 4). Respondents without exposure to college (<HS diploma and HS diploma) were less likely to consider their tap water safe to drink than respondents with a college education. Conversely, over 94% of respondents with more than 3 years of college education considered their home tap water safe.

State of residence also impacted citizen views of the safety of in-home tap water. Residents of Alaska and Idaho were more likely to consider their home tap water safe to drink than residents of Oregon and Washington (Table 5). It is interesting that more residents of

Table 4: The influence of formal education level on the safety of tap water, presence of water contaminants and the use of water filters, bottled water and testing drinking water based on surveys conducted between 1988 and 2019 in the Pacific Northwest. Answers are pooled for the 11 conducted surveys. Over 10,210 surveys were completed by the public.

Issue/answer	Education level				Significance
	<HS	HS	C 1–3	C 3+	
	----------%----------				
Tap water is safe to drink	80.4	82.4	89.3	94.8	****
Use in-home water filters	23.2	25.0	27.0	27.7	***
Use bottled water	26.2	29.2	33.4	21.3	****
Have water tested once in 5 years	14.2	18.2	22.4	21.0	****
Identified at least one major contaminant	5.0	7.2	13.5	13.4	****

, * = significant at 0.001 and 0.0001 levels of probability, respectively.
<HS = no high school diploma; HS = high school diploma; C 1–3 = 1–3 years of college;
C 3+ = more than 3 years of college.

Table 5: The influence of state of residence on the safety of tap water, presence of water contaminants and the use of water filters, bottled water and testing drinking water based on surveys conducted between 1988 and 2019 in the Pacific Northwest. Answers are pooled for the 11 conducted surveys. Over 10,210 surveys were completed by the public.

Issue/answer	State				Significance
	AK	ID	OR	WA	
	----------%----------				
Tap water is safe to drink	89.3	91.8	83.1	83.6	****
Use in-home water filters	17.1	19.2	28.6	29.1	****
Use bottled water	18.0	19.4	29.2	30.1	****
Have water tested once in 5 years	15.1	20.1	20.3	22.4	****
Identified at least one major contaminant	7.1	6.6	16.1	10.3	****

**** = significant at the 0.0001 level of probability.

the two more rural states, Alaska and Idaho, considered their tap water safer to drink. The lower population density of these two states along with plentiful water supplies probably contributed to this difference in opinion. Still, overall, over 83% of the residents of all four state considered their tap water safe to drink. Community size did not affect responses to tap water safety (Table 6).

Table 6: The influence of community size on the safety of tap water, presence of water contaminants and the use of water filters, bottled water and testing drinking water based on surveys conducted between 1988 and 2019 in the Pacific Northwest. Answers are pooled for the 11 conducted surveys. Over 10,210 surveys were completed by the public.

Issue/answer	Community size				Significance
	>100K	25–50K	7–25K	<7K	
	----------% ----------				
Tap water is safe to drink	87.0	86.2	85.7	83.0	NS
Use in-home water filters	29.2	27.3	24.7	23.0	**
Use bottled water	28.5	26.9	26.1	24.6	**
Have water tested once in 5 years	13.4	14.2	20.7	24.8	****
Identified at least one major contaminant	9.6	10.3	10.0	10.9	NS

, ** = significant at the 0.05 and 0.0001 levels of probability. NS = not significant.
>100K = >100,000; 25–50K = 25,000 to 50,000; 7–25K = 7,000 to 25,000; <7K = less than 7,000.

4.2 Use of secondary in-home water filters

The prevalence of use of secondary in-home water filters between 1988 and 2019 is shown in Fig. 2. A trend over the 32-year survey study is apparent. Prior to 1998 less than 20% of survey respondents used a secondary water filter for drinking water in their home. However, since 1998 the use of in-home water filters has increased up to 35.4%. In-home water filter use has levelled off since 2012. This is a highly significant trend over the last 32 years. Even though more than 80% of survey respondents felt that their drinking water was safe, about one-third of survey respondents sought to further improve their drinking water quality by using a secondary filter. Most of the secondary filters were of the inexpensive pour through type.

