Arsenic

National Water Pollution Sensor Priorities

Executive Summary

The U.S. Environmental Protection Agency (EPA), in cooperation with USGS and other federal agencies and state associations,[1] is working to promote the development and deployment of advanced water quality monitoring technologies for national priority pollutants and parameters. Arsenic was identified as a high priority parameter[2] for which sensor technology advancement was needed. Arsenic is a naturally-occurring element that is linked to health problems in people exposed to it long-term in drinking water. To protect consumers from these effects, the EPA has limited arsenic in drinking water to 10 µg/L.[3]

Currently, sample collection and analysis for arsenic is costly, making it difficult to monitor with high spatial or temporal resolution. As a result, current methods often do not capture the full complexity of how arsenic behaves in the environment. When samples are collected in the field and analyzed in the lab, there is a time lag between sample collection and analysis, making real-time decisions impossible. Advancing arsenic sensors could address many of the limitations presented by current approaches and allow monitoring to become more affordable, continuous, and field-deployable. Advanced arsenic sensors could meet the expected future needs for data to inform management decisions aimed at reducing arsenic concentrations in the environment, tracking progress, and targeting investments.

EPA and partners collected user input regarding priorities and preferences for new arsenic sensors, which is summarized below:

Characteristic	Need
Limit of Detection	Lower: 1 µg/L, Upper: 100 µg/L
Response Time	Real-time
Sampling Frequency	1 hour
Deployment Length	1 month
Data Logging	Integrates with external data logger
Data Transmission	Cellular/Satellite
Price	\$2,500 - \$5,000

To accelerate the development of sensor capabilities to meet the needs in the table above, the Bureau of Reclamation, the EPA, U.S. Agency for International Development, U.S. Department of Agriculture, the National Institute of Standards and Technology and the Indian Health Service are collaborating to launch an Arsenic Sensor Prize Competition to encourage technology developers to create technologies

[1] The Association of Clean Water Administrators (ACWA), the Association for Safe Drinking Water Administrators (ASDWA), the U.S. Bureau of Reclamation (BOR), the National Water Quality Monitoring Council (NWQMC), the U.S. EPA, the U.S. Geological Survey (USGS), and the Water Environment Federation (WEF) are working to accelerate the development of affordable and accurate technology to detect arsenic in water.

[2] The six parameters are: arsenic, total nitrogen, total phosphorous, *E. coli*, *Enterococci*, and toxins produced by cyanobacteria.

[3] https://www.epa.gov/dwreginfo/chemical-contaminant-rules

that meet these requirements. The Arsenic Sensor Prize Competition is anticipated to launch in late 2016.

1. Approach

Advanced arsenic sensor requirements were gathered in a three phase process. The focus of the first phase was to assemble information about requirements and preferences from Federal agencies and non-federal collaborators. Federal staff from a number of agencies were asked a series of questions about their needs and preferences for detecting and measuring arsenic. Several collaborating organizations, including the Association of Clean Water Agencies (ACWA), the Association of State Drinking Water Administrators (ASDWA), the National Water Quality Monitoring Council (NWQMC), and the Water Environment Federation (WEF) provided input as well. While the federal agencies, ACWA, NWQMC, and WEF used the same set of questions, ASDWA provided input from a slightly modified set of questions. These distinctions are noted in each figure presented in Section 2 (Results). The questions are included in Appendices 1 and 2.

The second phase was designed to create an opportunity for additional input and discussion regarding the input from Phase 1. Phase 2 consisted of a webinar open to the membership of the above organizations, federal agencies, the private sector, and members of the public.[4] After an initial introduction to the topic, webinar attendees were offered opportunities to share their perspectives through a series of dynamic poll questions, chatting comments and clarifying questions for discussion, and via email. The questions were similar to those posed in Phase 1. For the webinar polls, attendees were limited to selecting only one of the options presented. However, attendees were offered an "Other" option, which was unrestricted and could reflect options not offered or a preference for multiple options. On average, 57 responses were received for each poll during the webinar. The questions are included at the end of this report in Appendix 3.

The third phase was an opportunity to share the findings and discuss potential next steps at a May 4th, 2016 workshop at the National Water Quality Monitoring Council's 10th National Monitoring Conference () in Tampa, FL. The workshop included presentations and discussion of the input received to date and provided an opportunity for feedback from participants during breakout discussions.

