Clean Water Services

White Paper on Continuous Monitoring

Part of the 2015 RAD-02 Goal Share:

Efficient Delivery of Laboratory Services

Authors: Shanna Myers, Mark Disbury,
Doug Lager, and Marlena Milosevich
with oversight from Bob Baumgartner,
Marta Frank, Steve Thompson,
and Dr. Ken Williamson

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This paper was written in partial fulfillment of the Regulatory Affairs Department's Goal Share Measure 2015 RAD-02 to address efficient delivery of laboratory services. The team for this paper consisted of: Shanna Myers, Mark Disbury, Doug Lager, and Marlena Milosevich, with oversight from Bob Baumgartner, Marta Frank, Steve Thompson, and Dr. Ken Williamson.

Background

Agencies charged with monitoring water quality have historically relied upon discrete testing to support management decisions and to demonstrate compliance. Discrete monitoring can provide precise and accurate information about water for a defined moment and location; however, this type of monitoring has limited utility in dynamic water systems. Continuous water monitoring using sensors enables extensive real-time data collection over a fully representative time period. Recent advancements in the quality and reliability of continuous monitoring technology have made it a viable alternative to discrete water sampling.

As Clean Water Services (District) designs the next stage of its operational plan for the Water Quality Laboratory, consideration should be given to implementing continuous water quality monitoring. The availability of accurate continuous data sets would support the District's efforts to achieve regulatory compliance with our watershed-based permit, and could strengthen the District's position on innovative approaches to water quality trading programs for the Tualatin River Watershed.

Current District Water Quality Sampling

The District's laboratory procedures call for the collection of discrete grab and composite samples from a variety of specific locations. In the case of ambient monitoring, grab samples are collected two times per month. Most of the samples for wastewater treatment plant operations are composites collected on a flow or time basis, but some grab samples are also required for permit compliance. These ambient and treatment plant samples are analyzed at the laboratory using rigorous quality assurance and quality control (QA/QC) procedures to assure high quality data.

Continuous monitors are presently used at the District's Rock Creek and Durham Advanced Wastewater Treatment Facilities (AWTFs). Key parameters that are successfully monitored with continuous technology include residual chlorine, bisulfite, ortho-phosphate (OP), nitrate/nitrite, and total suspended solids (TSS). Information is immediately accessible to treatment plant personnel and is fed to the SCADA system, which can alert operators if measured parameters are outside acceptable values. These continuous monitors provide valuable data for the treatment plants, but require routine maintenance and calibration.

The District also receives ambient water quality data for the Tualatin River Watershed from partners such as the US Geological Survey (USGS) and Jackson Bottom Wetlands Preserve. The District has a contract with the USGS for seven continuous monitoring sites along the Tualatin River and its tributaries. This contract with the USGS provides temperature, pH, dissolved oxygen (DO), conductivity, turbidity, and chlorophyll data, depending on the site [1]. The District is considering assuming responsibility for continuous monitoring at the tributary sites and has engaged in discussions with the USGS about this transition.

The following sites are under contract with the USGS for maintenance and data processing [1]:

- Tualatin River @ Oswego Dam
- Tualatin River @ Scholls
- Scoggins Creek @ Dam Discharge
- Gales Creek @ Highway 47
- Rock Creek @ Brookwood
- Beaverton Creek @ 170th
- Fanno Creek @ Durham

In addition to the USGS sites, the Jackson Bottom Wetlands Preserve continuous monitoring site is located on the Tualatin River at Highway 219.

Use of Continuous Monitoring by Industry

Industry interest in continuous monitoring continues to grow. A 2012 Aquatic Informatics global study of 700 industries found that monitoring networks now prefer continuous over discrete water quality monitoring [2] (Figure 1).