The demographic factors of gender, age, formal educational level, state of residence and community size had an impact of survey responses. Females were much more likely to use in-home water filters than males (Table 2). Younger survey respondents were more likely to use in-home water filters than residents over 50 years old (Table 3). Educational level also affected the use of in-home water filters as respondents without a high school diploma were less likely to use them that respondents with college experience (Table 4). State of residence also had a significant impact the use of in-home water filters (Table 5). Here, residents of Washington and Oregon were more likely to use the in-home water filters. People living in communities of 25,000 or more people were also more likely to use in-home water filters than those living in smaller communities (Table 6).

The trend showing an increase of in-home water filters over the 32-year study period is likely caused by three factors. First, the water quality crisis in Flint, Michigan raise public concern about drinking water quality [18]. Second, the American news media highlighted drinking water issues more since 2005 than before 2005. Third, manufactures and sellers of in-home water filters have greatly increased advertising since 2000.

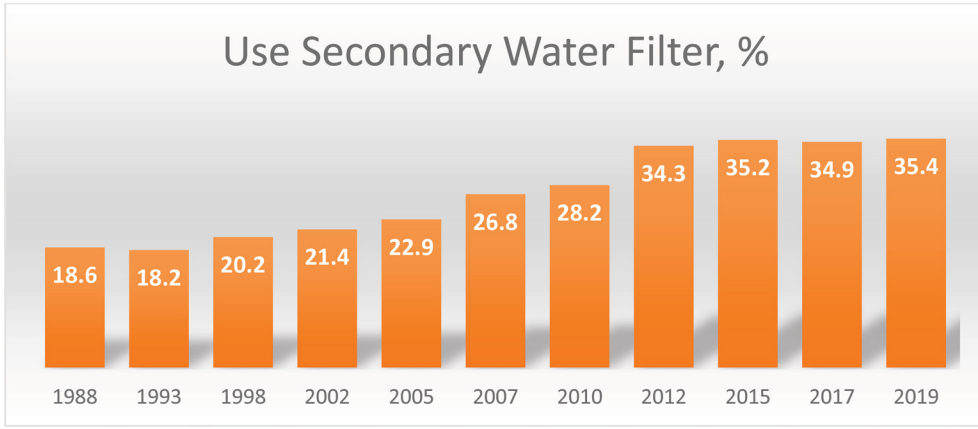

Figure 2: The percentage of survey respondents that used secondary in-home water filters between 1988 and 2019 based on 11 surveys conducted in the four Pacific Northwestern states.

4.3 Bottled water use

The use of bottled water by survey respondents over the 32-year survey study is shown in Fig. 3. Compared to bottled water use in 1988, the rate of use dropped by more than 40% in 2019. The general trend was a slow increase in bottled water use between 1988 and 2005, then stationary use between 2005 and 2010, followed by a significant decrease in bottled water use between 2010 and 2019. Bottled water use was halved in 2019 compared to 2010.

The demographic factors of gender, age, formal education level, state of residence and community size impacted the use of bottled water when the 11 surveyed years were pooled. Females were significantly more likely to use bottled water by a rate of 27.9%–19.8% (Table 2). Younger respondents were more likely to use bottled water (Table 3). High school graduates and residents with 1–3 years of college were more likely to use bottled water than people without a high school diploma and respondents with more than 3 years of college education (Table 4). Washington and Oregon residents were more likely to use bottled water than residents of Alaska and Idaho (Table 5). Residents of communities larger than 100,000 people were more likely to use bottled water than residents of communities of less than 25,000 people (Table 6).

4.4 Water testing

The percentage of survey respondents that have had their drinking water tested for contaminants at least once in the past 5 years is shown in Fig. 4. Two things are evident in this bar graph. First, less than 20% of the respondents in all surveys had their drinking water tested in the last.

The demographic factors of age, education level, state of residence and community size impacted how residents answered this question. Younger residents were less likely to have their water tested (Table 3). Residents with some college education were more likely to have their water tested than those with less education (Table 4). Residents of Alaska were less likely

