



THE
Water
Research
FOUNDATION

Project #5087: Implementation of Innovative Biological Nutrient Removal Processes through Improvement of Control Systems & Online Analytical Measurement Reliability & Accuracy

Utility Survey Results

2024



About the utility survey

The project team conducted a survey of water resource recovery facilities (WRRFs) in 2022 to understand firsthand real-world experiences with BNR sensor-based control systems. In addition to gathering general background information about each WRRF such as design capacity, effluent limits and biological processes, the survey requested that respondents identify the type of control systems being utilized, the type of sensors and analyzers installed, and the outcomes from implementing more advanced controls. The survey questions incorporated both objective inquiries (e.g., frequency of calibration) and more subjective inquiries (e.g., ease of calibration and acceptability of calibration requirements).

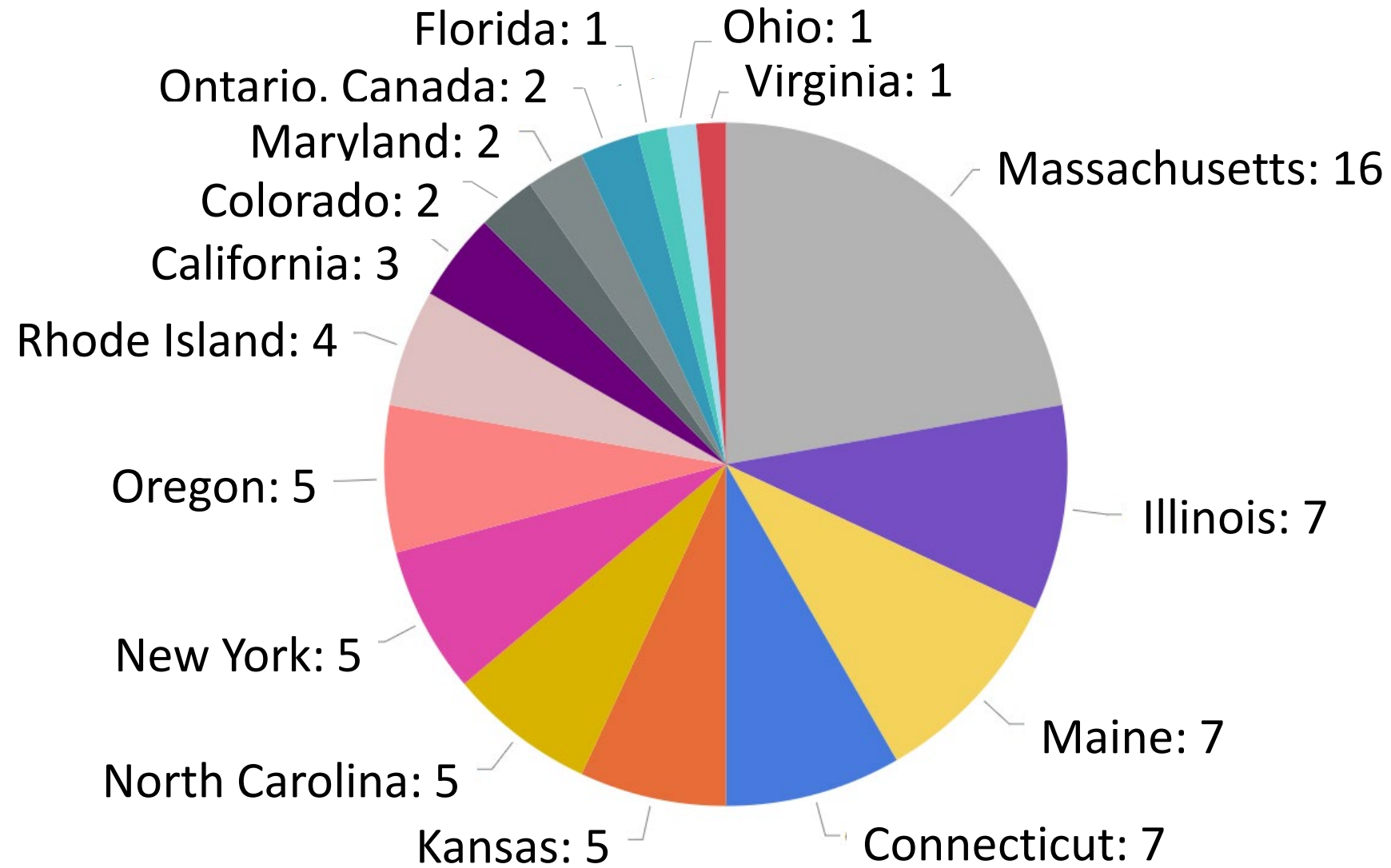
Over 800 survey requests were distributed to WRRFs across the United States and Canada, including the project utility partners and The Water Research Foundation's (WRF) subscriber network. The survey was administered through Survey Monkey by the project team, and a link to the survey was included both on the WRF website for the project and in an email to the recipients along with an electronic hardcopy of the questions.

We received 72 survey responses, which is a response rate of approximately 9%. While there are too few responses for the results to be statistically significant, the results provide a snapshot of general trends. The data collected from the survey responses were organized and visualized in Microsoft Power BI dashboards. Screenshots from the dashboards are included herein along with bulleted summaries of the results.

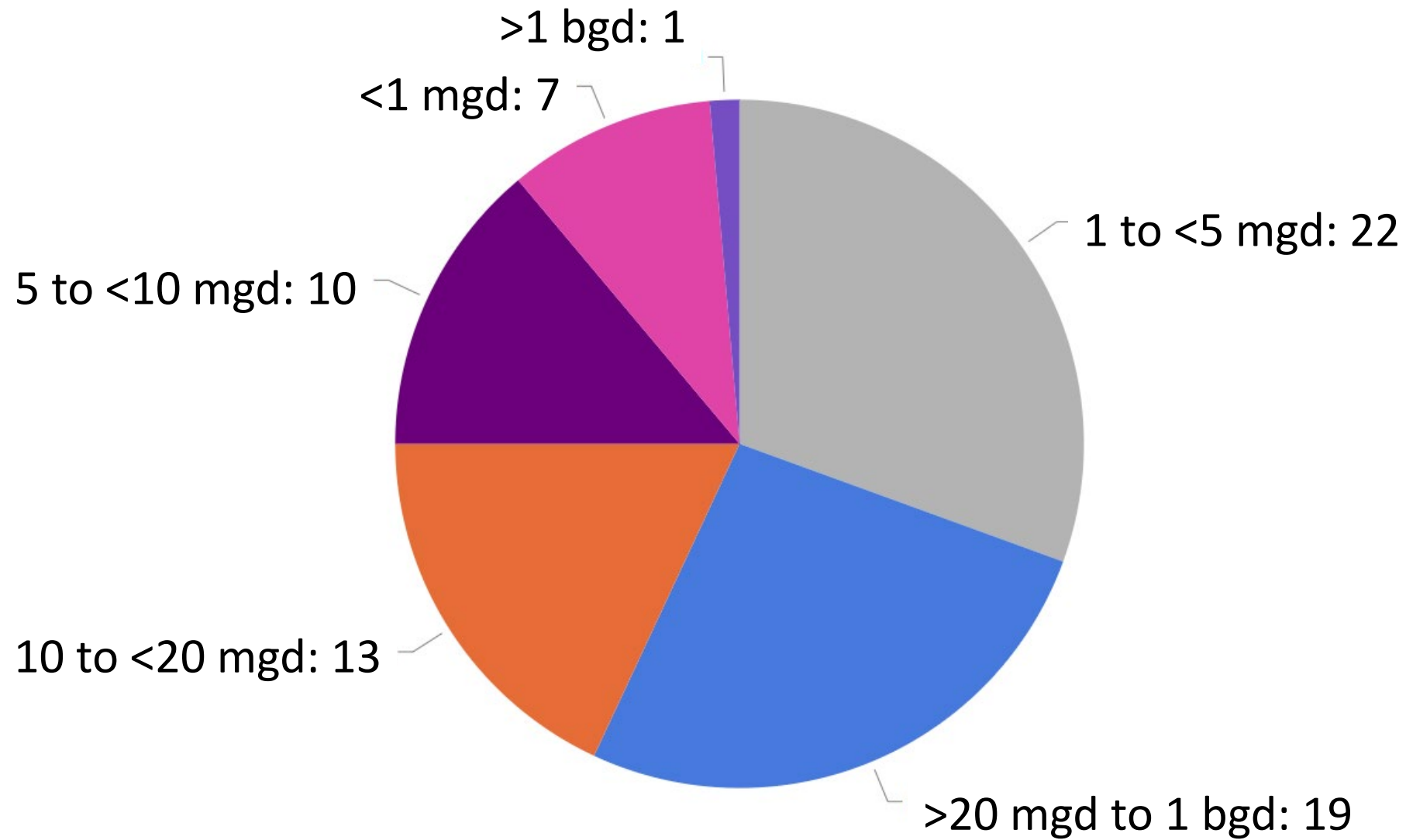
The following five pages contain charts that depict respondent characteristics based on the aggregate results of the utility survey, including location of responses, size of WRRFs, biological treatment process in use, and types of sensors and analyzers used for BNR monitoring and control. Survey results include:

- **72 survey responses**
 - Diversity in WRRF size and geography
 - Almost all operate activated sludge systems
- **Control systems**
 - Dissolved oxygen aeration control & RAS/WAS pumping control were the most common control systems in use
 - “Innovative” controls systems (e.g., AVN and ABAC) are less common and represent a small fraction of the survey responses
- **Instrumentation**
 - Dissolved oxygen sensors were the most common sensor utilized for BNR process control

