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NON-TRADITIONAL INDICATORS OF SYSTEM PERFORMANCE

by:
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ABSTRACT AND BENEFITS

Abstract:

The use of real-time sensors and supervisory control and data acquisition (SCADA) systems has not been widely used in smaller, decentralized wastewater treatment systems. As these decentralized wastewater treatment systems become more common, it will be important to apply state-of-the-art technology to ensure that adequate performance is maintained at reasonable cost.

This study was carried out to identify issues with the use of real-time remote monitoring of decentralized wastewater facilities and to provide information on what is required to increase the use of this technology. The study included a literature search, case study review and information from vendors in the U.S. and select international sources.

The study identified the main parameters to be monitored for decentralized wastewater treatment facilities. It also identified that the main issue with sensors for these parameters is likely to be maintenance requirements. A review of communication options shows that there are many factors in determining the type of system to implement the method of communications, the remote control and alarming methodology, and the data collection, storage and archival methods. All of these items must be factored in when determining what type of SCADA system to deploy. After reviewing sensor and communications systems, three main areas requiring further study were identified, namely technology and technology transfer, verification of cost-effectiveness; and education and training.

Benefits:

- Identifies a number of decentralized facilities successfully using real-time on-line monitoring as a management tool.
- Demonstrates that a range of parameters can be used to monitor plant performance and prioritizes the types of parameters that should be monitored.
- Identifies that there are a large number of sensors currently available to monitor plant performance remotely and provides detailed information that can be used to select sensors.
- Shows that there are a range of options for communication and storage of data and provides information on the advantages and disadvantages of each type.
- Identifies further research needed to encourage decentralized wastewater facility owners and operators to use real-time remote monitoring.

Keywords: Wastewater, decentralized, on-line sensors, real-time monitoring, SCADA, telemetry.

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BOD_5	biochemical oxygen demand
CDMA	code division multiple access
CDAC	centralized data acquisition center
COD	chemical oxygen demand
DO	dissolved oxygen
DAC	data acquisition center
DC	direct current
DSL	digital subscriber line
FCC	Federal Communications Commission
FOG	fats, oils and grease
GSM	global system for mobility
HART	highway addressable remote transducer
HMI	human machine interface
ITA	Instrumentation Testing Association
I/O	input / output
LCC	life cycle cost
LDO	luminescent dissolved oxygen
mA	milliamps
MEMS	micro-electro-mechanical systems
O&M	operations and maintenance
ORP	oxidation reduction potential
PC	personal computer
PLC	programmable logic controller
RDAP	remote data acquisition panel
RF	radio frequency
RS	recommended standard
RTU	remote terminal unit
RPU	remote processing unit
SBR	sequencing batch reactor
SCADA	supervisory control and data acquisition
STEG	septic tank effluent gravity

STEP	septic tank effluent pump
STP	sewage treatment plant
TM	technical memorandum
TSS	total suspended solids
U.S. EPA	United States Environmental Protection Agency
UV	ultraviolet
VDC	volts direct current
VPN	virtual private network
WEP	wireless encryption protocol
WERF	Water Environment Research Foundation
WIFI	wireless networking technology
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

The use of real-time sensors and supervisory control and data acquisition (SCADA) systems has become commonplace in large centralized wastewater treatment systems. On-line sensors and SCADA systems have not been widely used in smaller decentralized systems, possibly due to perceptions of high cost for installation and maintenance, and perceptions of poor reliability. However, the cost effectiveness and reliability of the technology has been demonstrated in larger systems and should be transportable to smaller clustered, decentralized systems.

This research project focused on assessing on-line sensing and data acquisition technologies applicable for use in decentralized wastewater treatment systems to provide real-time information on the performance and operational status of the facility.

The results of this study are intended to provide a guide to wastewater facility managers, operators and designers for selecting real-time sensors and SCADA systems for decentralized wastewater treatment facilities. Improved remote monitoring of these facilities should provide facilities with a cost-effective means to manage and improve the performance of decentralized wastewater treatment plants.

This study involved five main areas of investigation related to the use of on-line sensing and data acquisition technologies in decentralized wastewater treatment systems, including a literature and technical review, development of monitoring needs, identification of sensor capabilities, identification of SCADA capability, and identifying research needs.

The study has indicated that the number of decentralized wastewater treatment facilities currently using on-line sensors for real-time remote monitoring is relatively small. Many decentralized facilities using remote monitoring would appear to be supplied with "control boxes" that monitor and control pump on/off status, monitor tank levels and sound an alarm when an unusual condition occurs. The alarm connects to a panel onsite and can also be used to send a signal to the plant operator and to a remote central control location. A few decentralized facilities were identified that are using real-time sensors to monitor parameters such as dissolved oxygen concentration, conductivity and chlorine concentration.

The results of the literature and technical review were used to help identify the monitoring needs for decentralized wastewater treatment facilities. The review identified traditional and non-traditional parameters that could be monitored in decentralized wastewater treatment systems to allow operations or management staff at a remote location to assess the operating or performance status of a facility and to respond to upsets, process or mechanical failures or other non-routine situations. This study identified that operating conditions, process control parameters and effluent quality parameters could be monitored on-line at decentralized facilities, and a list of parameters requiring further investigation in the third area of the study ("identification of sensor capabilities") was identified.

The next stage in the study was to determine the status and characteristics of real-time sensing equipment for on-line monitoring of the parameters in decentralized wastewater treatment systems. Selection matrices were developed that display traditional and non-traditional instrument technologies and lists specific attributes of individual manufactured instruments categorized by cost of ownership and on-line monitoring capabilities to assist the end-user in making direct comparisons of the differences in manufactured instruments. The data also provides decentralized wastewater treatment system professionals with general principle of operation descriptions to assist the end-user in determining which technology would best fit their application. Additionally, individual instrumentation specification matrices are also provided which report supplementary instrument parameters for further consideration in the decentralized wastewater treatment system instrumentation selection process. A life-cycle cost analysis tool is provided that can be used by the decentralized wastewater system professional to provide defensible budgetary estimates of instrumentation procurement and installation costs and ongoing labor expenses to support maintenance requirements over the life-time of on-line sensing equipment.