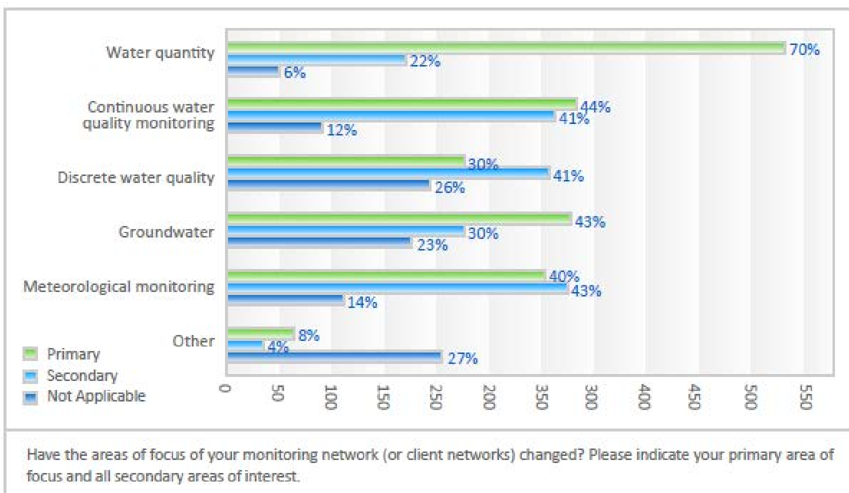

Figure 1. Responses to 2012 Aquatic Informatics survey on industrial focus of monitoring networks [2]

Aquatic Informatics also found that industrial resources assigned to continuous monitoring since 2012 increased by a greater percentage than resources assigned to discrete monitoring [2] (Figure 2).

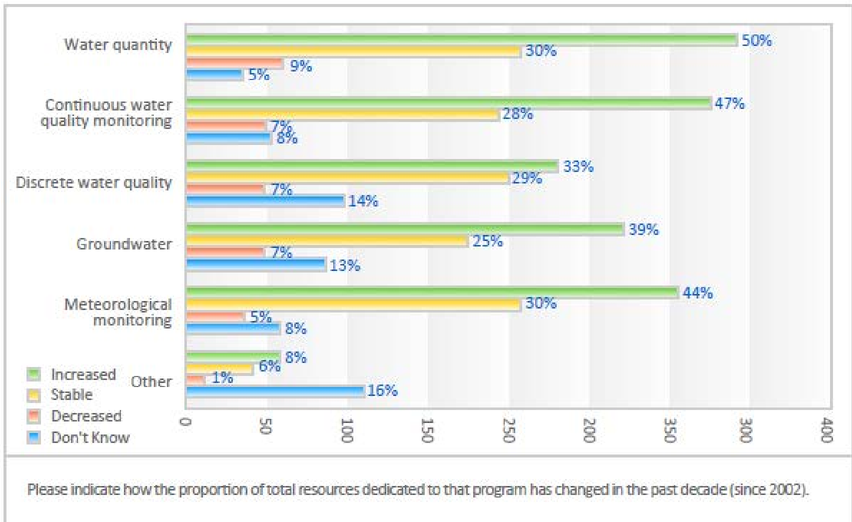

Figure 2. Responses to 2012 Aquatic Informatics survey on increase in total resources dedicated to different water monitoring programs since 2002 [2]

State-of-the-Art of Existing Continuous Monitoring Technology

The Water Environment Research Foundation (WERF) has thoroughly examined the use of continuous sensors and monitors by the water and wastewater industry [3]. Through publications, WERF provides information on the commercial availability of sensors and monitors, and on their applicability, accuracy, precision, maintenance requirements, and general end user satisfaction.

The primary uses of online monitoring in water treatment processes are to detect the presence of hazardous substances, provide information and assurance to customers about water quality, and to allow for more efficient operation of water treatment plants and/or water distribution systems [3]. Within wastewater treatment, online instrumentation is primarily used for monitoring key processes to enable more efficient plant operation and for assessing ambient water conditions to better understand the effects of water discharge. Continuous monitors are not extensively used to determine regulatory compliance, but do have capabilities for compliance parameters such as pH, conductivity, OP, DO, turbidity, and residual chlorine.