Geographical distribution of responses

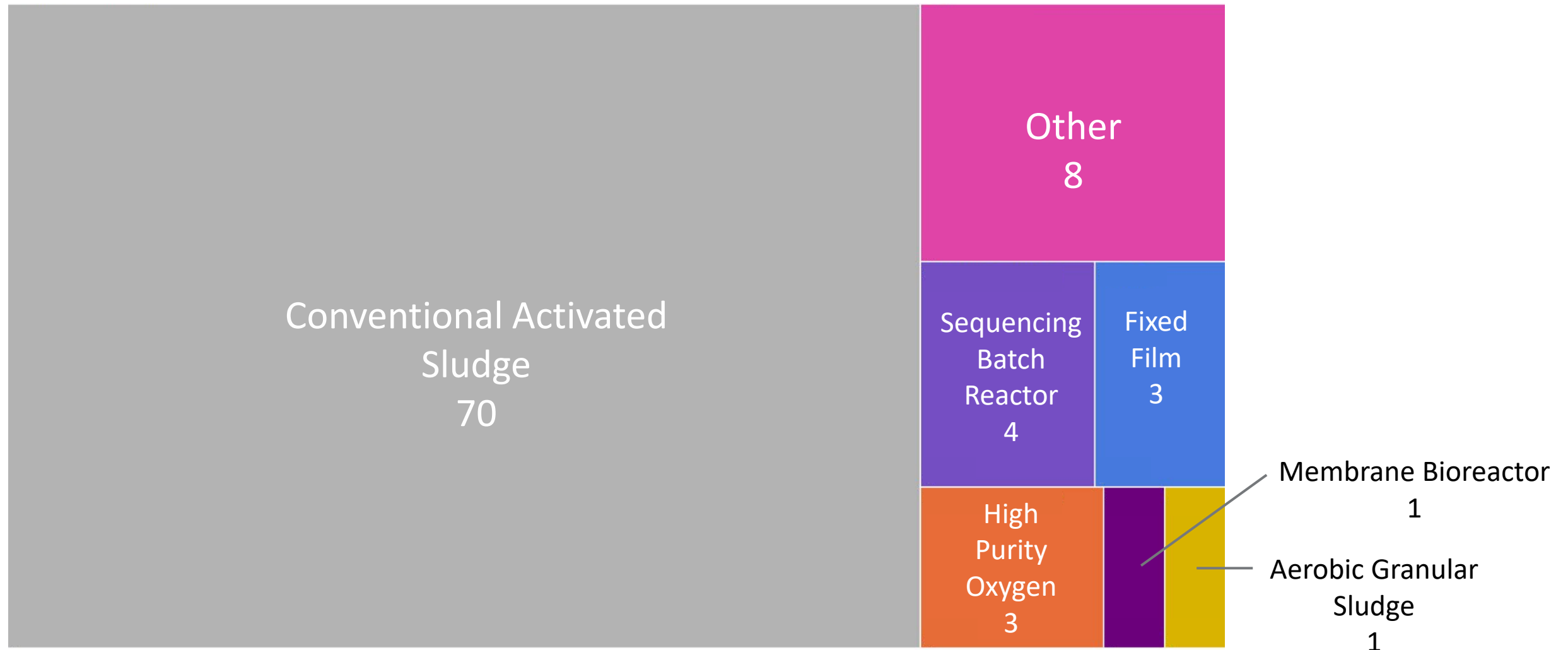


WRRF sizes

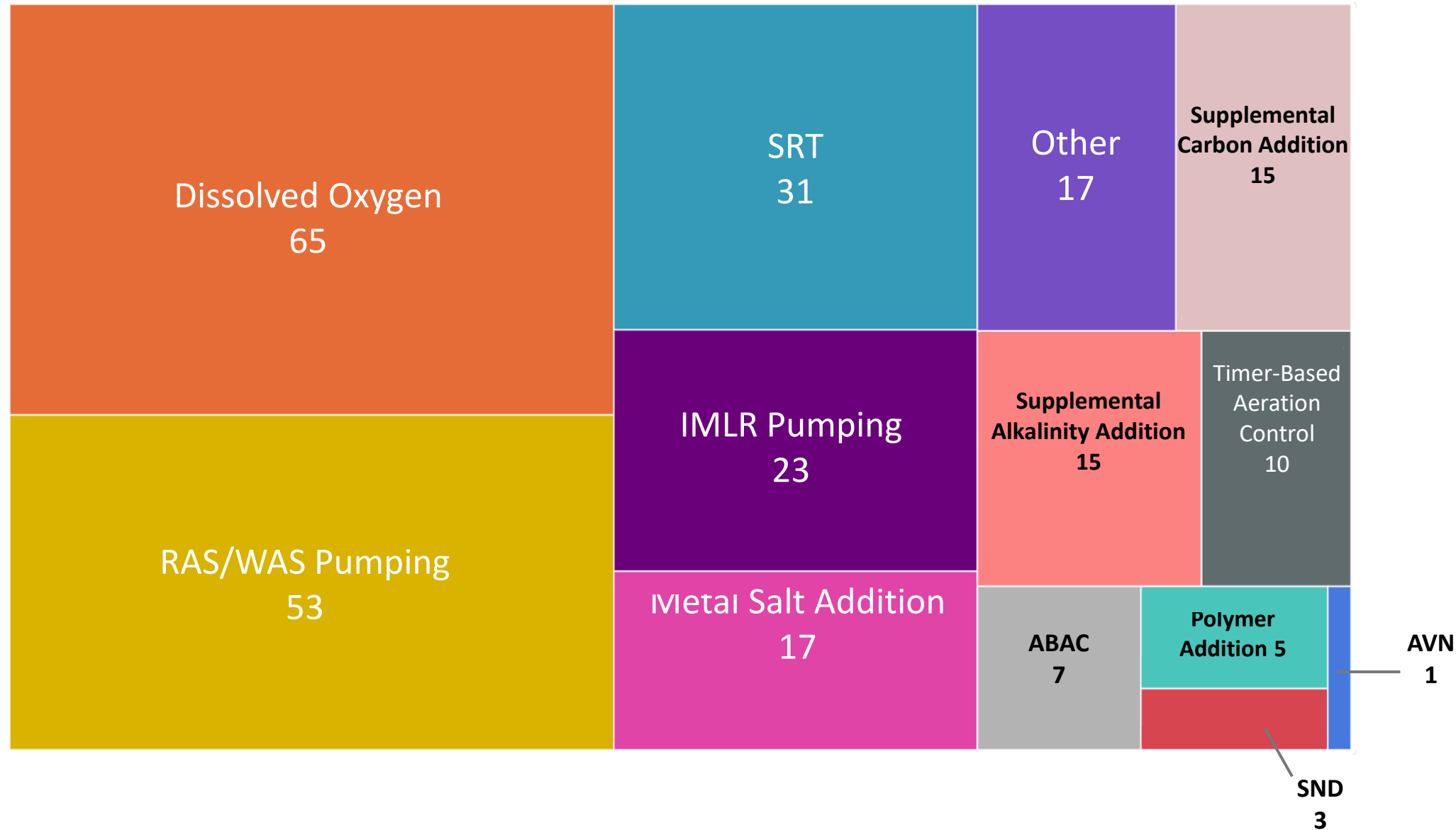


Legend:
mgd million gallons per day
bgd billion gallons per day

Biological processes utilized by WRRF respondents



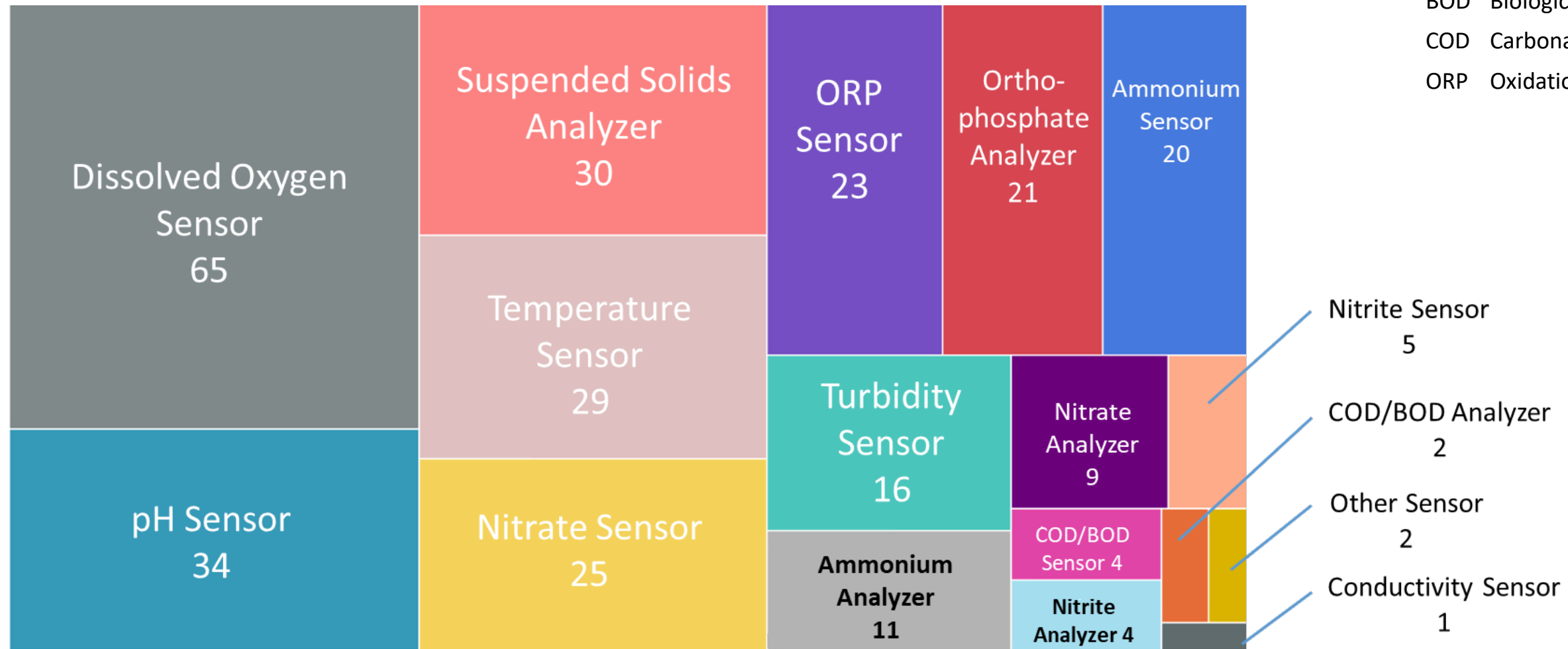
Control systems utilized by WRRF respondents



Legend:

- ABAC Ammonia based aeration control
- AVN Ammonia versus nitrate
- IMLR Internal mixed liquor recycle
- RAS Return activated sludge
- SND Simultaneous nitrification-denitrification
- SRT Solids retention time
- WAS Waste activated sludge

Sensors/analyzers utilized by WRRF respondents



Sensor & analyzer categories surveyed

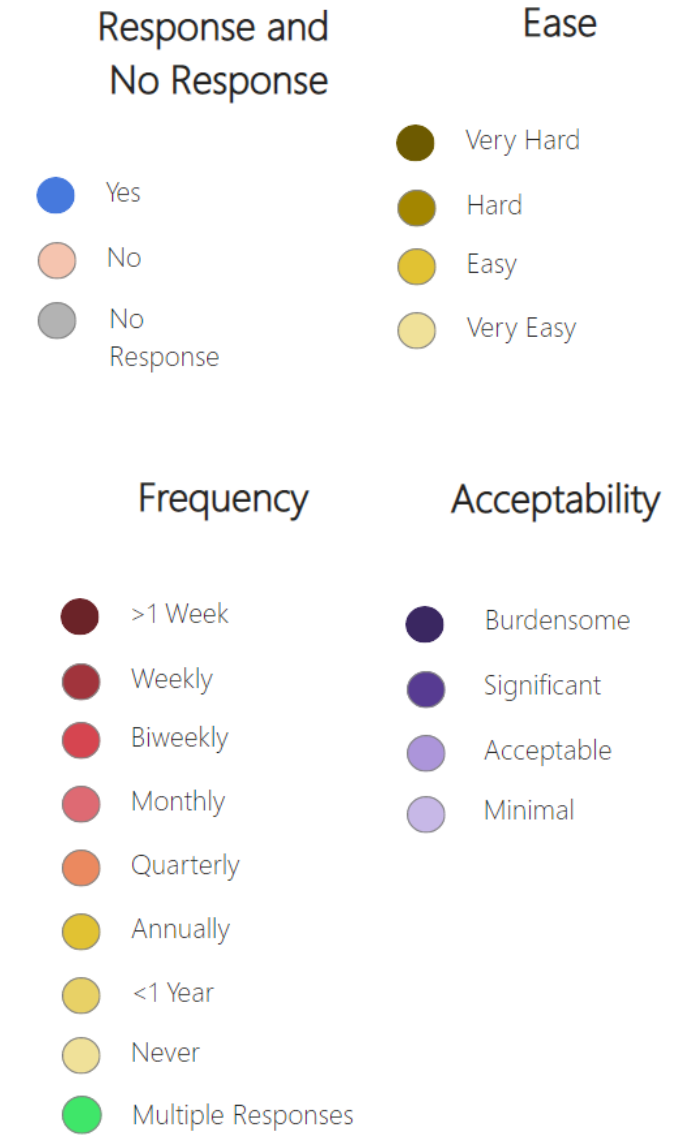
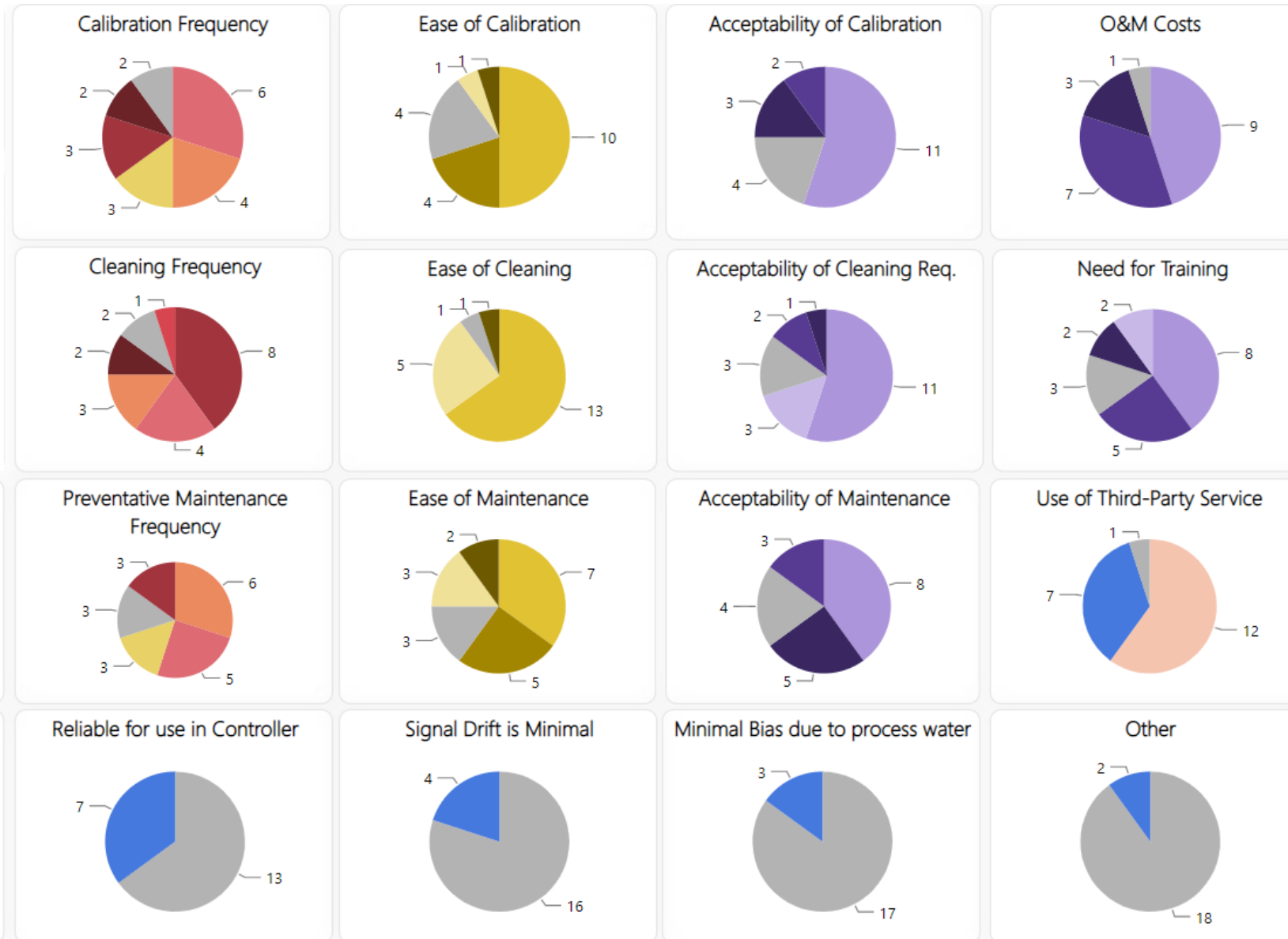
The following fifteen pages include pie charts for each of the sensors & analyzers included in the utility survey* summarizing the qualitative and quantitative survey results for the following categories:

Performance	Calibration	Cleaning	Preventive Maintenance	O&M costs	Need for Training
<ul style="list-style-type: none"> • Meets Qualitative Accuracy Needs • Meets Quantitative Accuracy Needs • Reliable Use in Controller • Signal Drift is Minimal • Minimal Bias due to Process Water 	<ul style="list-style-type: none"> • Frequency • Ease • Acceptability 	<ul style="list-style-type: none"> • Frequency • Ease • Acceptability 	<ul style="list-style-type: none"> • Frequency • Ease • Acceptability • Use of Third-party service 	<ul style="list-style-type: none"> • Acceptability 	<ul style="list-style-type: none"> • Acceptability

**No responses were provided by the survey respondents for the conductivity sensor.*

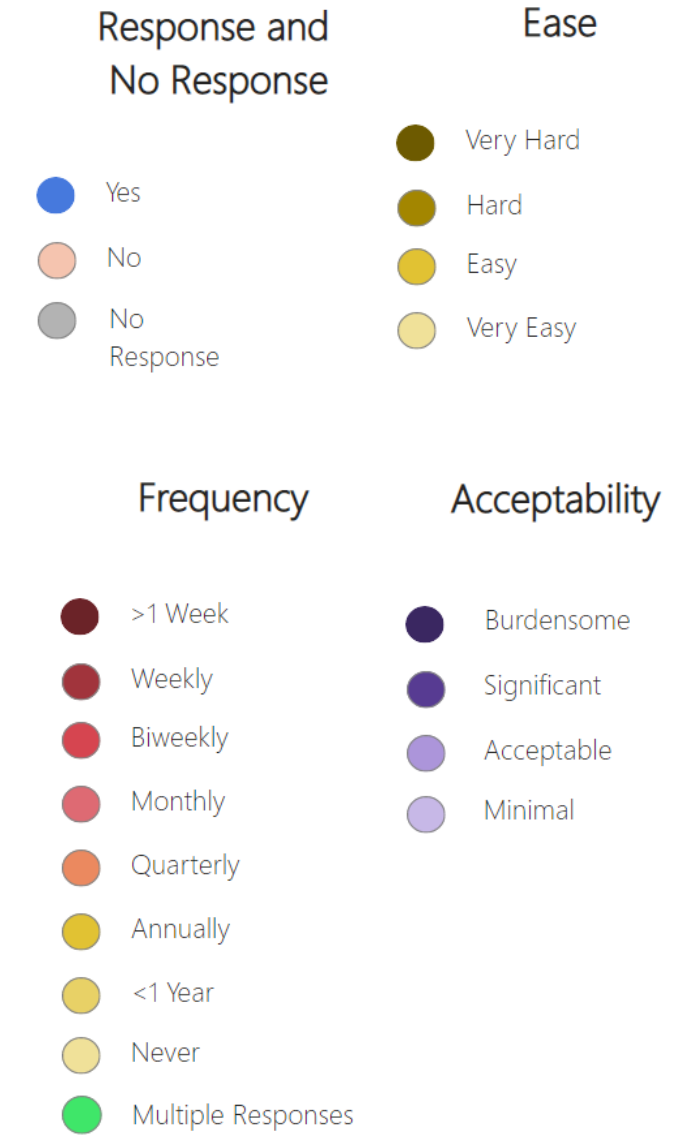
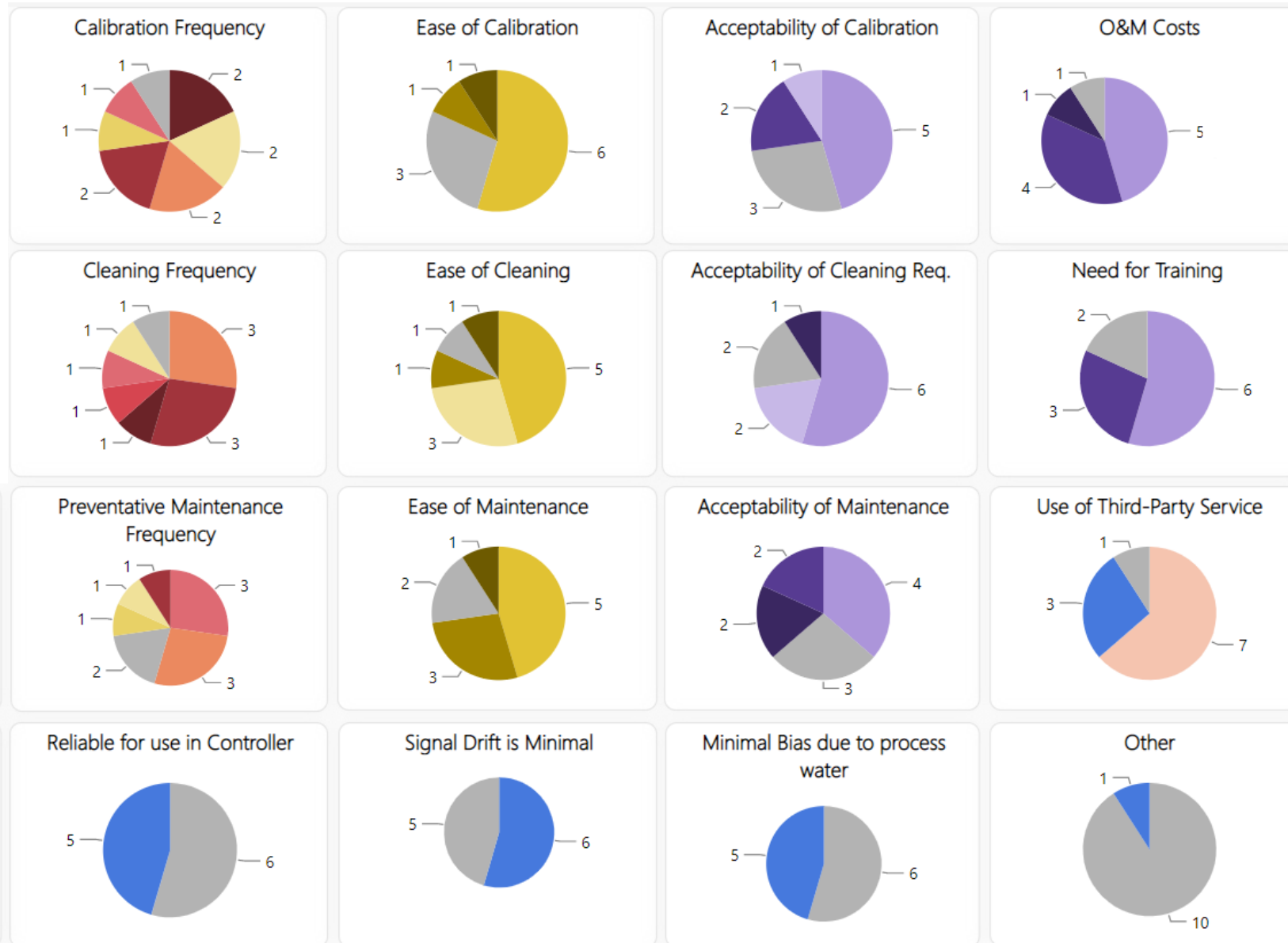
Utility survey results for ammonium sensors

Survey Results: Ammonium Sensors



Utility survey results for ammonium analyzers

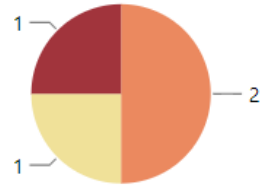
Survey Results: Ammonium Analyzers



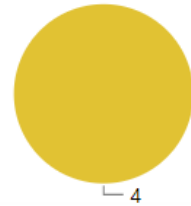
Utility survey results for COD/BOD sensors

Survey Results: BOD/COD Sensors

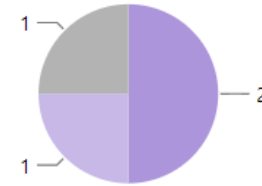
Calibration Frequency



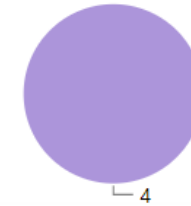
Ease of Calibration



Acceptability of Calibration



O&M Costs



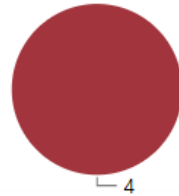
Response and No Response



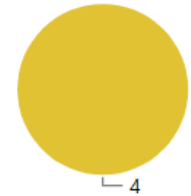
Ease



Cleaning Frequency



Ease of Cleaning



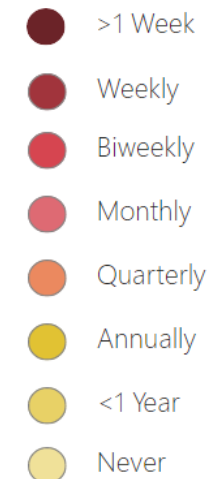
Acceptability of Cleaning Req.