A review of the capability of SCADA systems to collect and analyze the information generated by real-time sensors to provide relevant operational and performance information to remote operational staff was carried out. Wireless and wired communication systems can relay information from a decentralized site to an operator or central monitoring location. A review and discussion of the advantages and disadvantages and relative costs for the options available for data transfer from remote facilities to a centralized operations center is also provided.

Following on from information obtained from previous stages of the study, research needs that could lead to broader acceptance and use of real-time sensors and SCADA in decentralized wastewater systems were identified. This included identifying gaps in knowledge or technology for real-time remote monitoring of decentralized wastewater treatment systems. The study identified three main areas requiring further study, namely:

- technology and technology transfer;
- verification of cost-effectiveness; and
- education and training.

Specific recommendations for research are provided and presented in order of priority in the table on the next page.

Summary of Research Needs

Priority	Research Need	Description
1	Field Testing	A field testing program should be developed that will monitor the performance, maintenance and calibration requirements of sensor systems in decentralized wastewater treatment systems, and other costs. The program should use existing decentralized wastewater facilities and it is recommended that a number of facilities be included in the program to ensure all parameters identified for monitoring in this study are included.
2	Develop Sensor Standard Testing Protocols	Standard testing protocols should be developed to improve the comparability, reliability and quality of existing sensors. The protocols could be developed as part of a field testing program. Such protocols could aid in the development of sensors with improved maintenance and calibration requirements. Standard testing protocols should be developed collaboratively with decentralized facility owners and operators, sensor manufacturers and regulating authorities.
3	Cost-Benefit Analysis	Cost data from the field testing program and cost data from sensor and SCADA manufacturers/suppliers should be used to identify typical life cycle costs for real-time monitoring for decentralized wastewater facilities. These costs should be compared against potential benefits related to cost savings in labor and chemical and energy use as well as improved system performance and increased reliability or robustness.
4	Education and Training	Information from field testing should be disseminated to regulating authorities and also vendors, owners and operators of decentralized wastewater systems. In addition, education and training of O&M staff on selection, installation and/or maintenance of on-line sensor equipment should be provided. The best methods for providing education and training will need to be determined. Vendors should be made aware of potential markets within the decentralized wastewater industry that require further research and development. This information could be made available through technical papers and presentations at relevant technical forums.
5	Improve Cleaning and Calibration Frequency Of Sensors	If field testing of sensors identifies some critical sensors are not suitable for use in the decentralized wastewater industry due to excessive calibration and/or maintenance requirements, further research should undertaken to develop sensors with reduced cleaning and/or calibration requirements .
6	Develop Best Practices for SCADA Standards	This work would encompass a review of best practices for data archiving and management, software and SCADA protocols for the decentralized wastewater industry. This would involve a desk-top study of available data archiving and management systems to identify best practices, as well as the experiences of decentralized operation and maintenance organizations currently using SCADA.
7	Review SCADA Security Issues	A desk-top study of potential security issues and required measures to improve security (if required) should be carried out.

A proposed priority list of parameters for field testing of sensors was identified for field testing, which is presented in the following table.

Proposed Priority List of Parameters for Field Testing.

Priority	Measurement	Rationale
1	Ammonia-nitrogen DO Nitrate-nitrogen Turbidity	Good as early indicator of process conditions. May be used for monitoring to meet regulatory requirements (ammonia-nitrogen, DO) or be used as an equivalent (turbidity for TSS and/or BOD_5 monitoring). Have sensors that are considered to be robust and well established in centralized wastewater treatment and/or water treatment plants.
2	Alkalinity BOD_5 Chlorine Residual COD Conductivity ORP pH Phosphate Respirometry	May be used for monitoring to meet regulatory requirements (BOD_5, pH, phosphate). May be used to monitor variability in influent flow or load. Typically sensors are considered to be less robust than for Priority 1 parameters.
3	Flow Level Power Pressure Pump Run Status UV Light Intensity	Reasonably well established in decentralized wastewater treatment systems. Have sensors that are considered to be robust.

CHAPTER 1.0

INTRODUCTION AND PURPOSE

1.1 Background

According to the U.S. Environmental Protection Agency (U.S. EPA), one in every four households in the United States is served by a decentralized wastewater treatment system. According to the U.S. Census Bureau, approximately 40% of new homes in the United States are served by decentralized wastewater treatment systems. Although similar data are not available for Canada, it is likely that a similar proportion of existing and new households are serviced by decentralized wastewater treatment systems.

Decentralized wastewater systems include a wide range of onsite and cluster treatment systems that receive and treat household and commercial sewage. A cluster treatment system is defined by the U.S. EPA as "a wastewater collection and treatment system under some form of common ownership which collects wastewater from two or more dwellings or buildings and conveys it to a treatment and dispersal system located on a suitable site near the dwellings or buildings". Decentralized wastewater systems may be managed by the facility owner or be part of a distributed wastewater management system, which involves the management of multiple systems across a service area.

To control operating costs, many small decentralized wastewater systems operate without onsite staff. Without real-time sensors connected to a supervisory control and data acquisition (SCADA) system or equivalent telemetry system capable of providing critical performance and operational information to a remote operational center, these unmanned decentralized wastewater systems may fail to operate as designed and any failures can go undetected for significant periods of time. An overview of the typical components of a remote monitoring system is presented in Figure 1-1.

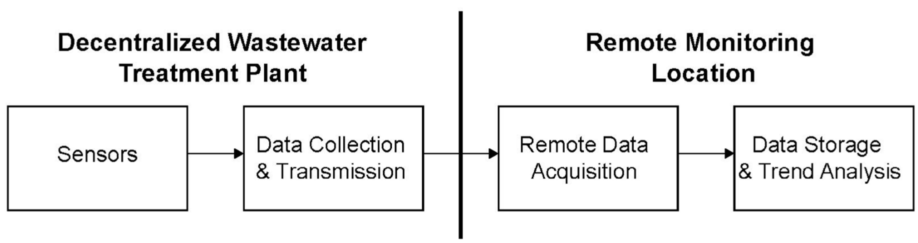

Figure 1-1. Typical Components of a Remote Monitoring System.