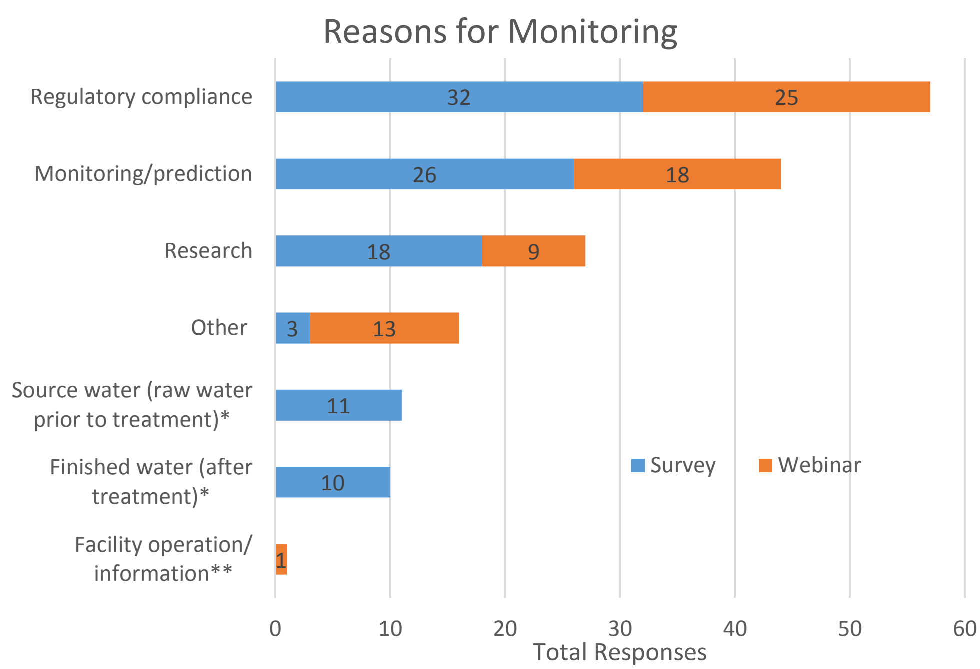
2. Results

Results from the first two input-gathering phases are combined in Sections 2.1-2.5. Input has been aggregated into two groups: surveys and webinar polls. Note that some people may have participated in a survey as well as a webinar; if so, their responses were counted twice. Also note that the questions varied somewhat between the surveys and the webinar polling. Clarifying notes are provided as necessary and the actual questions used are provided in Appendices 1 and 2. The feedback provided orally during the conference workshop (the third phase) is summarized in section 2.6.

[4] The surveys sent out prior to the webinar were blind (i.e. no identifying information was collected), therefore respondents' answers may have been double-counted if they also participated in the webinar polling.

2.1 Current Methods

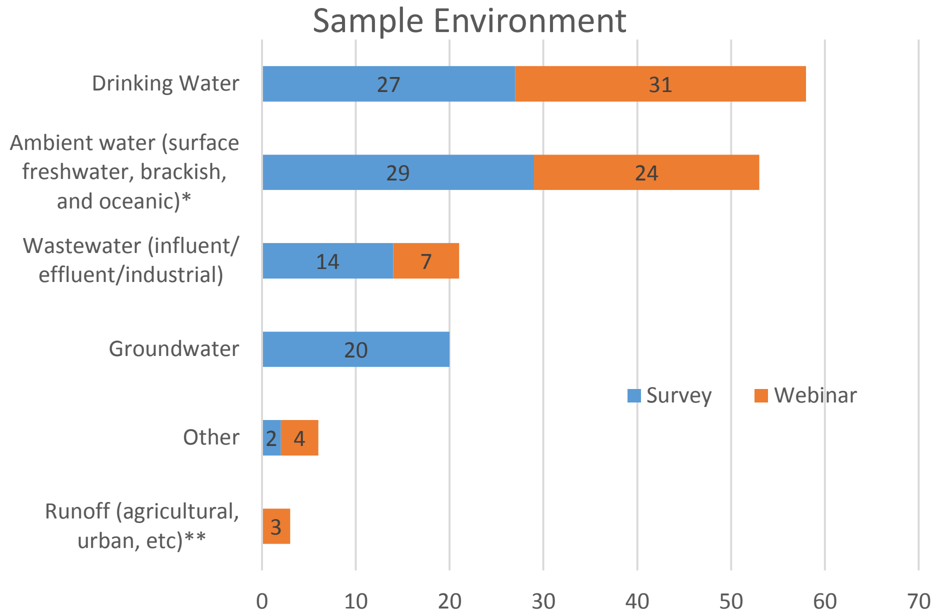
Respondents were asked about their existing arsenic measuring practices and needs. Generally, the results were similar. The most commonly-indicated reason for monitoring was regulatory compliance (57 responses; Figure 1), followed by monitoring/prediction (44 responses). The most common sampling environments were drinking water (58 responses; Figure 2) and ambient surface water (53 responses). Groundwater was selected 20 times by survey respondents and, although it was not offered as an option during the webinar, it was typed into the comment box as a clarification by one attendee who selected 'ambient water.' Of the four webinar respondents indicating "other," only one clarified their answer, describing "agricultural irrigation and in-field vegetable processing." More than half of ASDWA members expressed interest in measuring total arsenic in both drinking water source water (raw water prior to treatment) and finished drinking water (post-treatment).