Need for Training



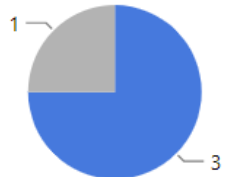
Frequency



Acceptability



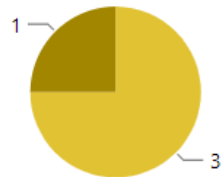
Meets Qualitative Accuracy Needs



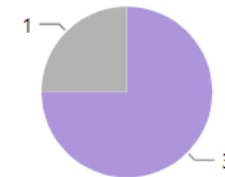
Preventative Maintenance Frequency



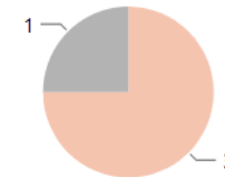
Ease of Maintenance



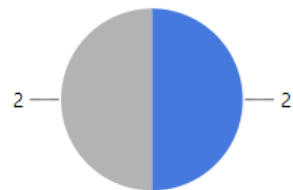
Acceptability of Maintenance



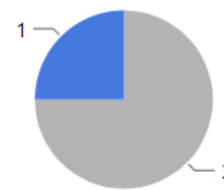
Use of Third-Party Service



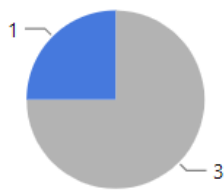
Meets Quantitative Accuracy Needs



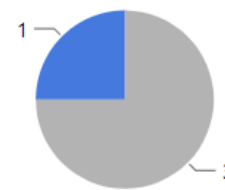
Reliable for use in Controller



Signal Drift is Minimal



Minimal Bias due to process water

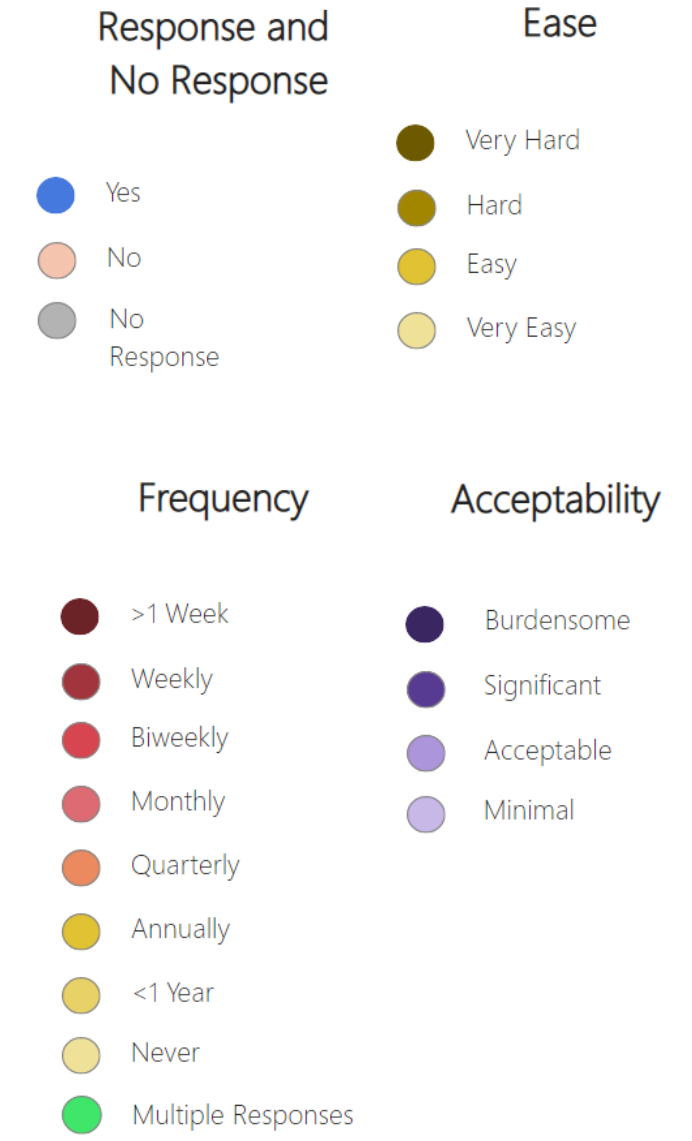


Other



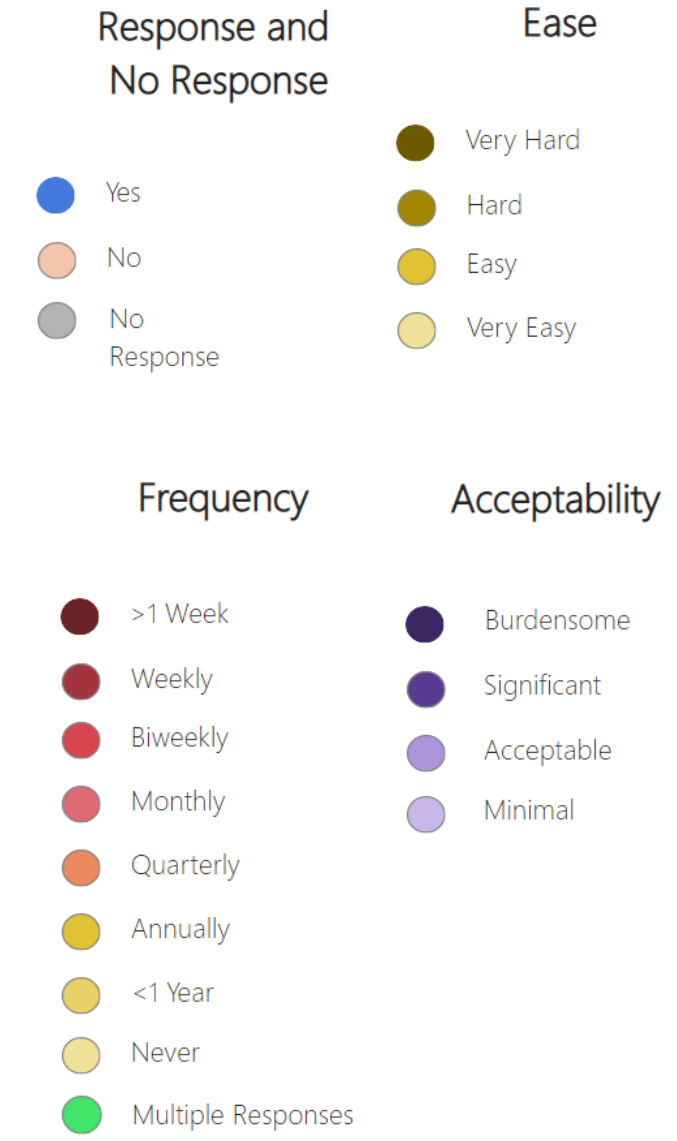
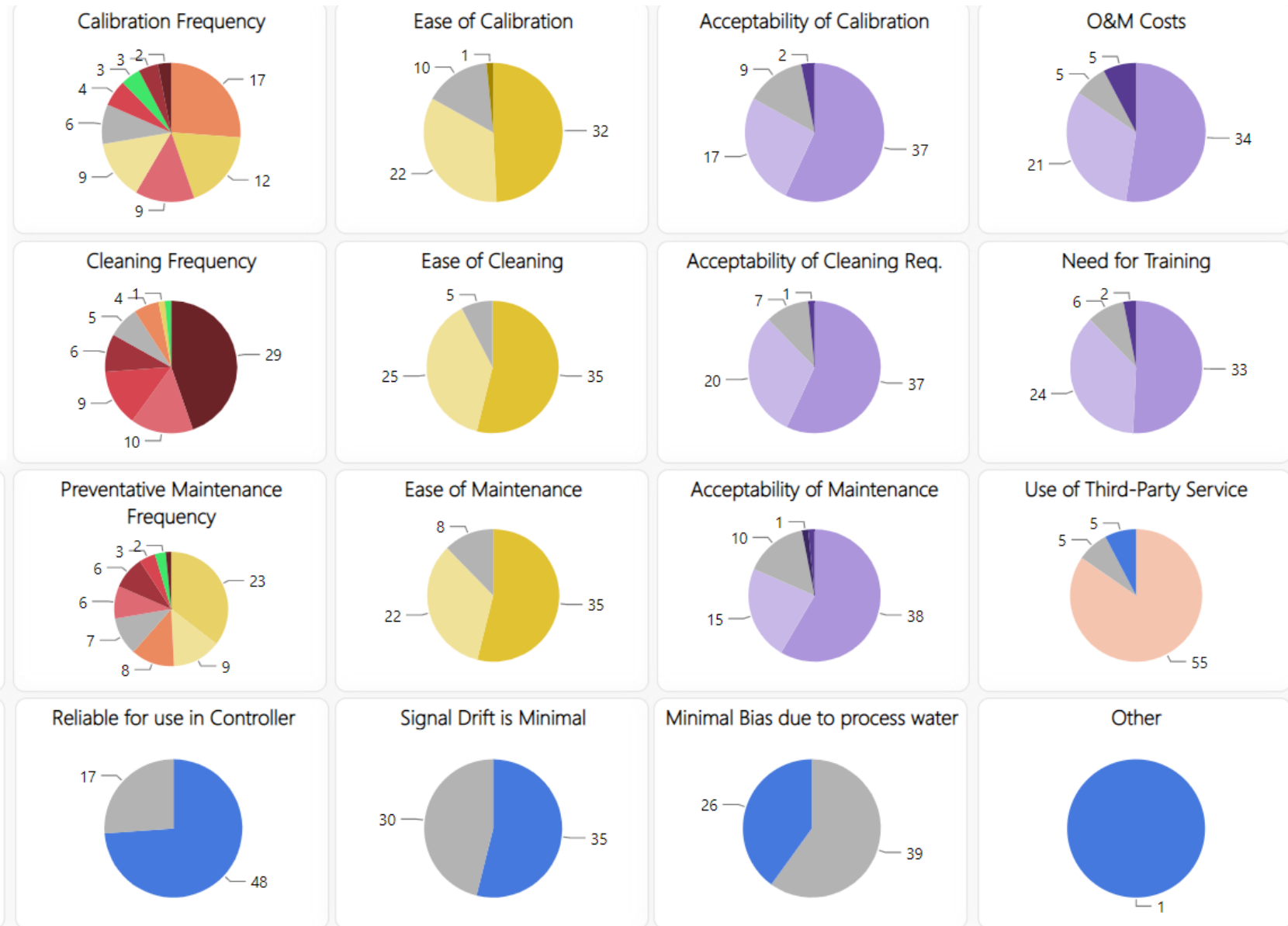
Utility survey results for COD/BOD analyzers