The use of real-time sensors and SCADA systems has become commonplace in large centralized wastewater treatment systems. On-line instruments and SCADA are available to remotely monitor a wide range of parameters at wastewater treatment facilities. These systems can provide early warning of an existing or impending mechanical equipment failure or process upset. Recent research undertaken by WERF demonstrates that significant improvements have been made in sensor technology and that such systems are cost effective and dependable in such applications. However, real-time sensors and SCADA systems have not been widely applied in decentralized wastewater treatment systems, possibly due to perceptions of high cost for installation and maintenance, and perceptions of poor reliability (which could be because of inappropriate selection, installation and/or maintenance of on-line sensor equipment).

There is a considerable knowledge base regarding onsite system design, implementation, and performance that enables most commonly used systems to be effectively deployed in most settings. However, the current state-of-knowledge and standard-of-practice does have gaps and shortcomings that can preclude rational system design to predictably and reliably achieve specific performance goals. While choices today are often constrained by prescriptive regulatory codes, they also can be hampered by the absence of a sound science and engineering knowledge base.

A study was carried out to try to address the acceptance and utilisation of real-time sensor and SCADA technology in decentralized wastewater systems. This study involved five main areas of investigation related to the use of on-line sensing and data acquisition technologies in decentralized wastewater treatment systems, which were as follows:

- A literature and technical review
- The development of monitoring needs
- The identification of sensor capability
- The identification of SCADA capability
- Identifying research needs

Each of these areas was investigated and the results are presented in this report. No reference made in this report to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by XCG Consultants Ltd, its subconsultants, or WERF.

1.2 Objectives

In order to ensure and promote the continued and effective use of decentralized wastewater treatment systems, it will be important to apply state-of-the-art technology to ensure that adequate performance is maintained at reasonable cost. Overcoming the perception of high cost and low reliability (possibly due to inadequate maintenance) requires that the current state of the technology and its applicability and benefit in decentralized wastewater treatment systems be documented.

The overall objective of the study was to assess on-line sensing and data acquisition technologies applicable for use in decentralized wastewater treatment systems to provide real-time information on the performance and operational status of the facility.

Specific objectives for the study included the following:

- to assess what parameters, both traditional and non-traditional, should be monitored in decentralized systems to provide information on its performance and operational condition;
- to determine the status and characteristics of real-time sensing equipment for on-line monitoring of the parameters of concern in decentralized systems;

- to evaluate the capability of SCADA systems to collect and analyze the information generated by real-time sensors to provide relevant operational and performance information to remote operational staff; and,
- to identify research needs that could lead to broader acceptance and use of real-time sensors and SCADA systems in decentralized wastewater treatment systems.

CHAPTER 2.0

METHODOLOGY

2.1 Overall Approach

The study was broken down into five separate areas specific to the overall objectives, namely:

- A literature and technical review
- The development of monitoring needs
- The identification of sensor capability
- The identification of SCADA capability
- Identifying research needs

The findings of each area of investigation were presented in Technical Memoranda (TM). These TMs were reviewed by the Project Team's Advisory Panel Members and WERF's project subcommittee (PSC). Comments from the Advisory Panel and PSC were taken into account when preparing the Final Report.

2.2 Literature and Technical Review

2.2.1 Literature Search

The review involved literature related to decentralized wastewater treatment sources as well as non-wastewater literature (i.e. water treatment, industrial processes) that contain information or approaches that could be utilized by the decentralized wastewater industry. The search focused on information available on the web, direct contact with individuals and organizations that would potentially have relevant literature, and also searches for technical papers from various organizations and proceedings.

2.2.2 Case Study Data Collection

In addition to the technical literature, industry contacts were solicited for information not readily available in the literature. This included case histories or examples where on-line instrumentation and data collection and transmission systems are being used to monitor remote, unmanned decentralized wastewater or water treatment systems. These case history reports are based on electronic mail and telephone interviews with staff responsible for operating the facilities.

A questionnaire was prepared by the Project Team and provided to all contacts, together with a description of the project and the key objectives of the study. The questionnaires were completed by the owner/operator of the facility or a telephone interview was carried out and the answers recorded.

Information requested from the owner/operator of each facility included the following:

- Where is the plant located?
- What type of plant is it? List all treatment processes at the facility.
- What is the plant capacity, and what is the operating capacity?
- What are the treatment objectives and discharge limits for the plant?
- What type of on-line instrumentation is used at the facility?
- What is the make/model of the instrumentation?
- What type of SCADA system is used and is information communicated by landline, cell, or satellite?
- Do you use localized data storage (digital files), paper files, or a remote database for data storage?
- How long has automated monitoring been in place?
- How many operating and maintenance staff are involved at the plant? What are their hours?
- What type of O&M is carried out on monitoring equipment?
- What is the time spent on maintaining the monitoring equipment and the estimated time savings resulting from remote monitoring?
- Have there been any issues with the automation system, and if so, what type?
- Can you provide an estimate cost of installing the on-line monitoring and SCADA system?

2.3 Development of Monitoring Needs

In order to identify sensor capabilities, the types of parameters that require monitoring were identified. This process involved reviewing traditional and non-traditional parameters that could be monitored in decentralized wastewater treatment systems to allow operations or management staff at a remote location to assess the operating or performance status of a facility and to respond to upsets, process or mechanical failures or other non-routine situations. The review was used to identify the operating conditions, process control parameters and effluent quality parameters that could be monitored on-line at decentralized facilities.