** Option only available to ASDWA survey respondents*

*** Option only available to webinar attendees*

Figure 1. Responses to the question "I want to measure total arsenic for…"



* This category combines multiple options offered only to survey respondents.
**Option only available to webinar attendees

Figure 2. Responses to the question "I primarily measure total arsenic in the following sample matrices"

When asked how they currently analyze water samples for arsenic, the majority of respondents indicated that they send water samples to a laboratory (35 survey and 16 webinar respondents). A much smaller number of respondents analyze water samples in an in-house laboratory (14 survey and 6 webinar respondents). A considerable number of webinar respondents (28) selected "other" and indicated that they are not directly involved in sampling. None of the survey respondents indicated current use of an on-line analyzer or in situ sensor.

2.2 Limits of Detection

All respondents were asked to indicate the desired concentration range of an arsenic monitoring instrument. Overall, webinar attendees and survey respondents selected similar lower and upper limits of detection (LODs), despite being presented with slightly different answer options. The majority of respondents indicated a preference for a lower LOD of 1 µg/L (47 total; Figure 3), followed by 0.1 µg/L (31) and an upper LOD of 100 µg/L (45), followed by 1,000 µg/L (38). One webinar attendee commented that "low LOD [is] more important than low price."

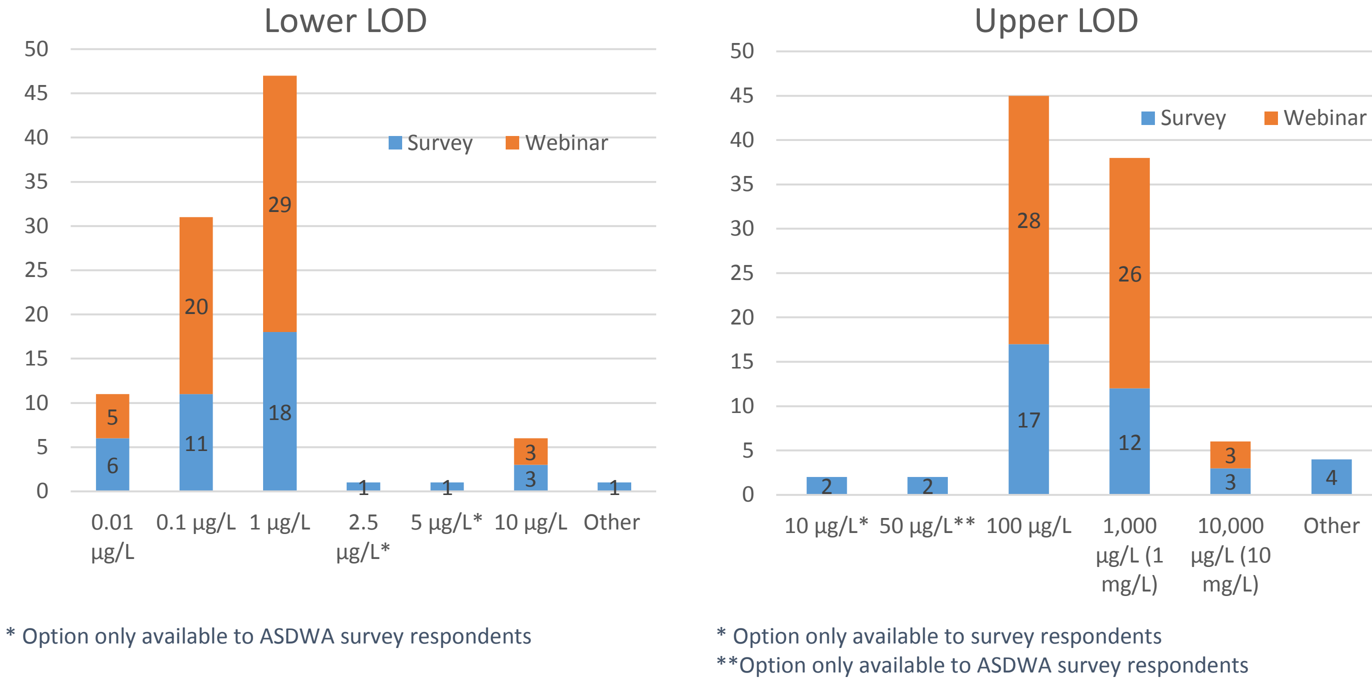
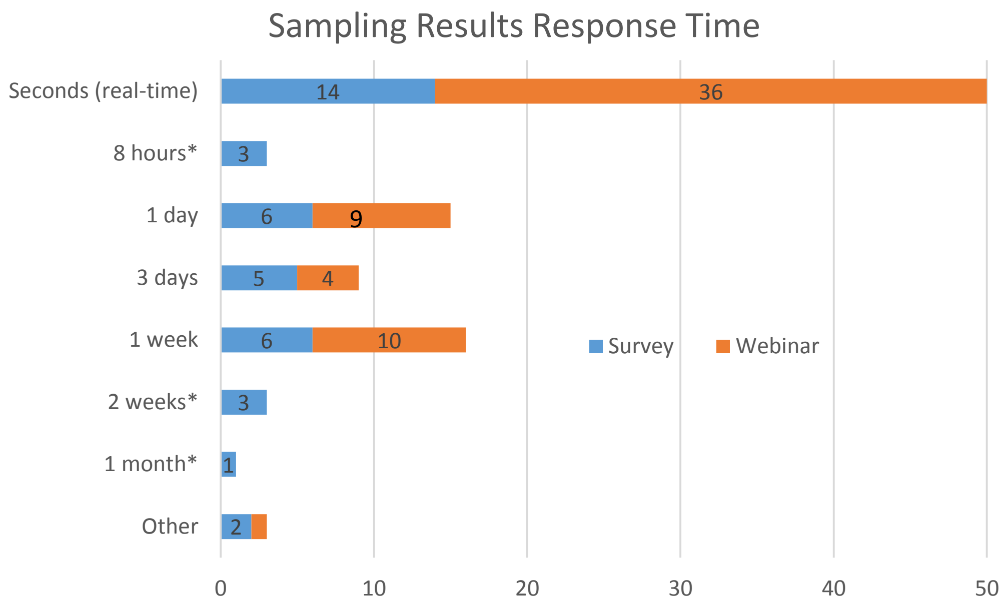