Survey Results: BOD/COD Analyzers



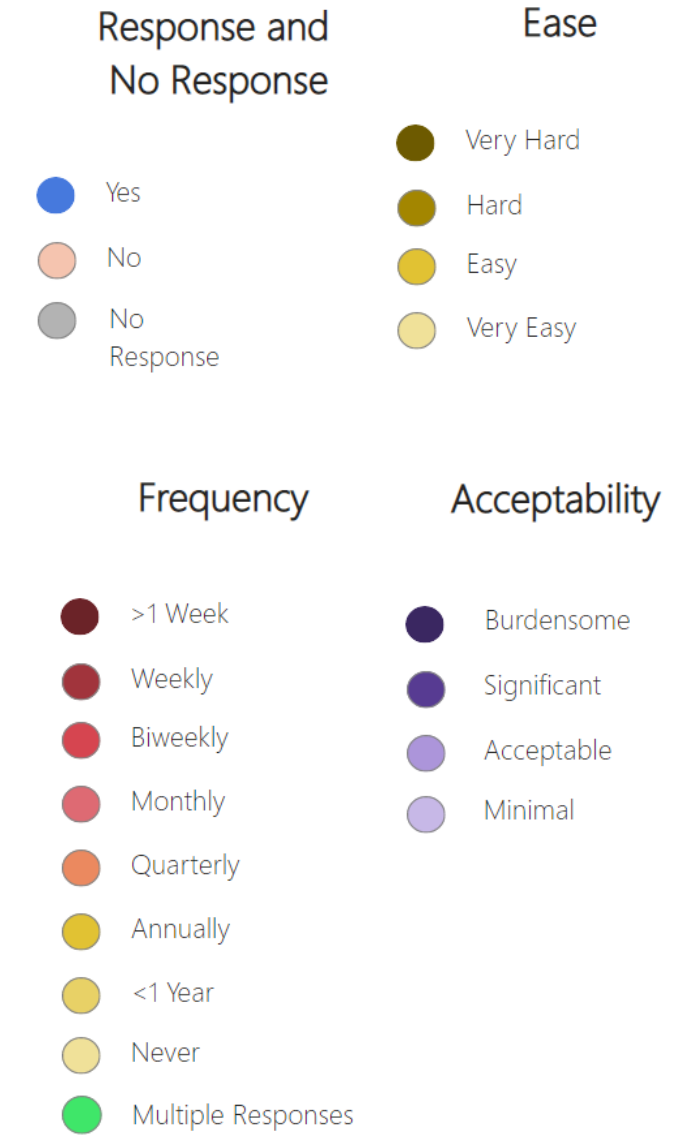
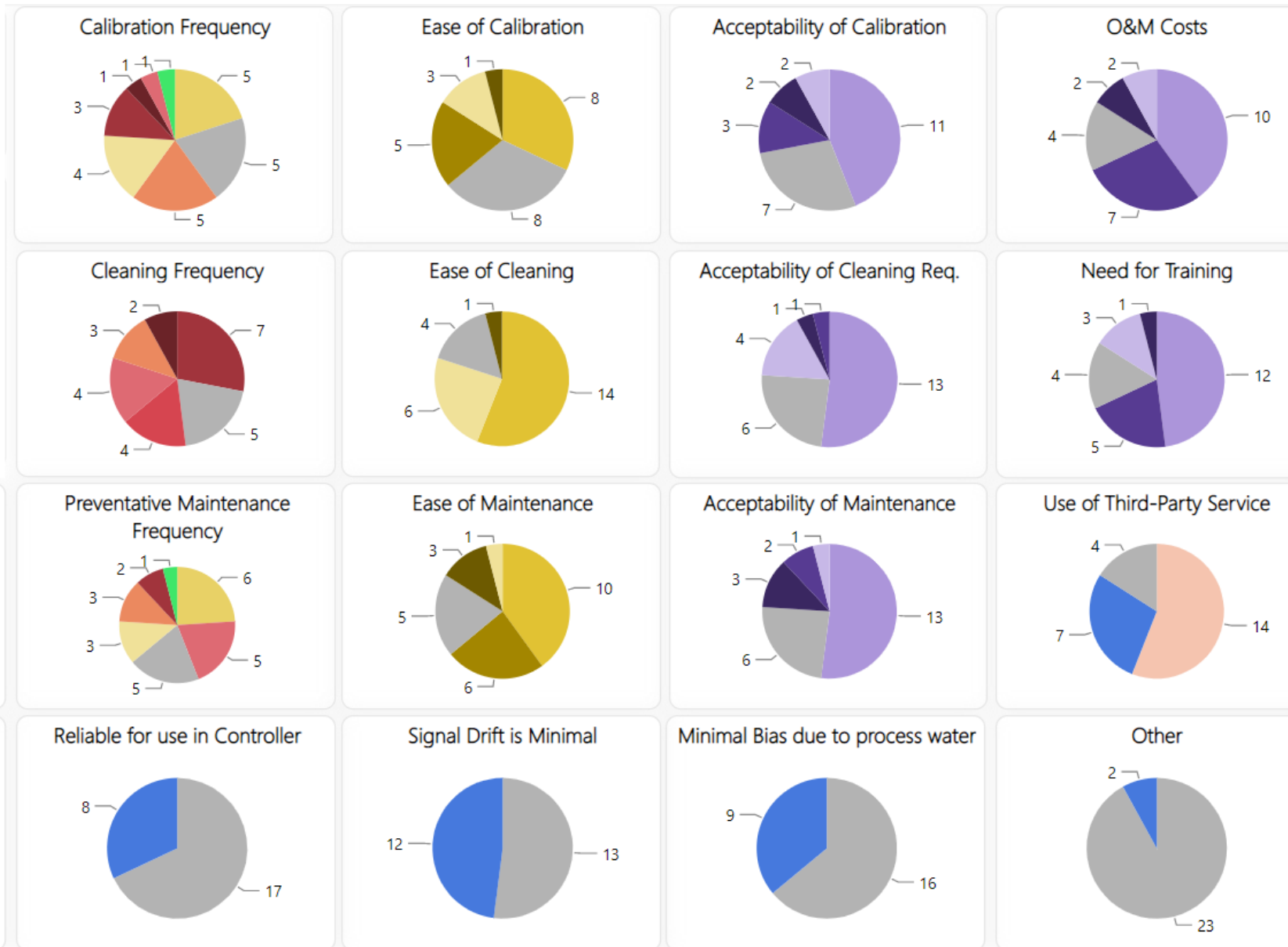
Utility survey results for dissolved oxygen sensors

Survey Results: Dissolved Oxygen Sensors



Utility survey results for nitrate sensors

Survey Results: Nitrate Sensors



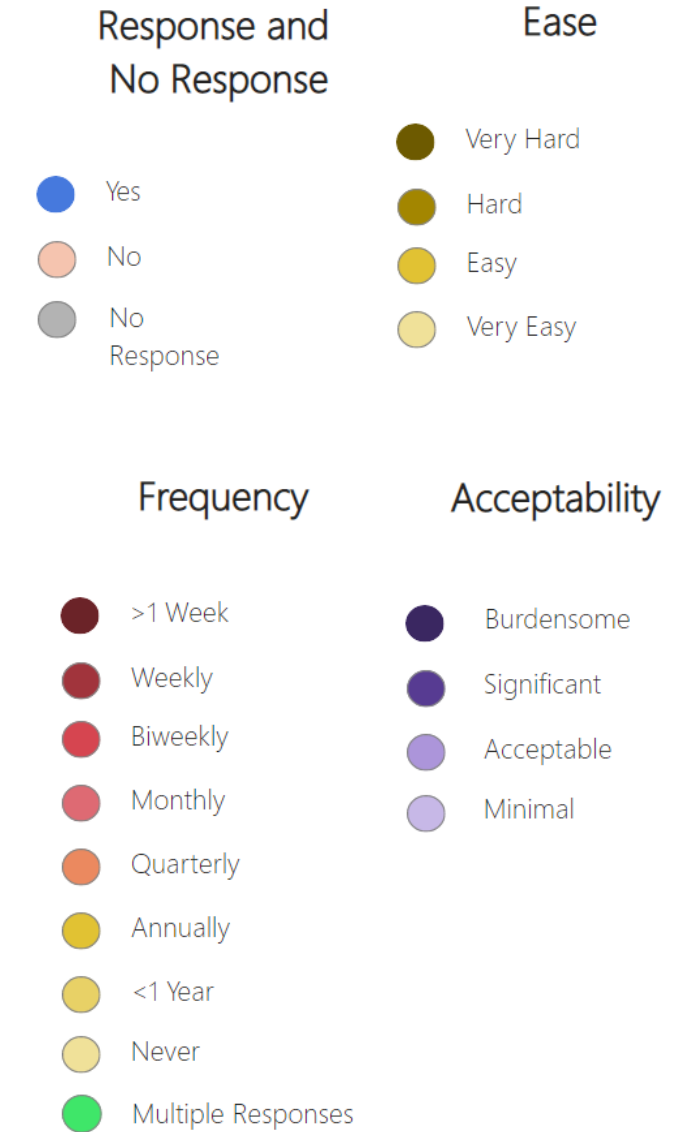
Utility survey results for nitrate analyzers

Survey Results: Nitrate Analyzers



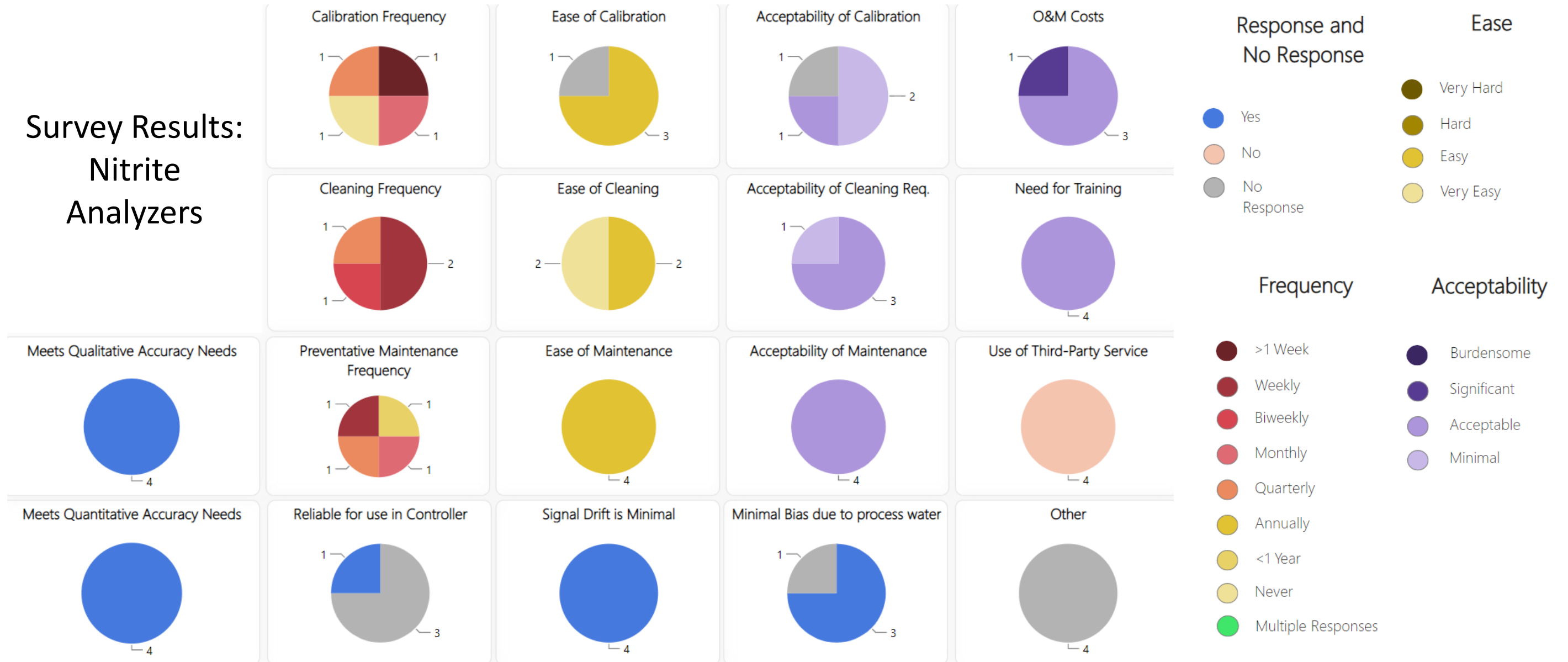
Utility survey results for nitrite sensors

Survey Results: Nitrite Sensors



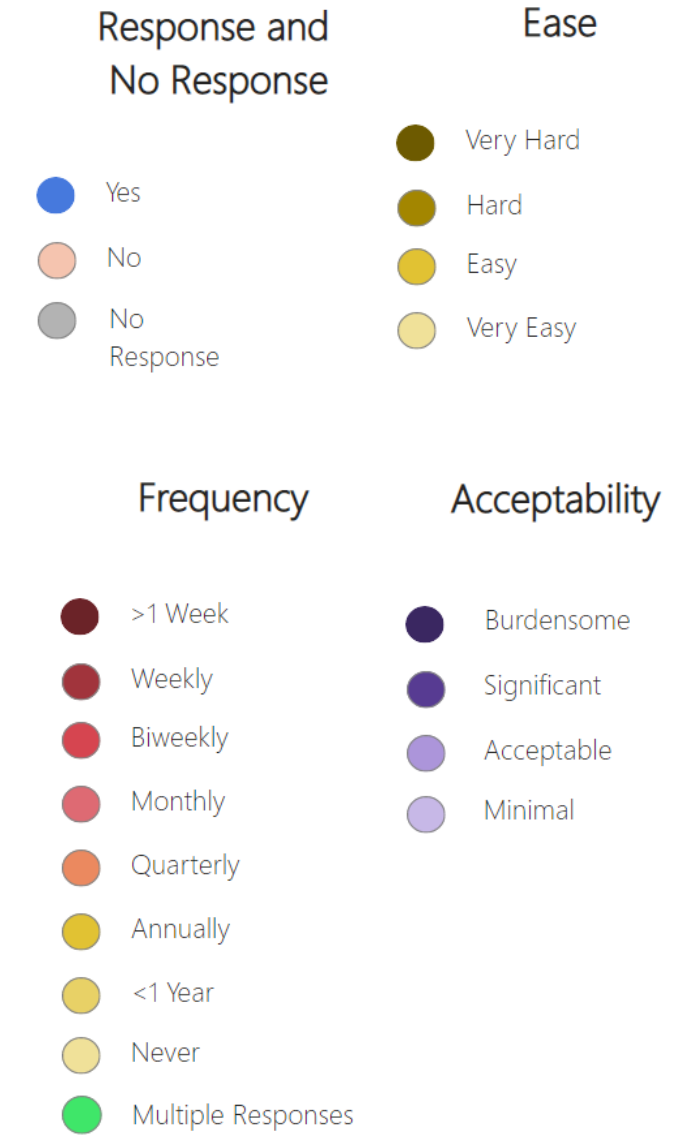
Results for nitrite analyzers

Survey Results: Nitrite Analyzers



Utility survey results for ORP sensors

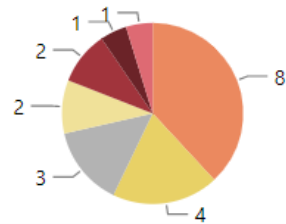
Survey Results: ORP Sensors



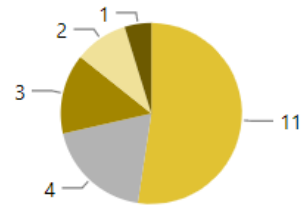
Utility survey results for orthophosphate analyzers