Measurable Parameters

The range of parameters that can be measured with continuous monitors is extensive, with sensors available for "over 100 physical, chemical, biological, and radiological parameters" [3]. However, the existence of a sensor does not guarantee satisfactory performance. From 22 case studies, the parameters most commonly measured (present in more than 5 case studies) continuously were DO, temperature, pH, conductivity, turbidity, ammonia, and chlorine (usually as residual chlorine) [3].

A survey of 58 companies in the drinking water sector found that over 50% of respondents used pH, conductivity, and turbidity sensors [3]. Additionally, over 25% of these companies used OP, DO, chlorine (free or total), and spectral absorption coefficient (SAC, also UV254) sensors. An equivalent survey of 56 companies from the wastewater sector found there was no single type of sensor in use by over 50% of the companies. However, over 25% of the wastewater respondents used pH, DO, turbidity, and ammonia monitors [3].

Accuracy and Precision

The accuracy and precision of online instruments relies heavily upon consistent maintenance and calibration of the equipment [3]. Additionally, dependable operation requires allocating adequate staff time for instrument maintenance.

The maintenance requirement within continuous monitoring programs varies depending on the size of an organization and the number of instruments operated. For a Dutch water treatment plant deploying multiple turbidity, DO, conductivity, hardness, and pH instruments, the maintenance and calibration time required for successful operation was 1.6 full-time equivalents (FTE). Alternatively, a waste water utility in the Netherlands with a treatment capacity of 140-185 MGD and a comprehensive river and sewer monitoring program (monitoring river DO and ammonia, and monitoring the sewers with 400 level sensors and 40 flow sensors) required at least 2.5 FTE to support their monitoring network [3].

The accuracy of sensors depends on the chemical matrix of the water tested and must meet the data requirements of the users. The previously mentioned Dutch water company considered a pH meter accuracy of ± 0.05 to be acceptable, but variance of greater than ± 0.1 to be unacceptable [3]. Alternately, the USGS expects their pH measurements from EXO YSI sondes in the Tualatin River to be accurate within ± 0.2 pH units [4].

It should also be noted that online sensors can display erroneous values temporarily. A water reuse company in Singapore employing reverse osmosis noted that refilling reagent in wet chemical analyzers resulted in “spikes” of incorrect data. Similarly, air bubbles and self-maintenance cycles on automatically cleaning probes can result in false data values. Figure 3 shows chlorine demand based off data from an S::can UV/Vis spectrophotometer (S::can) in use at the Myoponga treatment plant in Australia. Values from the S::can unit (pink line) are fairly consistent with laboratory grab sample measurements (small circles), but erroneous data spikes can be seen in the continuous data. The S::can unit is noted to perform automatic air cleaning, which could potentially explain some of the spikes seen in the continuous data. For publication or trend analysis, it is necessary to perform QA/QC review of the data to remove false values.

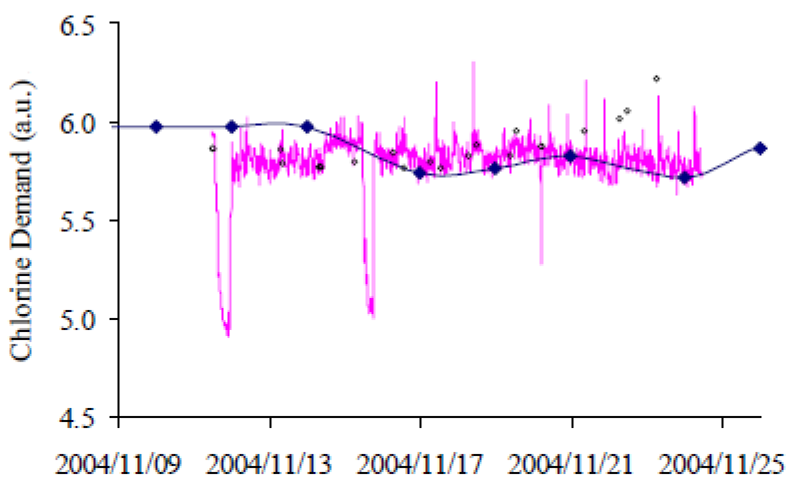

Figure 3. Online chlorine demand monitoring (pink line) compared to grab samples (small circles) and field chlorine demand (blue line with diamonds) at the Myoponga treatment plant [3]