Figure 3. Responses to questions about limits of detection (LOD)

2.3 Response Time, Sampling Frequency, and Deployment Length

Respondents were asked a series of questions related to the desired capabilities of a new instrument, including the response time (the time between when a sample is taken or water is contacted by a probe, and when results become available), the sampling frequency or throughput (the number of samples that can be analyzed per unit time, e.g. samples per hour), and the deployment length (amount of time the instrument will be in the field without a technician visit).

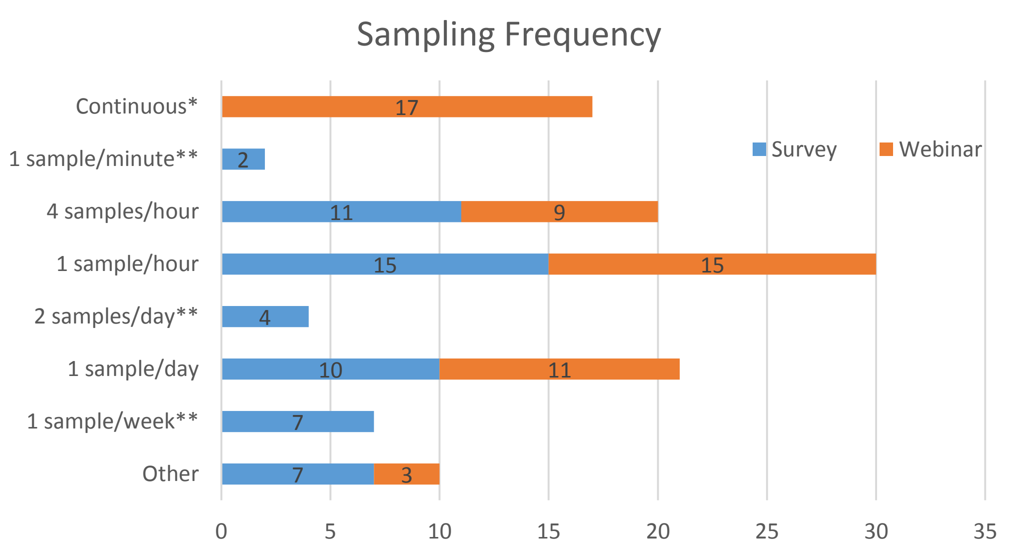
"Real-time" results was selected 50 times by survey and webinar respondents (Figure 4), indicating a clear desire for results as quickly as possible.



** Option only available to survey respondents*

Figure 4. Responses to questions about response time

The majority of participants indicated a preference for a sampling frequency of one measurement per hour or more frequent (Figure 5), although both survey and webinar respondents indicated interest in a variety of other sampling frequencies including 15 minutes (20 responses) and one day (21 responses). The “other” category for sampling frequency indicated that respondents were also interested in less-frequent sampling, e.g., quarterly.



*Option only available to webinar attendees; **Option only available to survey respondents

Figure 5. Responses to questions about sampling/measurement frequency

A one-month deployment length was the most common selection (42 responses; Figure 6). Respondents also indicated interest in a deployment length of three months (28 responses) or one week (17 responses). The six webinar attendees who selected "other" did not specify what their desired deployment length would be.