2.4 Identification of Sensor Capabilities

2.4.1 Analysis of Instrument Capabilities

Wastewater treatment system instruments were investigated and evaluated using a subjective analysis and objective capabilities. This analysis was based on the field experience of industry experts and product literature. Instrumentation cost of ownership (maintenance requirements) and documented manufacturer specifications were evaluated subjectively, based on the field experience of industry experts. An assessment of high, medium or low instrument maintenance requirements and the accuracy and reliability of available manufacturer instrument technologies was used. Instrument monitoring capabilities were objectively documented using manufacturer reported specifications for installation requirements and interface with the SCADA systems that were identified in this study.

The Instrumentation Testing Association's (ITA) research reports and field-testing knowledge base was used to estimate the cost of ownership, accuracy and repeatability assessments and ITA's instrumentation specification database. These were based on instrument manufacturer specifications and designed to assist the end-user in making direct comparisons of instrument features, applications, operating parameters, maintenance requirements, reported accuracy and costs.

A thorough examination of instrumentation cost of ownership would necessitate a life-cycle cost analysis. Such an endeavour would require significant resources to encompass all instrument parameters appropriate for decentralized wastewater treatment systems. For the purposes of this research project, a life cycle cost analysis discussion is included to be used as a tool by the decentralized system end-user. A life cycle cost analysis will specifically track the costs associated with installing, operating and maintaining an instrument (inclusive of labor and associated chemical costs over the useful life of the instrument). The life cycle cost analysis can provide the decentralized wastewater system end-user with information that can be used to develop realistic operating budgets, and to justify procurement and installation of instrumentation.

2.4.2 Life Cycle Cost (LCC)

The cost of obtaining dependable and precise information from accurate and reliable instrumentation is low when compared to the overall cost of facility operations and ownership on a year-to-year basis. Determining the cost of ownership requires the end user to calculate the Life Cycle Cost (LCC) of the instrument. The following LCC model was prepared by ITA for the WERF Project 99-WWF-6[4]. The LCC equation uses four cost factors to determine total life cycle costs of the instrument by the following equation:

$$LCC = [Cic + LRavg(Cin) + LRom(Com)] + [(Crs + LRom(Com))\, n] \qquad [1]$$

Whereby

LCC	=	life cycle cost
Cic	=	initial cost factor, purchase price (analyzer, system, filter, auxiliary and includes one year of reagents and spare parts)
Cin	=	installation, commissioning, and training cost factor (end user develops point system)
Com	=	operation, maintenance and repair cost factor includes cost of normal system supervision, routine and predicted repairs, parts, and staff time (end user develops point system)
Crs	=	annual reagent and spare parts costs
LRavg	=	hourly labor rate average for staff that installed instrument (including operations, instrumentation, and electrical)
LRom	=	hourly labor rate for operation, maintenance and repair and supervision of the instrument and depending on responsibilities this may include operations, instrumentation, and electrical. Derived from averaged labor rates for general operations and maintenance personnel and instrumentation specialist/technicians.
n	=	years of expected instrument life (i.e., typically 5-10 years)

The LCC equation is divided into two parts, the first represents year one costs (i.e., initial purchase and installation costs, etc.) and the second part of the equation allows for subsequent years represented by annual operation, maintenance and repair costs. Regional variations in hourly labor rates led to the development of the Labor Rate multipliers *LRavg* and *LRom*.

It is important to take into consideration the assumptions made in developing the LCC model to perform cost of ownership analysis. For example, the initial cost information (*Cic*) is supplied by end user purchase documents. The installation (*Cin*), operation and maintenance cost factors (*Com*) are considered subjective since they are developed by end user experiences, observations, and maintenance records and assume accurate record keeping by the end user. It is also assumed that installation, operation and maintenance costs vary from site-to-site depending on type of installation, time required to perform tasks, labor rates, and overhead costs.

For the purposes of this research project, the cost of ownership (maintenance requirements) was subjectively evaluated for the instruments listed in tabular format. A rating of High, Medium, and Low is shown and is based on instrument specifications, field observations and experience of experts, materials of construction, installation requirements, operations, probable maintenance tasks, consumables (chemical reagents, replacement parts, etc.), and support system equipment requirements. A High cost of ownership rating was assigned for instrument maintenance costs that were greater than or equal to $2,500 per year. A Medium rating was assigned where the associated costs of ownership were in the $1,000 to $2,500 range. A Low rating was assigned to an instrument with a cost of ownership less than $1,000 per year.

Further details on the methodology used to calculate LCC is included as Appendix A.

2.4.3 Instrument Monitoring Capabilities

Instrument monitoring capabilities of each instrument were prepared in tabular format and were evaluated using both subjective and objective analysis. Instrument monitoring capabilities takes into consideration the instrument technologies and makes a subjective determination of the sensor's accuracy (not the accuracy published by the manufacturer) and reliability based on research and the experience of experts in the industry. Objective instrument features, including installation requirements and the ability of the instrument to interface with SCADA systems, are based on the monitoring capabilities from the manufacturer's instrument specification data.

2.4.3.1 Accuracy

Accuracy describes how close an instrument can measure a constituent with bias errors. For the purposes of this research project, accuracy of a decentralized wastewater treatment system instrument was subjectively evaluated using a 2% value and is based on research and the field experience of experts in the industry. Instruments with an assessed accuracy of less than 2% are determined to be "Accurate" and instruments with an assessed accuracy greater than 2% are considered to be "Fairly Accurate."

2.4.3.2 Reliability

Reliability of the instrument is the ability of the instrument to operate consistently with stability and repeatability. A reliable instrument will have consistent results if repeated over time. Repeatability is the ability of an instrument to obtain consistent results when measuring the same constituent. A measurement is considered to be repeatable when the variation of the measurement over time is smaller than some agreed limit.

For the purposes of this research project, reliability was subjectively evaluated based on research and the field experience of experts in the industry. Instruments may be deemed more reliable if they have fewer moving parts and provide automatic maintenance features such as self-cleaning, self-calibration and self-diagnostic capabilities that may reduce maintenance labor requirements and assist in continuous operation.

2.4.3.3 Installation Requirements

Installation requirements of an instrument are objectively documented and are based on reported manufacturer specifications. Installation configuration capabilities such as pipe mounting, wall mounting, instrument sensor location and any auxiliary equipment required to support instrument measurements are documented.