Regulatory Use

Currently, the use of continuous monitoring to determine regulatory compliance for water and wastewater is very limited. This is primarily due to the fact that the EPA has to approve methods used for many parameters included in compliance monitoring. There are some instances where continuous or online monitoring has been granted method approval. As mentioned previously, DO, turbidity, conductivity, and OP can be measured with online sensors for regulatory compliance. Additionally, the EPA has granted method approval for on-line analyzer chlorine residual monitoring within the range of 0.2-4 mg/L if the monitoring is used in conjunction with a grab sample method approved for compliance monitoring [5]. Continuous pH monitoring from an electrode pH meter has been acceptable to the EPA since 1982 [6].

As the technology advances and data assurance is verified, regulatory agencies may approve a broader application of continuous monitoring equipment. ZAPS Technologies, Inc. (ZAPS), a Corvallis-based company that designs online optical analyzers that utilize UV/Visible wavelength absorption, fluorescence, and reflectance to measure water quality parameters, is in the process of appealing to the EPA for method approval to measure chemical oxygen demand (COD), biological oxygen demand (BOD), and TSS for regulatory purposes [7]. Companies that design online water quality analyzers have an interest in regulatory approval of their products, so it is likely that there will be more submissions to the EPA for method approval as equipment continues to improve in reliability.

There is concern that continuous monitoring could record short moments of non-compliance that would not register in a daily composite sample. As additional regulatory monitoring with continuous monitors is approved, this could become an issue for companies that wish to provide real-time data. However, these continuous monitors also have the potential to warn of an imminent issue so that treatment can be adjusted as necessary to avoid non-compliance. Additionally, continuous monitors provide evidence of time spent in compliance, and could serve to exonerate utilities that are consistently meeting their permit requirements. The future of regulatory continuous monitoring is not guaranteed, so the current greatest value of continuous monitoring remains the potential for early detection of contaminants and enhanced temporal resolution in ambient and operational data.

Associated Costs of Continuous Monitoring

Considerable capital outlay is required to shift from largely discrete sampling to continuous monitoring. The capital investment is composed of hardware for monitoring, software and storage capacity to handle the large volume of data produced, and costs for maintenance, training, and data management. Initial and ongoing costs would presumably be offset by a reduction in costs associated with traditional discrete sampling. Reductions are expected in long-term operating costs due to reduced sampling, vehicle use (fuel and maintenance), and chemical analysis costs. Additionally, the use of continuous monitors reduces the risk of sampling hazards to employees, and may decrease operational costs through the availability of real-time data.

Greater temporal resolution allows for discernment of important trends within a monitored system. However, continuous data collection produces a large volume of data, and requires additional software and technical resources. While costs of equipment, software, and installation are substantial, the cost per unit of data is much smaller for continuous monitoring when compared to discrete monitoring. Examples of costs associated with continuous monitoring are summarized in Table 1.

Table 1. Compilation of cost estimates for hardware, software, and infrastructure for continuous monitors. For the most part, annual costs do not include personnel hours necessary to run and maintain hardware, software, or infrastructure.

Hardware	**Parameters**	**Initial outlay**	**Annual costs**
YSI EXO2 Sonde[1,2]	Temp, conductivity, DO, pH, turbidity (fDOM, OP, depth, total algae)	\$13,000-\$19,000 (additional parameters increase cost)	\$1,500
ZAPS Unit[2]	Usual wastewater parameters: BOD, CBOD, COD, TSS, Ammonia, Nitrate/Nitrite	\$75,000 (depends on parameters selected)	not specified
YSI Vertical Profiler - Australia[3]	Temp, DO, pH, turbidity, conductivity, redox potential	\$110,000	\$7,000
TOC Analyzer – Singapore[3]	TOC	\$55,000	\$4,500
Software	**Functionality**	**Initial outlay**	**Annual costs**
Aquarius Time Series[2]	Water data management, built in rate curves	\$4,500 for database, \$9,000-\$14,000 per standalone license, \$15,750-\$24,500 per shared license	25% of initial cost, beginning year 2 (includes 4 software updates/yr)
Combination of CANARY, Blue Box, Clear SCADA, and Data Historian[3]	Two event detection softwares, SCADA system, and data system	\$500,000	\$300,000 (licenses and maintenance)
Infrastructure	**Components**	**Initial outlay**	**Annual costs**
Ambient Measuring Site[1]	cellular modem with antenna and cables	\$535	\$220
Ambient Site – Australia[3]	Modem, pipe works, trenching, footings, labor, and vehicle costs	\$6,000	\$320 (modem data charges)