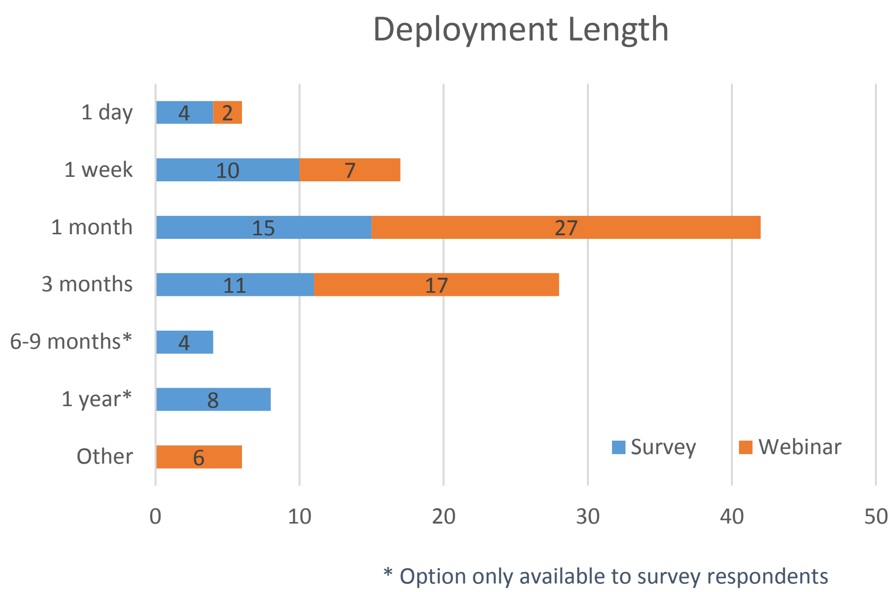


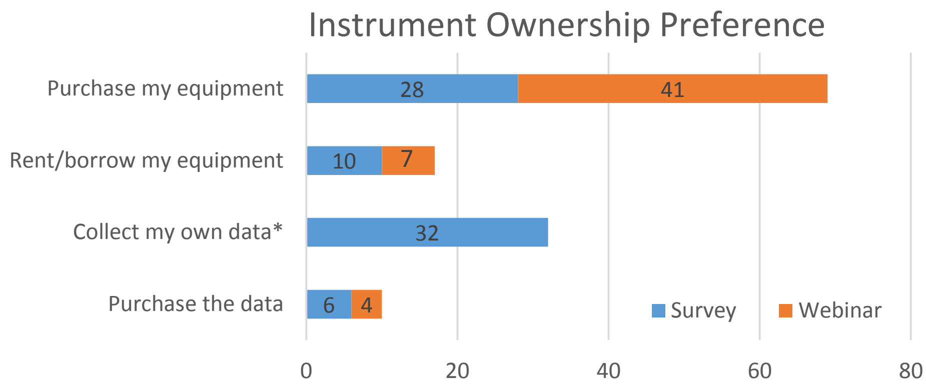
Figure 6. Responses to questions about maximum instrument deployment length between servicing

2.4 Instrument Ownership Preference and Price

Respondents were asked if they would prefer to rent or own equipment, whether they preferred to purchase data or gather data themselves, and what they would be willing to pay for their ideal sensor. The majority of respondents preferred to own their instruments and conduct their own monitoring rather than renting equipment and/or purchasing the data (Figure 7).

The most common price point for survey and webinar respondents was $2,500 - $5,000 (58 responses; Figure 8), with $5,000 - $10,000 a distant second (21 responses). Additional price point comments made by webinar attendees included a request for sensors at a price point below $2,500, consideration of the cost of maintenance, and consideration of sensor performance when tested in different matrices. Several survey responses indicating "other" for this question specified that they would appreciate a sensor that was less than $3,000.

Survey respondents were asked about common water quality parameters that they would like measure alongside arsenic. The most common parameter requested was pH (21 responses; data not shown). Total chromium and total cadmium received 8 and 7 responses, respectively. Eleven respondents indicated that they would like to measure a suite of other elements. Respondents identified the following other elements as priorities: lead, mercury, cadmium, iron, manganese, chloride, and sulfur, in addition to nitrate, dissolved oxygen, oxidation reduction potential, dissolved organic carbon, dissolved organic matter, and conductivity.