Sensor location defines whether the instrument measurement is taken ex-situ (measurement sample is transported to instrument sensor) or in-situ (instrument sensor takes its measurement directly from the process). Auxiliary equipment includes additional utilities, equipment or environmental controls to accommodate normal operation of the instrument. In the case of an instrument with an ex-situ sample measurement, support equipment such as a sampling system with pumps would be required to transport the sample to the instrument.

2.4.3.4 Interface with SCADA Systems

The capability of an instrument to interface with a SCADA system was objectively documented and based on reported manufacturer specifications. Various connections are available to interface with SCADA systems such as relay outputs, analog outputs and digital communication protocols. Relay outputs or relay contacts are switches used for control purposes. Analog outputs are a type of signal an instrument transmits that can be used for readouts and control functions. Typical analog output signals are 4-20 mA (milliamps) and 1-5 VDC (voltage direct current). Digital communication protocols are used for integrating instrument readings into a control system. Protocols such as Fieldbus, Profibus, Modbus, RS232, RS422, RS485, HART, Ethernet, and others allow the end-user to connect multiple instruments to a single wire that is used to transmit instrument data to the SCADA system.

2.5 Identification of SCADA Capabilities

2.5.1 Literature Search

This review was based on product literature and documentation as it pertains to decentralized wastewater treatment systems along with non-wastewater systems. These non-wastewater systems include water treatment, storage and pumping systems as well as other industrial processes for the purpose of reviewing content that would relate to the SCADA systems employed in the decentralized wastewater treatment systems.

The search involved literature on the internet and technical white papers as well as direct contact with suppliers and vendors of various equipment and services for SCADA systems.

2.5.2 Case Study Reference

The identification of SCADA capabilities utilized the data collected from case studies as part of the Literature and Technical Review. These systems employed various SCADA systems for the purpose of alarming, monitoring and control.

2.6 Identification of Research Needs

The Literature and Technical Review provided an insight on potential and actual issues with real-time monitoring systems for decentralized facilities. The Identification of Sensor Capabilities and SCADA Capabilities for decentralized wastewater treatment plants were used to identify gaps in knowledge in sensors and SCADA technology or application, respectively. Based on this and other information collected during the investigation, research needs that could potentially increase the use of real-time monitoring and SCADA systems in decentralized wastewater treatment were identified and prioritized.

CHAPTER 3.0

RESULTS AND ANALYSIS

3.1 Current Monitoring of Decentralized Wastewater Treatment Facilities

3.1.1 Types of Treatment Systems

A wide range of treatment technologies are used for decentralized wastewater treatment. The simplest systems include septic tanks (with a soil absorption field) and facultative lagoons. More complex systems include filters (i.e., recirculating sand, peat, and textile) and mechanically operated biological treatment systems (e.g., activated sludge, trickling filters and sequencing batch reactors).

All decentralized wastewater treatment systems are designed to reduce the concentration of solids and organic matter. Some treatment facilities may also provide a reduction in the concentration of ammonia-nitrogen, nutrients, and pathogens. Typically, effluent from decentralized wastewater systems is discharged to a soil absorption system, although larger cluster systems may directly discharge to a surface body of water.

The overall trend for decentralized wastewater treatment is the use of more complex treatment systems, likely due to an increase in grey water schemes, regulatory requirements for better effluent quality and more acceptance of these technologies by the general public and regulatory authorities. While this trend does not necessarily mean the potential for system problems will increase (many of these systems are very robust and require little maintenance or operational changes), there is an increase in the number of mechanical systems and process parameters that may need to be monitored to ensure consistent effluent quality.

3.1.2 Types of On-line Monitoring

Remote, on-line monitoring of decentralized facilities involves unattended analysis and reporting of a parameter. This type of monitoring produces data at a greater frequency than is possible by onsite sampling or assessment of the operational status of equipment by an operator. It also allows for real-time feedback for process control, and influent or effluent quality characterization that can be used for operational decisions.

There are four general types of monitoring that can be used for decentralized wastewater treatment facilities, which are as follows.

- Operational monitoring of the status of mechanical equipment (pumps, blowers, clarifier drives, etc.).
- Process control monitoring that can allow process adjustments to improve effluent quality and/or reduce treatment costs. This type of monitoring may include influent flows and constituents, monitoring of conditions at various points in the treatment process, and effluent flows and constituents. This type of monitoring could be carried out using on-line sensors.
- Raw wastewater or effluent quality monitoring, where the volume and/or concentration of certain parameters in the untreated sewage or treated effluent are monitored to indicate spills

or determine compliance with permit requirements. This type of monitoring could be carried out using on-line sensors.

- Monitoring of the receiving environment to determine if it is adversely affected by effluent discharges, which could include monitoring groundwater wells in the vicinity of decentralized treatment facilities that discharge to soil absorption systems. This type of monitoring is typically carried out by manual sampling and off-line laboratory analysis, but could be done using on-line sensors in some cases.

3.1.3 Potential Benefits of Using On-line Sensors for Remote Monitoring

The potential benefits of using on-line sensors to monitor decentralized wastewater treatment systems in real-time include the following.

- Early warning of changes in influent and effluent quality or flow. This allows for a treatment process to be modified as needed to achieve a consistent effluent quality and to meet discharge requirements. There is also the possibility of linking downstream regulatory monitoring stations to a plant's SCADA system as a means of warning owners/operators of a potential operational problem at a plant.
- Reducing the risk of adversely affecting the environment and/or public health. The discharge of contaminants into a receiving water or soil as a result of a system failure or poor performance has the potential to adversely affect the public and/or the local environment. Without real-time monitoring, system failures or malfunctions may go unnoticed for significant periods of time.
- Planning for additional treatment capacity. By monitoring systems and analyzing the data provided, times of peak use can be determined and system expansions can be planned accordingly.
- Reducing chemical and energy costs by optimizing and continuously regulating the treatment process. For example, by having accurate trending information, plant operators can determine when they have to add chemicals or backwash filters.
- The ability to automatically generate reports to meet management or regulatory requirements.
- Reducing operational costs and increasing the efficiency of the day-to-day operation by decreasing staff time and travel costs associated with site visits. In addition, there are potential monetary costs associated with system failures that are not detected and rectified in a timely manner that include the cost to repair or replace a failed system or components (which can be greater the longer a problem persists), an impact on property values as a result of pollution, and the loss of income for a business using the facility until the system is repaired.
- Building confidence in the general public and regulatory authorities that decentralized wastewater treatment is a suitable option for communities.