Abbreviations: fDOM = fluorescent dissolved organic matter, CBOD = carbonaceous biological oxygen demand

[1] Information from USGS [8], [2] Information from respective company [7, 9, 10], [3] Information from WERF [3]

Costs for equipment vary greatly depending on the items selected. Costs for single parameter monitors are often in the range of \$2,000-\$20,000, while multi-parameter units often cost more than \$20,000. Software needs depend upon the volume of data produced. The prudent approach is to plan for extensive data analysis and processing. Examples of data processing hardware costs of over \$300,000 have been noted [3]; however, estimated District cost would be less due to prior District investment in SCADA software.

The District currently contracts with the USGS for a sum of \$185,000 per year to maintain 7 continuous monitors on the Tualatin River and its tributaries [1]. It has become apparent from conversations with the USGS that the majority of the costs associated with monitor maintenance are the result of QA/QC. In a workforce and equipment cost estimate provided by the USGS, over 30% of all hours spent on ambient monitoring equipment were for data verification. The average time per site estimate was 40 days per year [8]. To manage this data collection, the District would need to purchase monitoring equipment, train personnel in monitor management and maintenance, and develop a system for data QA/QC.

District Experience with Continuous Monitoring

Ambient Monitoring

The District is currently utilizing continuous ambient monitoring to provide key data related to the Watershed Management Department (WMD) flow restoration projects occurring in McKay Creek and East Fork Dairy Creek. For the past 3 years, the laboratory has operated YSI 6-series sondes and VEMCO temperature loggers to collect water quality data for this project. McKay Creek was selected for a similar study involving continuous monitoring during 2007 and 2008. Although the monitoring programs were not exactly the same, these past data could provide a baseline condition against which to measure watershed health impacts. It is expected that targeted continuous monitoring will be used in the future to produce additional data to support the District's watershed enhancement efforts.

The current study location on East Fork Dairy Creek has recently been designated as an Enhanced Conservation Reserve Enhancement Program (ECREP) site. Utilizing data from the current study, it could be possible to monitor the effects of the ECREP program (particularly temperature) upon future creek conditions.

In 2008, in partnership with the USGS, the District entered into an investigation on anomalous conductivity spikes at a continuous monitoring site in Fanno Creek. Through coordinated efforts and the use of continuous monitoring devices, the source of the anomaly was pinpointed to a saline landscaping pond that was being emptied and refilled. Without the ability to deploy continuous monitoring devices, this discharge would not have been discovered and determining the source of the conductivity spikes would have been significantly more difficult.

Durham Continuous Monitoring Instrumentation Pilot

In 2013, the Durham AWTF conducted an instrumentation pilot project. The purpose of this pilot was to determine whether sensors could be used to reliably measure multiple parameters (OP, volatile fatty acids (VFA), nitrate, and TSS), to evaluate the maintenance requirements for these sensors, and to evaluate the effect of increased data availability on bio-P stabilization and alum reduction [11].