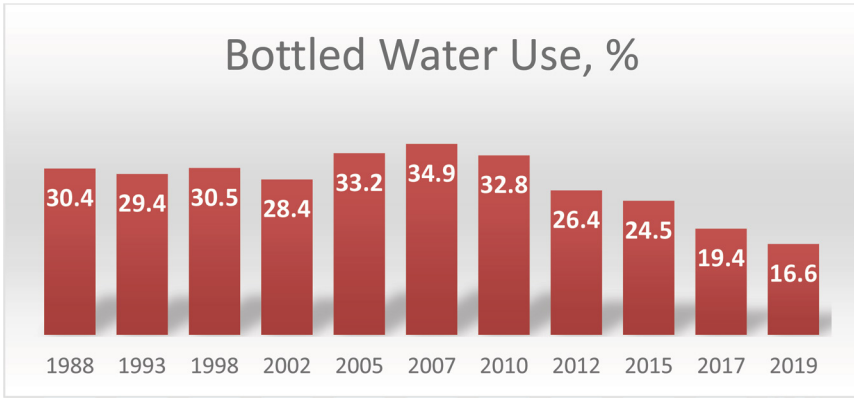

Figure 3: The percentage of survey respondents that used bottled water between 1988 and 2019 based on 11 surveys conducted in the four Pacific Northwestern states.

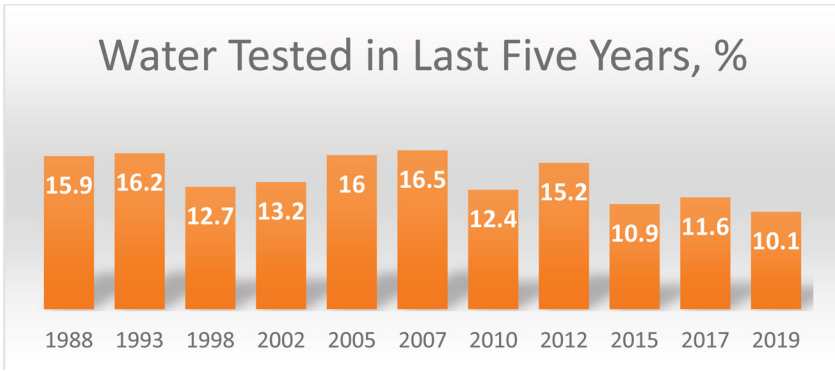

Figure 4: The percentage of survey respondents that have had their drinking water tested at least once in the last 5 years between 1988 and 2019 based on 11 surveys conducted in the four Pacific Northwestern states.

to test their water than other states (Table 5). Residents of communities with less than 25,000 people were more likely to test their water than residents of larger communities (Table 6).

4.5 Major contaminants

Long-term contaminant trends were not observed in this 32-year survey study. However, the demographic factors of gender, age, formal education level and state of residence impacted resident answers about contaminants.

The demographic factors gender, age, formal educational level, and state of residence impacted how respondents answered this survey question. Even though significant demographic differences were observed less than 15% of all respondents identified one or more major drinking water contaminants. Hard water was by far the most common impurity cited.

Females were more likely than males to identify at least one contaminant in their drinking water (Table 2). Younger residents (< 50 years old) were more likely to identify at least one major contaminant than older residents (Table 3). Residents that had attended college were more likely to identify contaminants than respondents with less formal education (Table 4). Oregon residents were most likely to identify at least one major contaminant in their drinking water supply.

5 CONCLUSIONS AND RECOMMENDATIONS

The major findings of this 32-year survey study were:

- Over 78% of residents considered their drinking water safe; however, trends indicate that perceived safety of drinking water has declined from 92.8% in 1998 to less than 79% in 2019.
- The use of secondary in-home water filters increased from 18.2% in 1998 to 35.4% in 2019.
- These first two trends show that the perceived decline in the safety of drinking water and the corresponding increase in the use of in-home water filters were likely caused by: (1) the drinking water quality crisis in Flint, Michigan, (2) the American media highlighting challenging drinking water issues, and (3) the increase in the number of in-home filter manufacturers and associated marketing.
- The use of bottled water peaked at 34.9% in 2007 but has declined since and was used by less than 17% of consumers by 2019.
- Media campaigns by environmental agencies, non-government organizations (NGOs) and schools that identified plastic waste issues in the environment were at least responsible for the decrease in bottled water use.
- There were no apparent rends in drinking water testing by residents. Less than 20% of residents in all 11 surveys had their drinking water tested in the previous 5 years.
- Less than 10% of the public identified a major contaminant in their drinking water.

The demographic factors of gender, age, formal education level, state of residence and community size often affected the response of residents to survey questions. However, the overall trends observed were the major outcomes of this 32-year survey study. The collected data should be used by educators, scientists and public health officials to determine the appropriate outreach methods that should be used to accurately pair public perceptions with scientific facts within the Pacific Northwest.

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