3.1.4 Current Monitoring of Decentralized Treatment Systems

For cluster wastewater treatment systems, regulatory authorities will typically require some level of effluent quality and quantity monitoring, and sometimes require monitoring of the receiving water environment (surface or groundwater). The monitoring required will be specified in the permit for the facility, which will vary from site to site. Typically, the permit will have limits on total suspended solids (TSS) and 5-day biochemical oxygen demand (BOD_5). Some facilities may also have specified limits for fecal and/or total coliform, ammonia-nitrogen, nitrate-nitrogen, phosphorus and total chlorine residual.

Individual onsite wastewater treatment systems are rarely required to undertake monitoring as they do not typically have discharge limits specified in a permit. The acceptance of onsite systems by a regulatory authority (usually a county or state health department in the U.S.) is typically based on design standards for the treatment and disposal system rather than treatment performance.

3.2 Literature and Technical Review

3.2.1 Literature Search

A search for readily available information on existing on-line real-time monitoring systems for decentralized wastewater systems identified limited information, indicating that this is not a widespread management practice.

Information from three monitoring equipment and service suppliers in the U.S. was identified, as well as two independent studies on on-line monitoring of decentralized wastewater systems.

The types of on-line monitoring identified from the literature reviewed included mechanical systems (e.g., pump run status, level sensors), water quality parameters (e.g., pH) and a few process operating parameters (e.g., DO, UV light intensity).

From a search of available technical literature, the telemetry system used to transfer performance and operational data to a remote operational center was found to range from auto dialers (minimal data transmitted) to programmable logic controllers (PLC), SCADA systems and web-based telemetry.

The literature search findings are presented in the following subsections.

3.2.1.1 Orenco Systems

Orenco Systems Inc. designs and manufactures control and monitoring panels for water and wastewater facilities, including decentralized plants (www.orenco.com). The VeriComm and TCOM systems include remote wireless telemetry control panels that can be used with a web-based monitoring system. The Orenco telemetry systems are in effect a type of SCADA system as they include a PLC and communication modules.

The telemetry system allows plant operators to remotely monitor and control certain parameters for a decentralized treatment system using regular computer software. Monitoring may include UV light sensors, liquid level, pump run time and filter/screen cleaning. As well as allowing operators to remotely monitor the plant, the system notifies operators of alarms or alerts and also allows operators to change some plant settings remotely. Based on a programmed probability matrix resulting from stored events and data, an operator may receive an email outlining diagnostic problems.

The control panel connects with the monitoring system to download plant data to the web, typically once a month. Operators can also access the control panel remotely to view real-time data using a computer with a modem. Alarm or alert conditions are transmitted to operators immediately. All data are stored in a central database that can be accessed by operators via the web.

Typical Orenco residential remote telemetry panel costs are approximately $780 and basic panels for a cluster treatment system around $3,500. The approximate cost of a customised control and monitoring panel for a cluster system typically ranges from $9,000-16,000 U.S.

A number of case studies were identified where the Orenco monitoring system was being used. These are discussed in Section 3.2.2.

Other similar systems to Orenco include the SCADAlliance product (EasyControllers: http://www.wit.fr/en/index.aspx), the Semaphore TBox (http://www.cse-semaphore.com/default.php), Aquaworx control panels (http://www.aquaworx.com/products/control.asp) and American Onsite Controls control panels (http://www.americanonsite.com/american/controls.html).

Other options for management of data from decentralized wastewater treatment facilities include Hach's Water Information Management Solution (http://www.hach.com/WIMS), the OnlineRME™ Wastewater Management Tool (http://www.onlinerme.com/product.htm), Endress + Hauser's Life Cycle Management (http://www.us.endress.com/) and the WaterTrax product (http://www.watertrax.com/product-services/software-as-a-service.html).

3.2.1.2 Aquapoint System

Aquapoint's Aqua Alert remote wireless telemetry package or hardwire modems allows monitoring and control of specific system functions directly from an internet accessible computer (www.aquapoint.com). Data transmission is not in real-time, but data is sent in packets several times per day between the control panel and an internet-based software program. The Aqua Alert system can be used with Aquapoint package wastewater treatment plants only and can be customised.

Mechanical equipment cycles and operation are adjustable and operators can monitor plant history, elapsed run times and alarm conditions remotely.

Information is provided on facilities using the Aquapoint remote monitoring and control system in Section 3.2.2.

3.2.1.3 NSF International Onsite Monitoring Program

NSF International provides an Onsite Monitoring Program (OMP) as a service primarily to regulators and service providers to receive independent verification that advanced onsite wastewater treatment systems are being regularly maintained, and that those with alarm activations are being responded to appropriately (www.nsf.org/info/omp).

The system does not provide real-time water quality or process monitoring data and does not allow for remote manipulation of the treatment process. However, service providers do receive immediate notification of alarms via text message to cell phone, pager, and/or email. OMP subscribers can access and use data from wastewater facilities via a password-protected website.

The system maintains a permanent record of each event to document the history of alarm/events at a given location, and to track response times to those alarms/alerts.

The communication devices are purchased from NSF at a cost of $74-163 and the service contract is $48/year for residential and $72/year for commercial facilities for the first year, with lower annual service contract costs after the first year. All costs are in U.S. dollars.

The system has been in place since 2005 and users are located all over the U.S.. The number of NSF OMP subscribers is proprietary information and was not available for this study.