Survey Results: Orthophosphate Analyzers

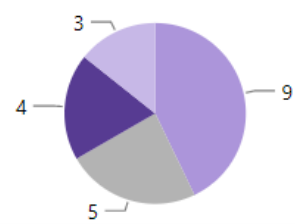
Calibration Frequency



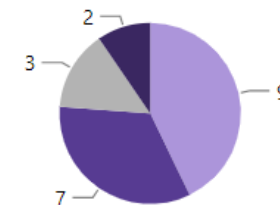
Ease of Calibration



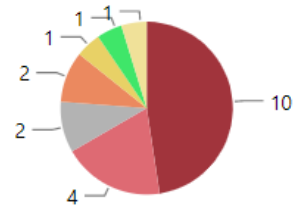
Acceptability of Calibration



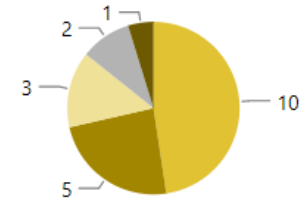
O&M Costs



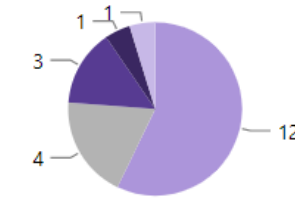
Cleaning Frequency



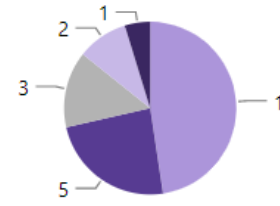
Ease of Cleaning



Acceptability of Cleaning Req.



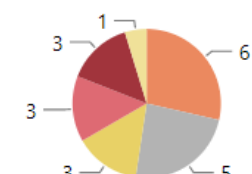
Need for Training



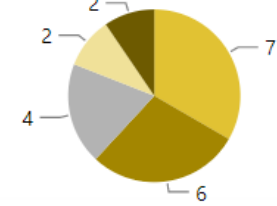
Meets Qualitative Accuracy Needs



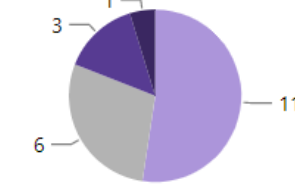
Preventative Maintenance Frequency



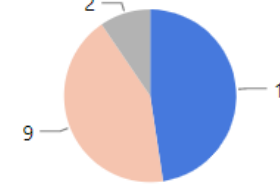
Ease of Maintenance



Acceptability of Maintenance



Use of Third-Party Service



Meets Quantitative Accuracy Needs



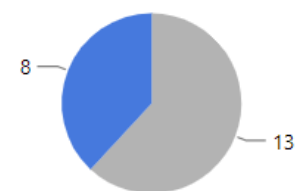
Reliable for use in Controller



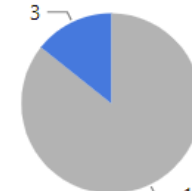
Signal Drift is Minimal



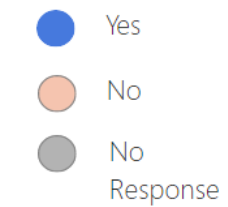
Minimal Bias due to process water



Other



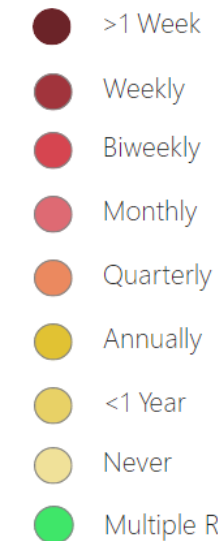
Response and No Response



Ease



Frequency



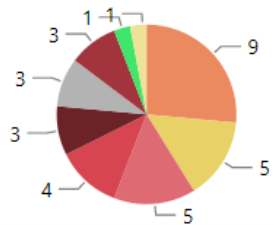
Acceptability



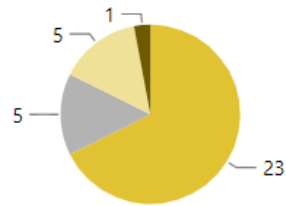
Utility survey results for pH sensors

Survey Results: pH Sensors

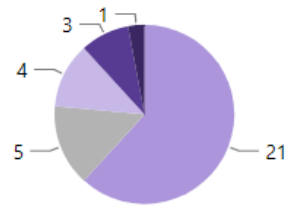
Calibration Frequency



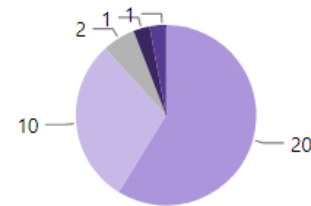
Ease of Calibration



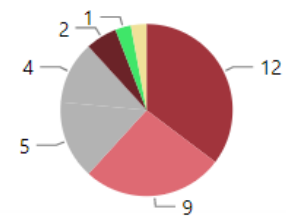
Acceptability of Calibration



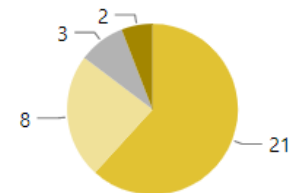
O&M Costs



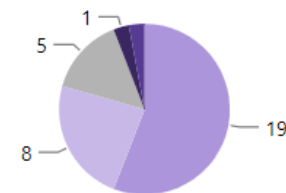
Cleaning Frequency



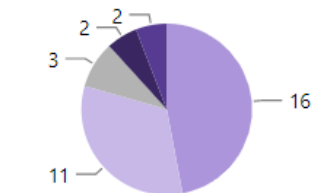
Ease of Cleaning



Acceptability of Cleaning Req.



Need for Training



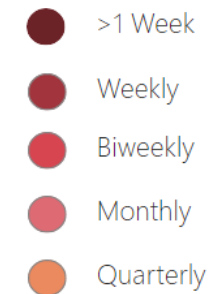
Response and No Response



Ease



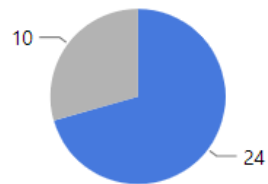
Frequency



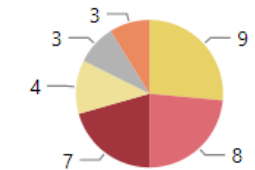
Acceptability



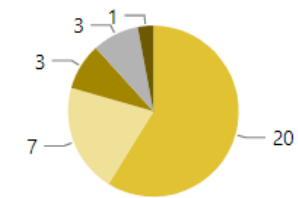
Meets Qualitative Accuracy Needs



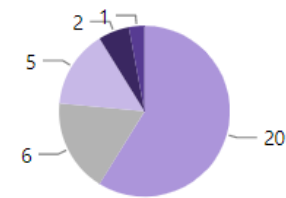
Preventative Maintenance Frequency



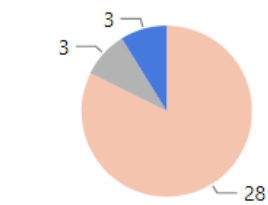
Ease of Maintenance



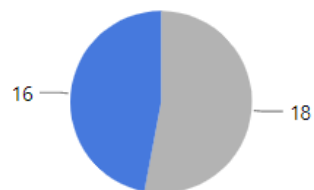
Acceptability of Maintenance



Use of Third-Party Service



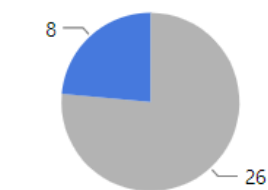
Meets Quantitative Accuracy Needs



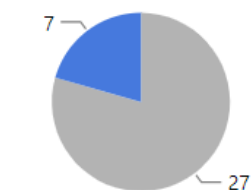
Reliable for use in Controller



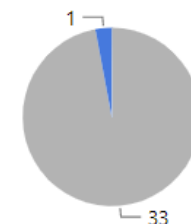
Signal Drift is Minimal



Minimal Bias due to process water

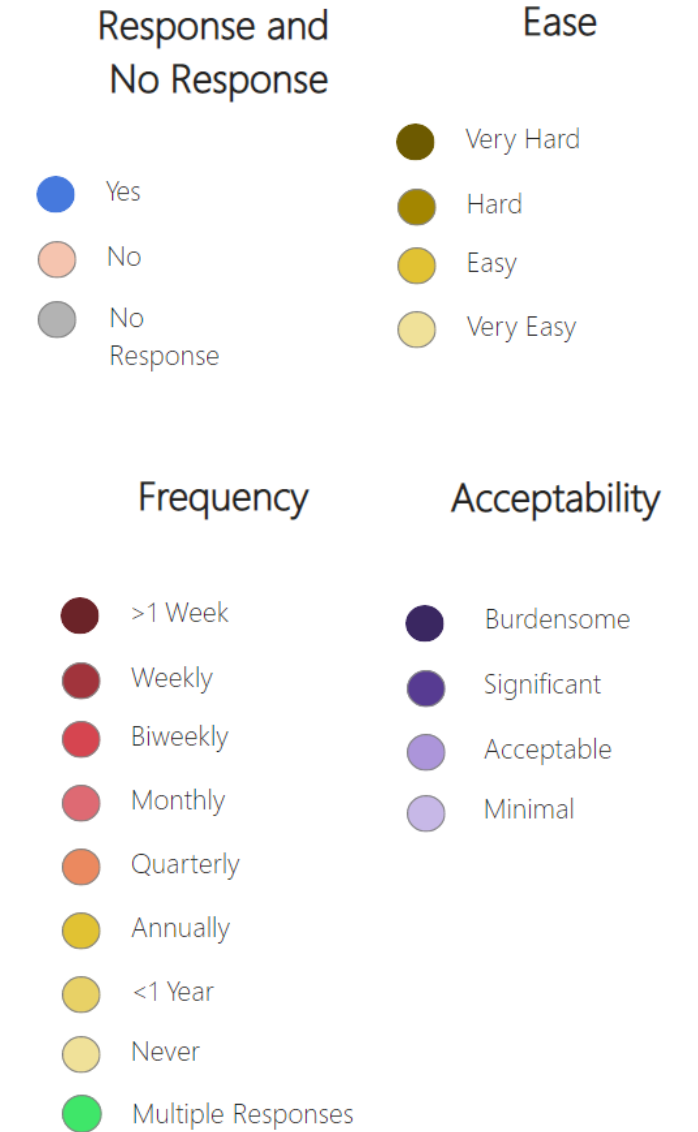


Other



Utility survey results for suspended solids sensors

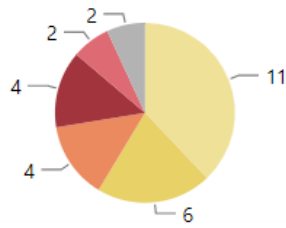
Survey Results: Suspended Solids Sensors



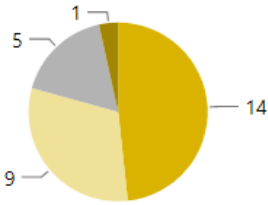
Results for temperature sensors

Survey Results: Temperature Sensors

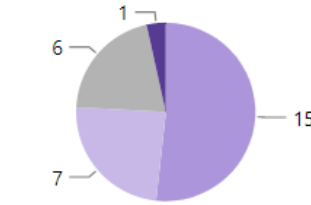
Calibration Frequency



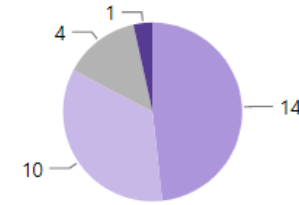
Ease of Calibration



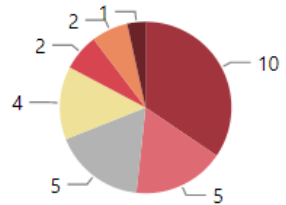
Acceptability of Calibration



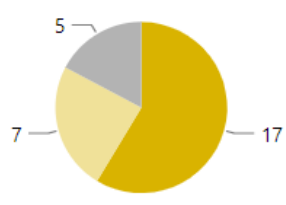
O&M Costs



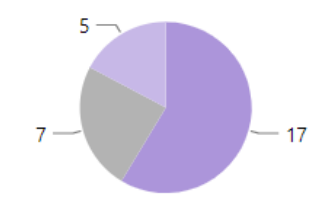
Cleaning Frequency



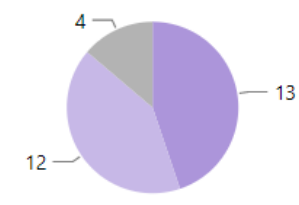
Ease of Cleaning



Acceptability of Cleaning Req.