The pilot study employed three different sensors and one LiquID station from ZAPS. The monitors installed were as follows:

- ZAPS unit, primary effluent, measured VFA [12]
- 3 Hach PHOSPHAX sc units (1-50mg/L), primary effluent and anaerobic zone of 2 aeration basins (ABs), measured OP, approximate value $15,000/unit [13]
- 3 Hach FILTRAX units, filtered water prior to OP sampling by PHOSPHAX units, approximate value $7,000/unit [14]
- 2 Hach NITRATAX plus sc units (1-100 mg/L. 1 mm path length), anoxic zone of 2 ABs, measured nitrate, approximate value $15,000/unit [15]
- 4 Hach SOLITAX sc units, aerobic zones and WAS streams of 2 ABs, measured TSS, approximate value $4,000/unit [16]

Sensors in operation during the pilot project are shown in Figure 4. Prior to this pilot, Durham had been using ChemScan units on the secondary effluent to measure ammonia, nitrate, nitrite, and OP. These units had been found to be reliable over several years of operation.

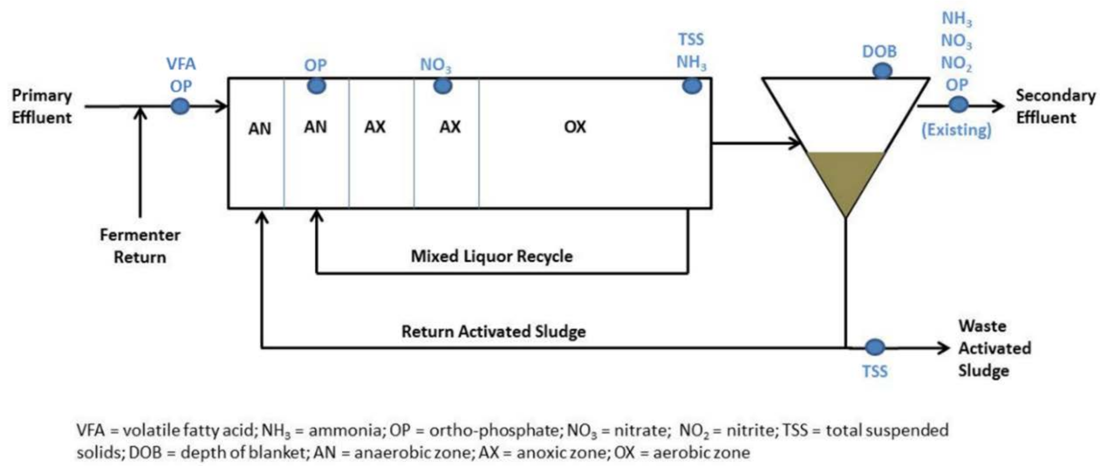

Figure 4. Location and type of sensors installed in instrumentation pilot project at Durham AWTF. Neither ammonia nor depth of blanket sensors were considered in the pilot program [11]

In the instrumentation pilot, OP and TSS sensor results were consistent with laboratory data. Nitrate data were unreliable at the measured concentrations, and it was discovered that the path length of light in the optical sensor was meant for high nitrate concentrations. One of the nitrate sensors was moved to a location with higher nitrate concentrations and proved acceptable. The ZAPS unit on the primary influent experienced mechanical issues with the pump, so it was not possible to determine if the ZAPS unit was accurate. An example of observed accuracy can be seen below in two graphs comparing meter readings to grab samples. The meter and lab data were very similar, with some outliers observed in TSS data, and similar trends were consistently seen in both examples.

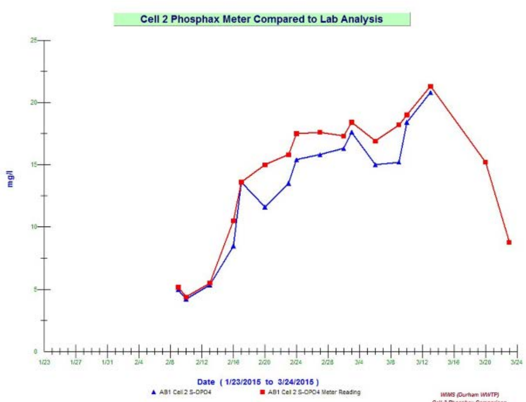

Figure 5. Continuous OP data (red) compared to lab results (blue) in Durham cell 2 [11]