3.2.1.4 National Onsite Demonstration Program

West Virginia University carried out a study between 2004 and 2006 on remote monitoring of decentralized wastewater systems. Part of the study involved developing a method of monitoring multiple decentralized wastewater treatment systems from a central location, and demonstrating the potential of remote monitoring equipment as a tool for performance-based standards and decision making.

The parameters monitored in the study were DO, pH, pump run times, air temperature, wastewater temperature, liquid level, and water flow. Data from the sensors from six plants was collected every three minutes and transmitted to a custom Remote Data Acquisition Panel (RDAP). Data transfer from the RDAP to the Centralized Data Acquisition Center (CDAC) was done using a telephone landline. A custom Data Acquisition Computer (DAC) was used to connect with the RDAP and to store data.

Limited data are available on the performance or reliability of the monitoring system used, but based on a discussion with one of the study authors, there were no issues with these factors during the study.

The authors of the study concluded that a significant reduction in labor costs could be achieved by using a targeted response approach with remote monitoring, but that an economic analysis to confirm this is required.

The study followed on from work carried out in 2001 and 2002 on real-time monitoring of recirculating filters. In this work, data from pH, oxidative reductive potential (ORP), temperature, DO, flow and level sensors were downloaded every 30 minutes and data transmitted to a central data logger and a subset of the data was transmitted for remote monitoring. Three different proprietary data transfer systems were used at the test site. Issues encountered with the sensors included surge damage. Maintenance of some of the probes was time consuming and inconsistent readings were received for some sensors. There were occasional issues with lightning strikes and communication problems with the data transfer and acquisition systems used.

3.2.1.5 Rocky Mountain Institute Study

The Rocky Mountain Institute conducted a study on behalf of the U.S EPA in 2004 on the methods to carry out a cost benefit analysis for decentralized wastewater treatment systems.

This study concluded that remote monitoring and control of decentralized systems has the potential to reduce the risks of treatment failure and the costs of professional maintenance. It also concluded that the technologies and approaches for remote monitoring and control need to be examined as there are little data available on this.

The results of this study indicate that remote monitoring can reduce the maintenance and repair costs for some systems, but it is not always clear what needs to be monitored and what system types give net returns on the investment in monitoring technology. It was suggested that consideration should be given to whether remote monitoring can reduce the resistance of owners of decentralized wastewater systems to use maintenance programs.

3.2.1.6 White Paper on Distributed Sensing Systems for Water Quality Assessment and Management

The Center for Embedded Networked Sensing (CENS) is developing embedded networked sensing systems and applying this technology to specific applications. CENS prepared a white paper on potential applications of sensing systems to a number of water quality management problems, including providing early warning for septic system failures. It is suggested that this could be provided by having a technician use a handheld computer to locate a wireless signal from a battery-powered water quality sensor. The technician's computer analyses the data collected over time and determines from this if the septic system is leaking. A notice would then be sent to the homeowner. Field-ready sensors that could be used for this purpose are discussed and include electrical conductivity and water level.

3.2.1.7 Remote Monitoring of Treatment Plants on Golf Courses

Waterloo Biofilter Systems Inc. installed a remote monitoring system for wastewater treatment plants at four golf courses in Ontario, Canada. Effluent from a septic tank is treated in a proprietary biological filter at each of the golf courses. The remote monitoring system includes software and hardware connected to mechanical equipment. Data that is monitored includes pump status and cycles, rotating valve cycles, flow, temperature and UV light intensity. Daily viewing of plant data remotely was used to optimize the treatment at each facility. Further information on the remote monitoring system used is provided in Section 3.2.2.8.

3.2.2 Case Studies

Based on the results of the case study review, the number of decentralized wastewater treatment facilities currently using on-line sensors for real-time remote monitoring is relatively small. Many decentralized facilities using remote monitoring would appear to be supplied with "control boxes" that monitor and control pump on/off status, monitor tank levels and sound an alarm when an unusual condition occurs. The alarm connects to a panel onsite and can also be used to send a signal to the plant operator and to a remote central control location. A few decentralized facilities were identified that are using real-time sensors to monitor non-traditional parameters such as dissolved oxygen concentration (DO), conductivity and chlorine concentration.

A summary of each case study is presented in the following subsections and summarized in Table 3-1. Appendix B presents the completed questionnaires supplied by the owner or operator of each facility discussed.

3.2.2.1 Charles City County, Virginia

On-line instrumentation and SCADA were installed at two wastewater treatment plants in Charles City County in 2005 to remotely monitor the treatment process at each plant. Each plant includes a sequencing batch reactor (SBR), gravel filter and UV disinfection. The Jerusalem wastewater treatment plant (WWTP) has a treatment capacity of 13.2 m^3/d (3,500 gpd) and the Kimages WWTP has a treatment capacity of 26.4 m^3/d (7,000 gpd).

Each plant has pH, luminescent dissolved oxygen (LDO), oxidation-reduction potential (ORP) and conductivity monitors. The Kimages plant also has a nitrate sensor installed, which was out of commission for approximately one year, due to a faulty junction box. Plant operators can call into the SCADA system to review real-time sensor data using a dedicated landline. Data are electronically stored locally.

There have been issues with the hardware for the nitrate probe and its connections to the SCADA, which may have been due to the problem with the junction box. There have also been problems with the data collection and storage system at the Kimages plant. There have been challenges with the DO control system and, as a result, the plants may switch to a timer based operation for the blowers. The DO sensors are used to turn off the blowers at 5 mg/L DO and on at 2 mg/L. There have also been problems with frequent alarms from the probes.

Plant operators carry out routine daily site visits and typically spend about one hour per week on maintenance of the remote monitoring system. The installation of a remote monitoring system has not reduced labor requirements at these facilities. It is the opinion of the Technical Services Engineer at the Virginia Department of Health that remote monitoring of the on-line sensors is not necessary for successful operation of these facilities. He has suggested that the main reason for this is the technology used may not be the best choice for the treatment technology at the plants, as well as the operational practice of the plants.