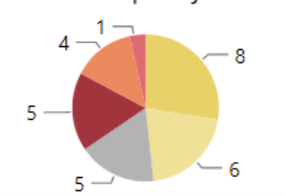
Need for Training



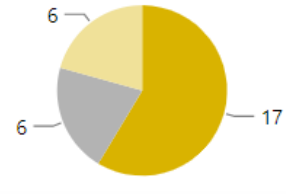
Meets Qualitative Accuracy Needs



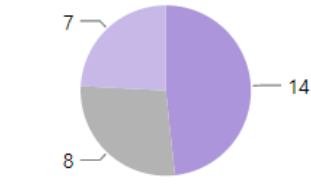
Preventative Maintenance Frequency



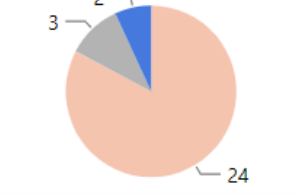
Ease of Maintenance



Acceptability of Maintenance



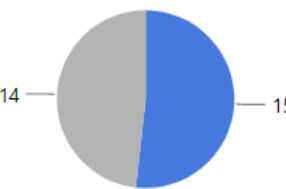
Use of Third-Party Service



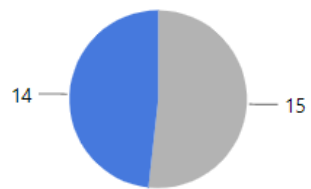
Meets Quantitative Accuracy Needs



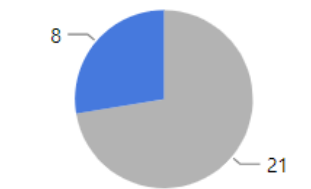
Reliable for use in Controller



Signal Drift is Minimal



Minimal Bias due to process water



Other



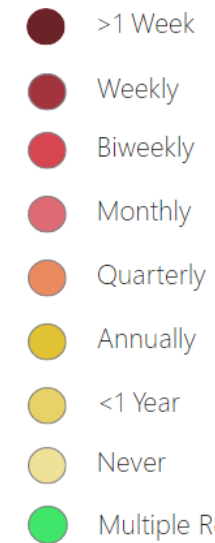
Response and No Response



Ease



Frequency



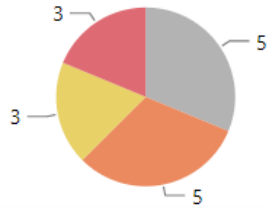
Acceptability



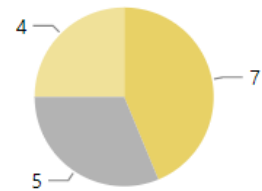
Utility survey results for turbidity sensors

Survey Results: Turbidity Sensors

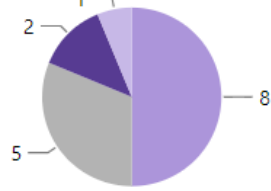
Calibration Frequency



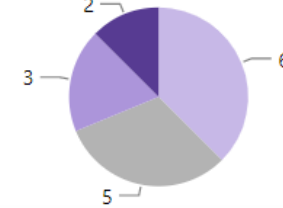
Ease of Calibration



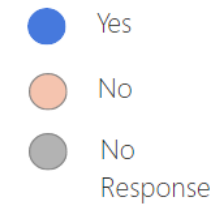
Acceptability of Calibration



O&M Costs



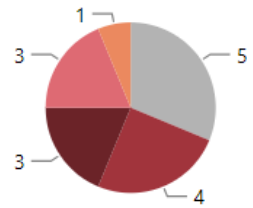
Response and No Response



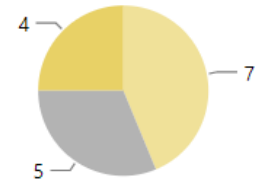
Ease



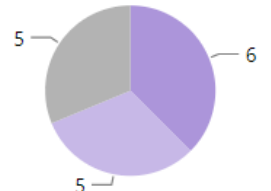
Cleaning Frequency



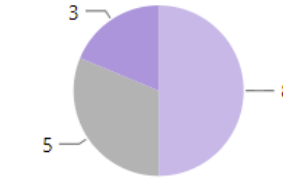
Ease of Cleaning



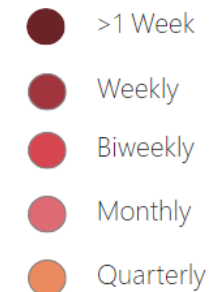
Acceptability of Cleaning Req.



Need for Training



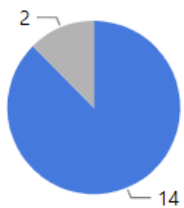
Frequency



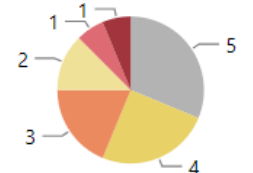
Acceptability



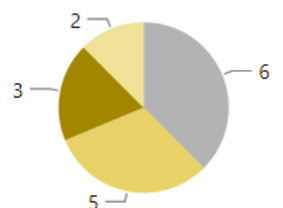
Meets Qualitative Accuracy Needs



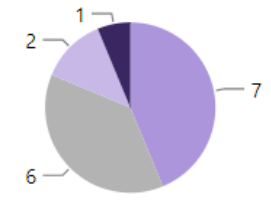
Preventative Maintenance Frequency



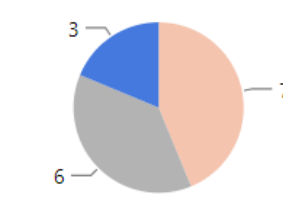
Ease of Maintenance



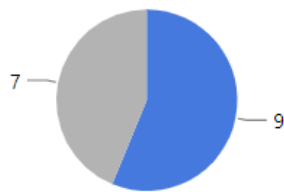
Acceptability of Maintenance



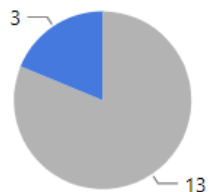
Use of Third-Party Service



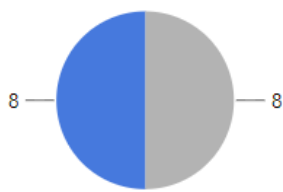
Meets Quantitative Accuracy Needs



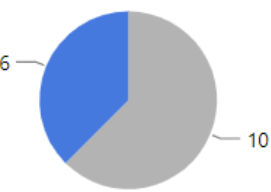
Reliable for use in Controller



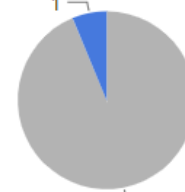
Signal Drift is Minimal



Minimal Bias due to process water



Other



Multiple Responses



Summary of sensor & analyzer results

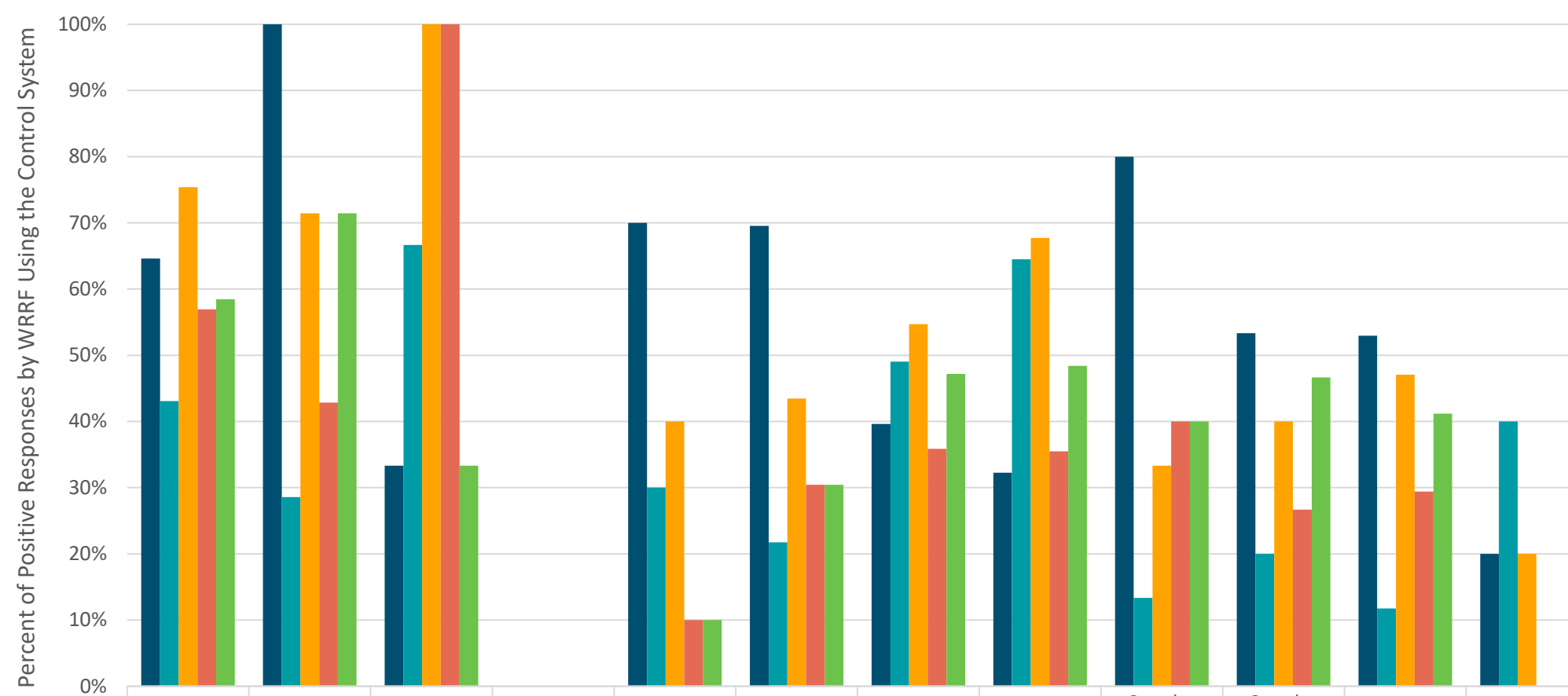
- **Dissolved oxygen sensors are the most common sensor utilized for BNR process control**
 - Cleaning, calibration, and maintenance is generally easy and acceptable
 - Almost 75% of respondents think they are reliable for use in a controller
- **Nutrient sensors and analyzers are less common and require more O&M**
 - Third party service for O&M of orthophosphate analyzers is used in almost 50% of the WRRFs included in the survey
 - 35% to >50% of respondents replied that O&M costs were significant or burdensome
 - Over 50% of respondents using the sensors and analyzers for control thought they were reliable.
 - However, combined with those using them for monitoring only, fewer than 50% of respondents think nutrient sensors and analyzers are reliable for control.
 - Utilities using nitrate and/or ammonium sensors for control reported a higher cleaning frequency than those using them for monitoring only.
- **Suspended solids sensors are less common, but O&M is generally acceptable**
 - O&M related to suspended solids sensors is generally acceptable
 - 87% of respondents (7 out of 8) using the sensors for control thought they were reliable and met their quantitative and qualitative accuracy needs; however, when combined with those using these sensors for monitoring-only, the percentage of respondents who found them reliable dropped to 30% (9 out of 30)
- **Weekly sensor cleaning is common for most sensors and analyzers**

Outcomes of BNR control system implementation

The following four pages include charts that summarize the improvements, benefits, challenges, and overall outcomes identified by the survey respondents. Respondents were asked to check a box for the improvements, benefits, and challenges that applied to them and rate the overall outcomes by responding on a sliding scale from “not worth it” to “extremely worth it.”