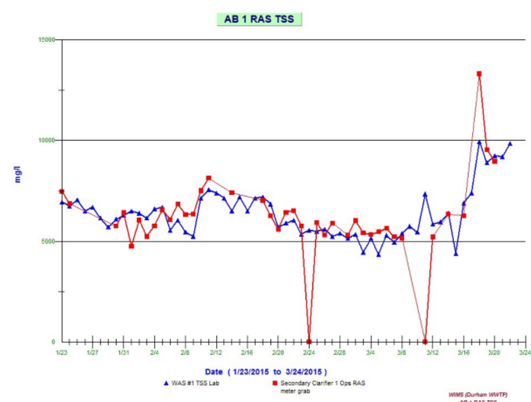

Figure 6. Continuous TSS data (red) compared to lab results (blue) in return activated sludge from aeration basin1 at Durham [11]

Operation and maintenance hours for all probes included in the instrumentation pilot project totaled to 233 hours in 2014. However, this did not include time spent performing validation sampling. A breakdown of the hours is shown in Figure 7. The PHOSPHAX unit labeled PE (primary effluent) experienced a clogged drain line and required additional maintenance. It was concluded that TSS measurements provided the greatest benefit in data compared to maintenance effort. OP measurements were accurate, but required comparatively more maintenance. Nitrate monitoring had potential to provide high quality data, but experience with nitrate sensors capable of measuring lower nitrate concentrations was necessary.

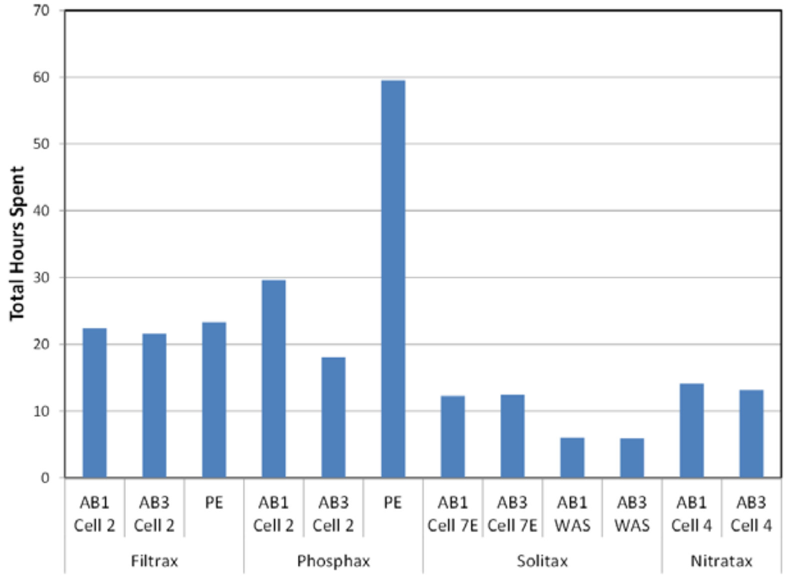

Figure 7. Operation and maintenance hours for continuous monitoring devices tested during Durham instrumentation pilot [11]

Advantages and Disadvantages of Continuous Monitoring

Continuous monitoring can provide greater temporal resolution of water quality compared to grab samples and composites. Through access to continuous water quality data, it may be possible to discover previously unknown trends. In some cases, knowledge of these trends can result in more efficient water treatment and reductions in chemical addition or energy use. It is also possible to react more quickly to changes in water quality due to real-time monitoring with online sensors, which can identify imbalances more quickly. An additional potential benefit of continuous monitoring is the ability to acquire more data for a similar or slightly lower number of man hours and cost.

For treatment plant parameters that are measured often (such as TSS and OP, which are measured daily by the laboratory), a well-maintained and accurate continuous monitor could significantly decrease the number of samples needed. This could reduce the cost for laboratory consumables and reagents and reduce analysis time, freeing up laboratory staff to engage other tasks or projects. Within the District AWTFs, there is also the possibility to gain a better understanding of advanced systems such as the Bio-P processes.