* Option only available to survey respondents

Figure 7. Responses to questions about instrument ownership

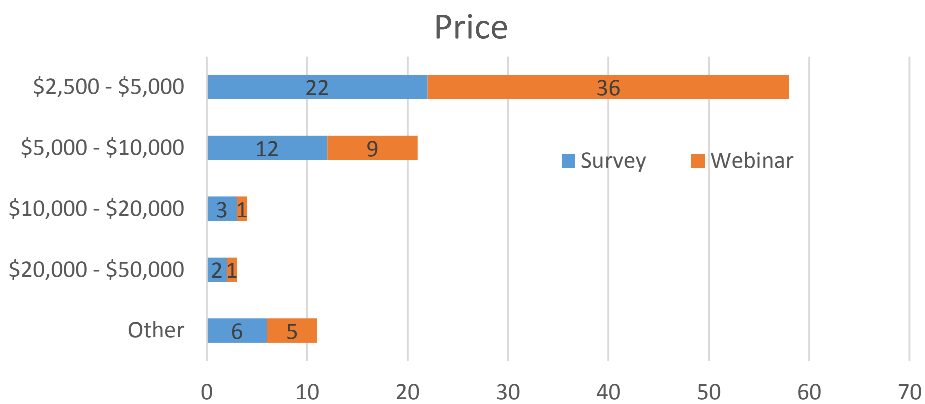
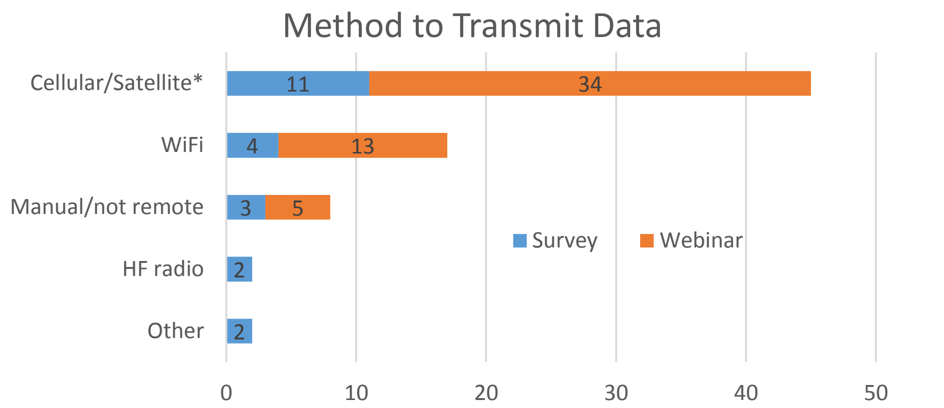


Figure 8. Responses to questions about desired instrument price

2.5 Remote Communication and Data Logging (ASDWA survey and webinar only)

ASDWA asked its members additional questions about preferences for methods of transmitting and integrating data. Webinar participants were then polled on the same question. The most commonly selected method of transmitting data from deployed sensors was cellular/satellite (45 responses; Figure 9), followed by Wi-Fi (17 responses). Integrating data logging into existing data loggers and existing external systems were the preferred methods for capturing and storing data (Figure 10).



**Cellular and Satellite options were given separately during the survey to ASDWA members.*

Figure 9. Responses to questions about data transmission methods

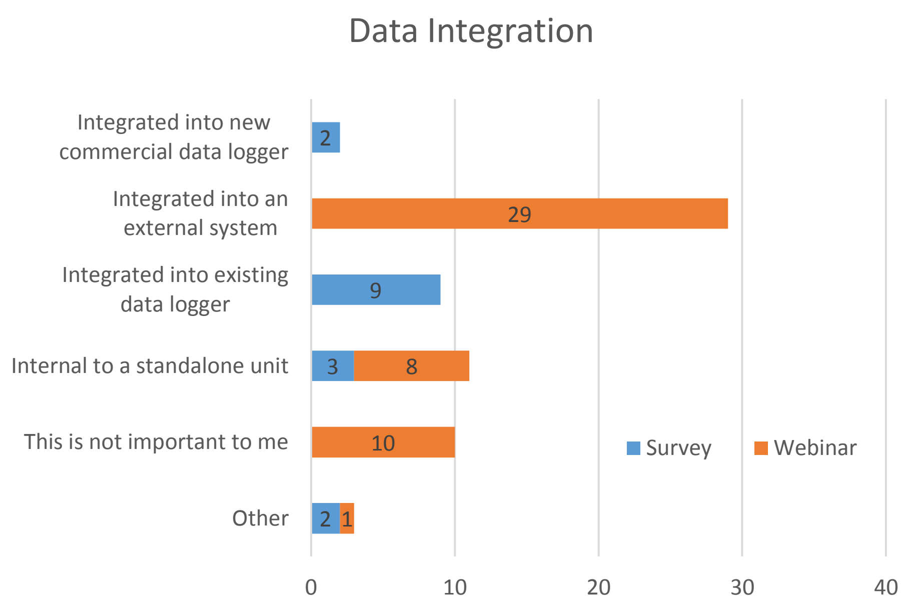


Figure 10. Responses to questions about data logging integration

2.6 National Water Quality Monitoring Council Workshop

During the May 4th, 2016 Advancing Sensor Technology for Priority Water Parameters session at the National Water Quality Monitoring Council's 10th National Monitoring Conference in Tampa, FL, attendees were presented with a summary of the above results and asked to discuss the following questions:

- Are these the ideal requirements?
- What is audacious yet feasible?
- Who else should we talk to?

- Thoughts on next steps?

The attendees generally agreed with the requirements presented. In addition, they noted that a sensor should have a diameter to fit into a two inch monitoring well, have long cables to enable down-well sensing and resist iron fouling. The group valued precision and recommended focusing on drinking water rather than wastewater. Interest was also expressed in a sensor that could measure arsenic in household drinking water via a point-of-use device. An advanced arsenic monitor could be a digital or even a non-electronic, color- changing sensor on a treatment system. Regarding the planned next step of a prize competition organized by the U.S. Bureau of Reclamation and collaborators, some attendees expressed the need for a large prize (~ $1 million) to motivate participation.