Improvements	Benefits	Challenges	Overall Outcomes
<ul style="list-style-type: none"> • Nutrient removal • Operations: more control • Operations: more monitoring • Settleability / characteristics of the mixed liquor • Reliability / less variability • No response 	<ul style="list-style-type: none"> • Energy savings • Greenhouse gas (GHG) reduction • Chemical savings • Sludge generation reduction • O&M labor savings • Other • No response 	<ul style="list-style-type: none"> • Capital costs • O&M costs • Control system stability • Sensor accuracy • Sensor complexity • Other • No response 	<ul style="list-style-type: none"> • Was the installation worth it?

Improvements indicated by survey respondents



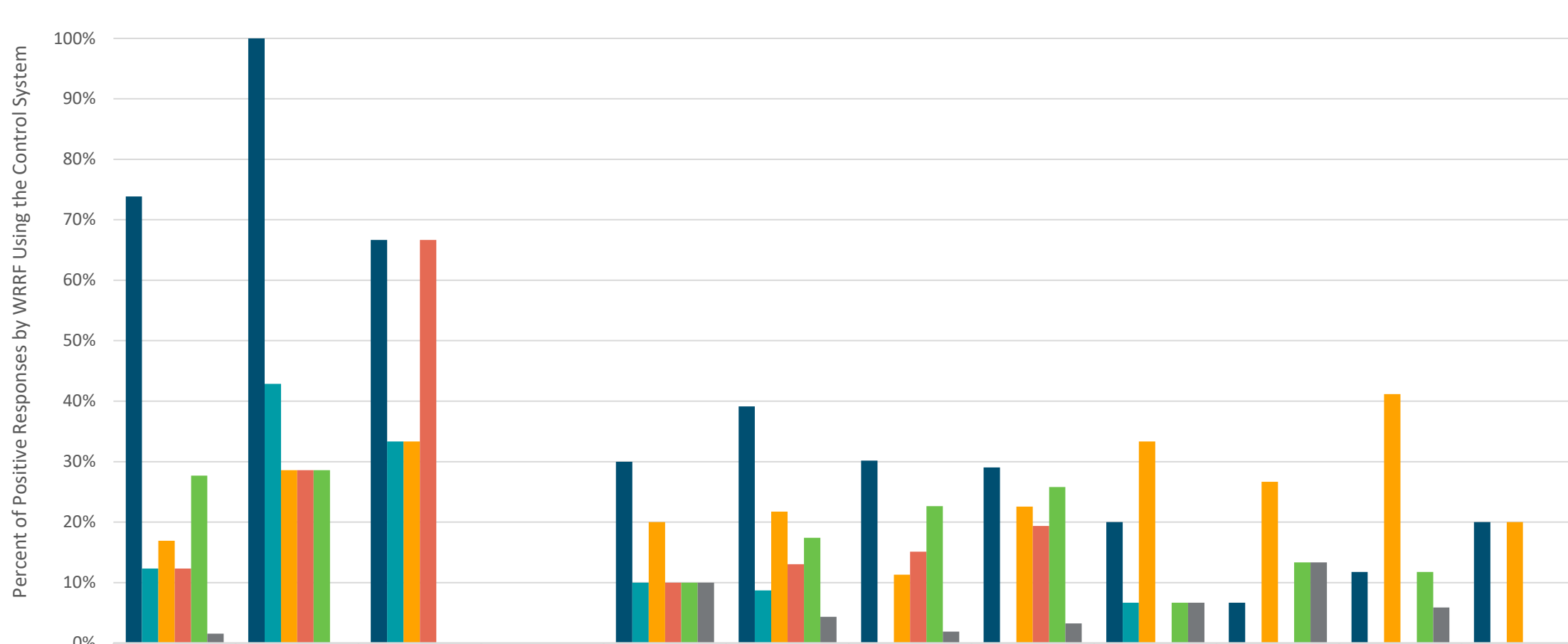
- Legend:**
- ABAC Ammonia based aeration control
 - AVN Ammonia versus nitrate
 - IMLR Internal mixed liquor recycle
 - RAS Return activated sludge
 - SND Simultaneous nitrification-denitrification
 - SRT Solids retention time
 - WAS Waste activated sludge

Number of Positive Responses

	Dissolved Oxygen	ABAC	SND	AVN	Timer-based Aeration Control	IMLR Pumping	RAS/WAS Pumping	SRT	Supplemental Carbon Addition	Supplemental Alkalinity Addition	Metal Salts	Polymer Addition
■ Nutrient Removal	42	7	1	0	7	16	21	10	12	8	9	1
■ Improved Settleability and MLSS Characteristics	28	2	2	0	3	5	26	20	2	3	2	2
■ Improved Operations / More Control	49	5	3	0	4	10	29	21	5	6	8	1
■ Improved Operations / More Monitoring	37	3	3	0	1	7	19	11	6	4	5	0
■ Improved Reliability & Less Variability	38	5	1	0	1	7	25	15	6	7	7	0

Note: Survey respondents were asked to check off the applicable improvements. Non-positive responses (no check in the survey box) could either indicate that they did not experience the improvement, or they did not answer the survey question.

Benefits indicated by survey respondents



- Legend:**
- ABAC Ammonia based aeration control
 - AVN Ammonia versus nitrate
 - IMLR Internal mixed liquor recycle
 - RAS Return activated sludge
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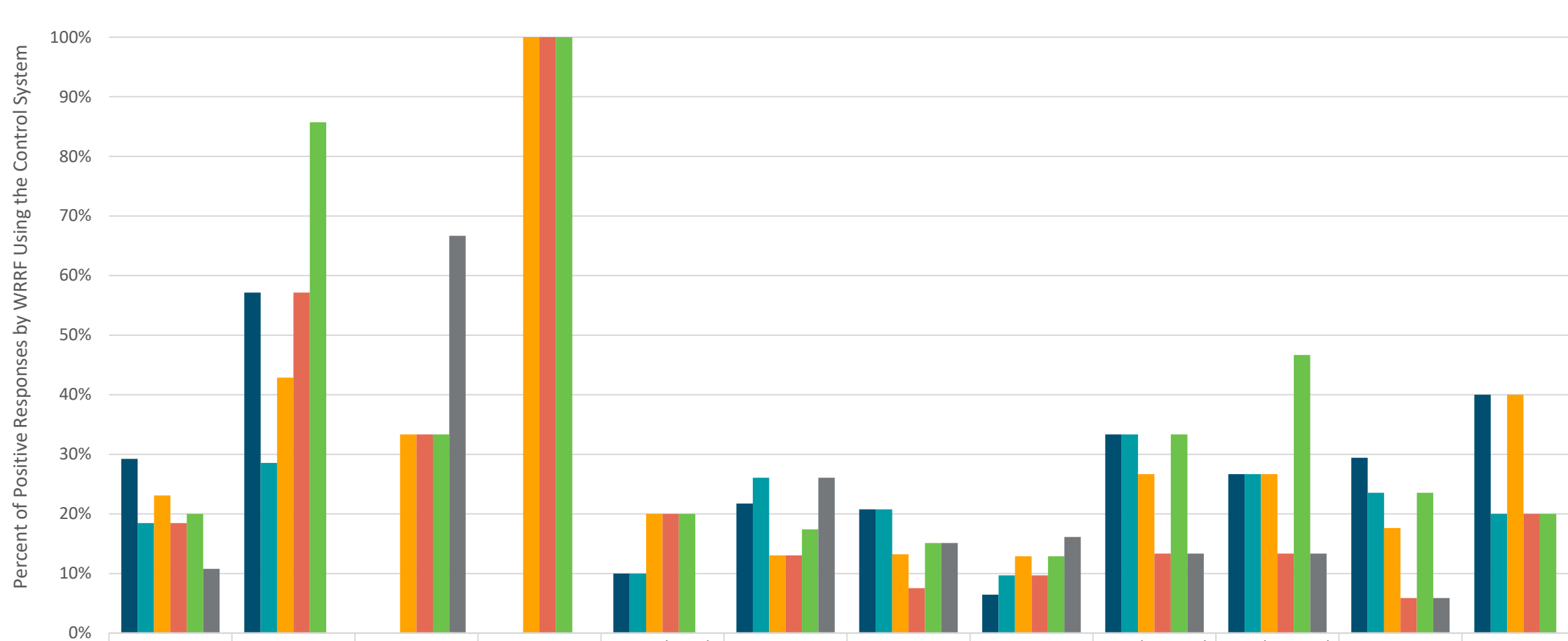
Number of Positive Responses

	Dissolved Oxygen	ABAC	SND	AVN	Timer-based Aeration Control	IMLR Pumping	RAS/WAS Pumping	SRT	Supplemental Carbon Addition	Supplemental Alkalinity Addition	Metal Salts	Polymer Addition
■ Energy Savings	48	7	2	0	3	9	16	9	3	1	2	1
■ GHG Reduction	8	3	1	0	1	2	0	0	1	0	0	0
■ Chemical Savings	11	2	1	0	2	5	6	7	5	4	7	1
■ Sludge Generation Reduction	8	2	2	0	1	3	8	6	0	0	0	0
■ O&M Labor Savings	18	2	0	0	1	4	12	8	1	2	2	0
■ Other Benefits	1	0	0	0	1	1	1	1	1	2	1	0

Notes: Survey respondents were asked to check off the applicable benefits. Non-positive responses (no check in the survey box) could either indicate that they did not experience the benefit, or they did not answer the survey question.

Comments were requested for "other benefits," and responses included compliance & performance.

Challenges indicated by survey respondents



- Legend:**
- ABAC Ammonia based aeration control
 - AVN Ammonia versus nitrate
 - IMLR Internal mixed liquor recycle
 - RAS Return activated sludge
 - SND Simultaneous nitrification-denitrification
 - SRT Solids retention time
 - WAS Waste activated sludge

Notes: Survey respondents were asked to check off the applicable challenges. Non-positive responses (no check in the survey box) could either indicate that they did not experience the challenge, or they did not answer the survey question.

Comments were requested for "other challenges," and responses included consultant implementation (several responses), aerated zone isolation, and lack of flow meters on RAS and IMLR.

Number of Positive Responses	Dissolved Oxygen	ABAC	SND	AVN	Timer-based Aeration Control	IMLR Pumping	RAS/WAS Pumping	SRT	Supplemental Carbon Addition	Supplemental Alkalinity Addition	Metal Salts	Polymer Addition
■ Capital Costs	19	4	0	0	1	5	11	2	5	4	5	2
■ O&M Costs	12	2	0	0	1	6	11	3	5	4	4	1
■ Control System Stability	15	3	1	1	2	3	7	4	4	4	3	2
■ Sensor Accuracy	12	4	1	1	2	3	4	3	2	2	1	1
■ System Complexity	13	6	1	1	2	4	8	4	5	7	4	1
■ Other Challenges	7	0	2	0	0	6	8	5	2	2	1	0

Snapshot of survey results for implementation



Overall summary & key outcomes

Overall, key takeaways from the survey responses include:

- **Dissolved oxygen sensors are the most common sensor utilized for BNR process control**
 - Cleaning, calibration, and maintenance are generally easy and acceptable
 - Almost 75% of respondents think these sensors are reliable for use in a controller
- **O&M is important and can be a significant cost**
 - Weekly cleaning is common for most sensors and analyzers
- **Most respondents indicated that implementation of BNR controls is worth it, but it is not without challenges**
 - Most respondents with DO, ABAC, or SND aeration controls thought they were extremely or very worth it and cited several benefits including nutrient removal, energy savings, and improved monitoring & control
 - There were relatively fewer challenges cited for the pumping control systems. Most respondents did not indicate whether sensors and analyzers (other than flow meters) are used in the pumping control systems
 - Instrument accuracy and system complexity were cited as challenges by over 50% of the respondents with aeration control systems utilizing nutrient analyzers (ABAC and AVN)
 - Respondents with polymer controls thought it was relatively less worth it compared to the other chemical feed control systems