In ambient monitoring, the primary continuous monitoring benefits expected are the quantity and quality of information collected, and the potential for greater understanding of water quality trends and variations in the watershed. The possibility for real-time alerts concerning algal blooms and illicit discharges could also be of great value in managing water resources.

However, continuous monitoring is not without risk. The greater volume of data provided by continuous monitors can result in an onslaught of poor-quality, unanalyzed data if proper action is not taken to address the increase in data. There is also an initial calibration phase for any continuous monitoring device, regardless of the quality of the device. During this time, the device must be compared with laboratory generated values to ensure results are accurate and the sampling location selected is adequate. Maintenance and calibration are required to ensure accurate information from each device. The maintenance cycle could be weekly or yearly, depending on the level of upkeep required. Calibration may be necessary on a daily or monthly basis depending on the accuracy required for data collected and the tendency of the equipment purchased to "drift" from correct values.

A common finding from industrial successes with continuous monitors was that consistent calibration and maintenance of equipment was directly linked with confidence in instrument data [3]. If calibration and maintenance are neglected, instruments will begin to show incorrect values and confidence in instruments will decrease. Adequate investment in maintenance is essential.

If continuous monitors are sufficiently maintained and staff are available to analyze the data collected, these instruments can provide an abundance of valuable information. There is potential to further optimize treatment systems using instrumentation and, within ambient monitoring, there is the potential to decrease the amount of time spent sampling. It is important to understand expectations and perform significant research before implementing large-scale continuous monitoring.

Recommendations

Due to an ever expanding need for continuous water quality monitoring, the District should begin preparing for continuous monitoring in the following ways:

- Begin piloting mobile ambient continuous monitoring sites in order to develop an understanding of the quality and quantity of data produced by continuous monitors, as well as to understand the time requirements and associated costs;
- Expand the pilot studies for additional continuous monitoring of operational parameters at all of the treatment plants;
- Develop a small-scale research study to determine the capabilities of the ZAPS unit installed at Durham in order to understand its ability to perform in wastewater applications; and
- Develop short- and long-term personnel plans to support a continuous monitoring program.

In order to monitor changes in the watershed with greater temporal resolution, the District needs to expand its ability to conduct continuous ambient monitoring on the Tualatin River and its tributaries. Some sites could be taken over from the present USGS monitoring system, but monitoring should also include mobile units that could be deployed on a project-based schedule. This would ensure that data are collected for an intended use, such as measuring ecological uplift. The District laboratory will need to gain experience with continuous monitors and data management, so an instrument pilot phase may be necessary.

The District should expand the use of continuous monitors at all its wastewater treatment plants, as these will allow for a greater knowledge of the treatment processes as well as faster turnaround time for operational data. District laboratory staff desire to be involved in the upkeep and calibration of these continuous monitors to ensure QA/QC is acceptable for treatment plant operation. However, collaboration between treatment plant and laboratory staff will be necessary for equipment maintenance and calibration. Operator and operations analyst confidence in and understanding of continuous monitoring data will be essential to continuous data use at the treatment plants. Additionally, it will be necessary to pilot and calibrate these sensors when they are first obtained, so adequate support will be required.

The ZAPS unit that was installed at the Durham AWTF has tremendous potential to meet the need for continuous monitoring within the plant. However, the experiences with this unit at Durham do not provide enough information to ascertain its effectiveness. A small-scale research project should be conducted by laboratory staff to determine the efficacy of this device for identifying a wide range of operational parameters.

A data management system will be required to support expanded continuous data management. It is unknown whether the present management of operational data at the treatment plants with the Hach WIMS database will prove to be adequate. The capabilities of this system should to be determined by laboratory and IT personnel. If it is insufficient, research into alternative systems will need to be conducted.

Finally, the skill sets required for personnel to support expanded continuous monitoring need to be addressed. The ideal employee for the future Water Quality Laboratory would likely be a combination of field sampler, analytical chemist, instrument technician, data analyst, and project manager. The District currently employs and develops very specialized skill sets within the laboratory, with two job classes consisting of specialists and technicians. Developing our current workforce to operate in this broad new role may require a new job classification and could result in new positions or expanded employee training.

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