3. Next Steps – The Arsenic Sensor Prize Competition

The results from these information-gathering efforts offer a clear idea of the performance specifications and functionality requirements that users require from a new arsenic sensor. The Bureau of Reclamation, the EPA, U.S. Agency for International Development, U.S. Department of Agriculture, the National Institute of Standards and Technology and the Indian Health Service have formed a collaboration to launch an Arsenic Sensor Prize Competition to encourage technology developers to create technologies that meet these requirements. The challenge will be divided into two phases. Phase I of this challenge will focus on theoretical submissions (i.e. concept papers) and include cash prizes. Assuming Phase I is successful, Phase II will focus on prototype development and testing, and offer cash prizes, assistance from government scientists, and opportunities for commercialization partnerships or cooperative purchasing agreements. The Arsenic Sensor Prize Competition is anticipated to launch in fall of 2016. In addition, sensor technology developers are encouraged to use the specifications presented here as design guidelines and to take advantage of the sensor market represented by the group of users who contributed input to this report, whether through the Arsenic Sensor Prize Competition or independently.

Appendix 1: Multi-organization Questionnaire

PLEASE INDICATE REQUIREMENTS BELOW:

I want to measure total arsenic for: (select all that apply)

a. Regulatory compliance
b. Monitoring/prediction
c. Research
d. Other

If Other, please describe:

Comments

I currently measure/monitor total arsenic by: (select all that apply)

a. Sending water samples to a laboratory for analysis
b. Analyzing in an in-house laboratory
c. Using an on-line analyzer/in situ sensor
d. Other

If Other, please describe:

Comments

My current method meets my need: Y/N

Comments

If not, why not:

What other parameters would you like to see measured along with total arsenic in a single deployment? (select all that apply)

a. None
b. pH
c. Total chromium
d. Total cadmium
e. A suite of other elements
f. Other

If Other or a suite of elements, please describe:

Comments

I would like to see sampling results within:

a. Instantaneous / near-real-time
b. < 8 hours
c. < 24 hours
d. < 3 days
e. < 1 week
f. < 2 weeks
g. < 1 month

h. Other

If Other, please describe:

Comments

I would be interested in a device that can make repeated measurements in the field: Y/N

If yes, I'd like to make repeated measurements for the following deployment length (needed amount of time the instrument will be in the field without a visit from a technician (for service, calibration, etc.)): (select all that apply)

a. 1 day
b. 1 week
c. 1 month
d. 3 months
e. 6-9 months
f. 1 year
g. Other

If Other, please describe:

Comments

Regulations or permits require me to be able to measure at the following frequency:

a. 15 minutes
b. 1 hour
c. 12 hours
d. 1 day
e. 1 week
f. Other

If Other, please describe:

Comments

I would like to be able to measure at the following frequency:

a. 1 minute
b. 15 minutes
c. 1 hour
d. 12 hours
e. 1 day
f. 1 week
g. Other

If Other, please describe:

Comments

Definitions:

Lower LOD: Lowest concentration needed (µg/L)

Upper LOD: Highest concentration needed (µg/L)

I primarily measure total arsenic in the following sample matrices: (select all that apply)

a. Fresh surface water
b. Ground water
c. Brackish/estuarine water
d. Coastal/Oceanic water
e. Drinking water
f. Wastewater
g. Other

If Other, please describe:

Comments

I need to be able to measure total arsenic in the following concentration range: (see questions below)

Lower LOD:

a. 0.01 µg/L
b. 0.1 µg/L
c. 1 µg/L
d. 10 µg/L
e. Other

If Other, please describe:

Comments

Upper LOD:

a. 10 µg/L
b. 100 µg/L
c. 1,000 µg/L
d. 10,000 µg/L
e. Other

If Other, please describe:

Comments

Considering the current cost of monitoring, if my ideal on-line/real-time sensor or instrument existed, I would willing/able to purchase it for: (select all that apply)

a. < $50,000
b. < $20,000
c. < $10,000
d. < $ 5,000
e. Other

If Other, please specify:

Comments

I would rather rent or borrow an on-line/real-time instrument than own one: T/F

Comments

I would rather purchase the data or access to the data than conduct monitoring myself: T/F
Comments

Additional comments:

Appendix 2: ASDWA Questionnaire

My answers below reflect the interests of: (select all that apply)

a. State drinking water programs
b. Drinking water systems
c. Other

If Other, please describe.

Comments:

PLEASE INDICATE REQUIREMENTS BELOW:

Which of the following statements best reflect the importance of measuring arsenic?

a. High priority. I currently or plan to allocate resources in the near future to monitoring/measuring arsenic.
b. Medium priority. Arsenic is important, and I may have sufficient resources to allocate for monitoring it, but other issues are more important.
c. Low priority. Many other issues take priority over arsenic.
d. Other. Please explain:

Comments

I want to measure total arsenic for: (select all that apply)

a. Source water (raw water prior to treatment)
b. Finished water (after treatment)
c. Regulatory compliance
d. Monitoring/prediction
e. Research
f. Other

If Other, please describe:

Comments

I currently measure/monitor total arsenic by: (select all that apply)

a. Sending water samples to a laboratory for analysis
b. Analyzing in an in-house laboratory
c. Using an on-line analyzer/in situ sensor
d. Other

If Other, please describe:

Comments

My current method meets my need: Y/N

Comments

If not, why not:

What other parameters would you like to see measured along with total arsenic in a single deployment?
Comments

I would like to see sampling results within:

a. Instantaneous / near-real-time
b. < 8 hours
c. < 24 hours
d. < 3 days
e. < 1 week
g. Other

If Other, please describe:

Comments

I would be interested in a device that can make repeated measurements in the field: Y/N

If yes, I'd like to make repeated measurements for the following deployment length (needed amount of time the instrument will be in the field without a visit from a technician (for service, calibration, etc.)): (select all that apply)

a. 1 day
b. 1 week
c. 1 month
d. 3 months
e. 6-9 months
f. 1 year
g. Other

If Other, please describe:

Comments

Regulations or permits require me to be able to measure at the following frequency:

a. 15 minutes
b. 1 hour
c. 12 hours
d. 1 day
e. 1 week
f. Other

If Other, please describe:

Comments

I would like to be able to measure at the following frequency:

a. 1 minute
b. 15 minutes
c. 1 hour
d. 12 hours

e. 1 day
f. 1 week
g. Other
If Other, please describe:
Comments

How would you like to transmit data from sensor deployed in situ? (select all that apply)

a. WiFi
b. Cellular
c. Satellite
d. HF Radio
e. Manual download
f. Other

If Other, please explain:
Comments:

What type of integration would be ideal? (select all that apply)

a. Integrated into existing data logger
b. Integrated into new commercial data logger
c. Stand-alone units with internal data logging
d. Other

If Other, please explain:
Comments:

Definitions:
Lower LOD: Lowest concentration needed (µg/L)
Upper LOD: Highest concentration needed (µg/L)

I need to be able to measure total arsenic in the following concentration range: (see questions below)

Lower LOD:

a. 1 µg/L
b. 2.5 µg/L
c. 5 µg/L
d. 10 µg/L
e. Other

If Other, please describe:
Comments

Upper LOD:

a. 10 µg/L
b. 20 µg/L
c. 50 µg/L
d. 100 µg/L

e. Other

If Other, please describe:

Comments

Considering the current cost of monitoring, if my ideal on-line/real-time sensor or instrument existed, I would willing/able to purchase it for: (select all that apply)

a. < $50,000
b. < $20,000
c. < $10,000
d. < $ 5,000
e. Other

If Other, please specify:

Comments

I would rather rent or borrow an on-line/real-time instrument than own one: T/F

Comments

I would rather purchase the data or access to the data than conduct monitoring myself: T/F

Comments

Additional comments:

Appendix 3: Webinar Poll Questions

1) I am interested in measuring total arsenic in:

   a. Ambient water
   b. Drinking Water
   c. Runoff (agricultural, urban, etc)
   d. Wastewater (influent/effluent/industrial)
   e. Other

2) I want a sensor with a lower detection limit of:

   a. 0.01 µg/L
   b. 0.1 µg/L
   c. 1 µg/L
   d. 10 µg/L
   e. Other

3) I want an arsenic sensor that can measure concentrations up to:

   a. 1,000 µg/L (1 mg/L)
   b. 10,000 µg/L (10 mg/L)
   c. 100 µg/L
   d. Other

4) I want sample results within:

   a. 1 week
   b. 3 days
   c. 1 day
   d. Seconds (real-time)
   e. Other

5) I want a sensor capable of the following measurement frequency:

   a. 1 day
   b. 1 hour
   c. 15 minutes
   d. Continuous
   e. Other

6) I want a sensor capable of being deployed without maintenance for:

   a. 1 day
   b. 1 week
   c. 1 month
   d. 3 months
   e. Other

7) I prefer the following method for remote communication:

a. Cellular/Satellite
b. Manual/not remote
c. WiFi

8) I prefer a sensor with data logging that is:

a. Integrated into an external system
b. Internal to a standalone unit
c. This is not important to me
d. Other

9) Ownership – If I had the option, I would prefer to:

a. Purchase my equipment
b. Borrow my equipment from a membership based union/consortium
c. Rent my equipment
d. Purchase the data
e. Other

10) The following price would be reasonable for an arsenic sensor/instrument:

a. $20,000 - $50,000
b. $10,000 - $20,000
c. $5,000 - $10,000
d. $2,500 - $5,000
e. Other