3.2.2.2 Warren, Vermont

A U.S EPA demonstration project in the Core Village Growth Center in Warren, Vermont uses remote monitoring and control for wastewater treatment systems and pump stations. Included in this project are two cluster wastewater treatment plants (design capacity 114 m^3/d or 30,000 gpd and 8 m^3/d or 2,000 gpd), eight onsite treatment/disposal systems, pump stations and 31 septic tank effluent pump (STEP) systems. Remote monitoring has been in place since 2003.

The pump stations and the two cluster plants have control panels that communicate via radio telemetry to a master panel located at the Town office. Monitoring for these systems includes level sensors and pump run times. Operators can access the master panel from personal computers using a modem in the panel. The master panel has a dialer that sends alarms to an operator's cell phone. Data is stored electronically at a remote database and paper copies are also kept for each site.

The STEP systems and onsite facilities plants have Orenco VeriComm control panels that monitor liquid levels, float switches and pump run times. One of the onsite systems uses a custom Orenco control panel to monitor liquid levels, float switches, pump run times and filter cleaning. The custom panel also allows remote access to the control panel using a personal computer with a modem. Operators receive an alarm for these systems to a pager or email via the homeowner's telephone line. Monitoring data for each of these sites, which is downloaded approximately once a month, can be accessed through the Orenco website.

Operators check all plants remotely on a weekly basis and carry out routine site visits once every two weeks. There is no routine maintenance scheduled for the remote monitoring system and the estimated time savings as a result of the system is 12 hours/week for all facilities.

There have been some minor problems with monitoring of these systems, including lightning strikes causing panel failures and homeowners switching from landlines to cellular telephone systems.

3.2.2.3 Seven Cluster Treatment Plants, Michigan

SCS Systems LLC provided information on the remote monitoring systems used by seven cluster filtration treatment systems in Michigan. The treatment plants include storage ponds, sand filters, textile filters and infiltration systems. The treatment capacity of the plants ranges from 10

m^3/d (5,600 gpd) to 95 m^3/d (25,000 gpd). All plants receive wastewater from STEP or septic tank effluent gravity (STEG) systems. All of the systems use custom Orenco control panels that utilize a land line. Data are stored locally for 3 to 12 months (varies with facility) and are downloaded remotely to Excel files at a central computer.

Monitoring at the plants includes liquid level, pump run, flow meters and floats. Very limited site visits are carried out. There have been some issues with reliability with some telemetry systems, including failures due to voltage spikes and inconsistent phone service at some sites. There was a problem with a level sensor and a flow meter at two of the sites, which was believed to be due to incorrect installation of these sensors.

The maintenance time for the remote monitoring system is estimated to be between 0.5 and 2 hours per year, and time savings as a result of remote monitoring between 5 and 30 hours per year for each site.

SCS has noticed an increased demand for control panels that will communicate over an internet connection, cellular or wireless service as many homeowners are changing from a landline service to cellular phones or cable internet.

3.2.2.4 Piperton, Tennessee

The Town of Piperton has a network of six wastewater treatment plants, each using the same treatment technology (Aquapoint Bioclere trickling filters). The capacity of the treatment plants ranges from 76 m^3/d (20,000 gpd) to 303 m^3/d (80,000gpd). Each plant is tied into the same telemetry monitoring network, which uses a proprietary Aquapoint telemetry control package called “Aqua Alert”. On-line monitoring includes pump and fan operation. Data transmission is not in real-time, but data packets are sent several times per day between the control panel and internet-based software program. All facilities use cellular-based remote wireless telemetry with an integrated automatic dialer.

A maximum of two hours per month is spent at each site by plant operators. The actual time required for maintenance of the remote monitoring system is negligible, and site visits by operators is part of a preventative maintenance program for the plants. There have been no issues with the monitoring systems at the Piperton plants. The approximate cost of the telemetry control package is $4,000.

It is the opinion of the vendor that many of the owners/operators of systems that have telemetry or SCADA control system do not use it and most would be happy to have a system that notifies operators of an alarm condition only.

3.2.2.5 Charleston, South Carolina

The SBR and UV disinfection system at the Charleston WWTP is a relatively large facility (capacity 3,785 m^3/d, 1 MGD), which uses a number of on-line sensors for remote monitoring. The plant has a range of instrumentation, including level and flow monitors, DO meters and UV light monitors. The on-line monitoring also provides remote process control. Data from the on-line instrumentation can be monitored in real-time and are transmitted via radio from the local SCADA system to two SCADA nodes at the control centre. Data are transferred every minute. There is temporary local data storage as well as long-term storage on a database at the control centre.

The plant does have a full-time operator Monday to Friday and plant operators view the real-time monitoring data remotely during evenings, weekends and holidays.

The on-line monitoring system has been in place since 2001 and since that time, the only issue has been an occasional communications failure due to radio failure. The operator has estimated the average up time of the system to be greater than 99%.

3.2.2.6 Mobile County and Fulton, Alabama

Information was received for fifteen decentralized wastewater treatment facilities owned and operated by three utilities in Alabama. All plants use filtration treatment systems and Orenco control and monitoring systems, and range in capacity from approximately 76 m^3/d (20,000 gpd) to 227 m^3/d (60,000gpd).

The devices being monitored include floats, liquid levels and flow meters. Data are transmitted to Orenco's central database using land lines. There have been no issues with these plants, other than an occasional problem with communication due to non-functioning telephone lines. The remote monitoring systems require virtually no maintenance. As multiple sites are monitored and most sites are 15 to 20 miles from the central monitoring station, there are considerable time savings related to the monitoring systems.

3.2.2.7 Miller Catfish Farm, Alabama

DO and temperature sensors have been installed to monitor and manage the aeration to sixty catfish ponds at this facility. Real-time data from the DO and temperature sensors in each pond are collected by the analyzer at the bank of the pond and relayed to a central office approximately 10 miles away using radio transmission or cell phone. Data are also provided for the operating status for each aerator. Data are collected and stored on a central computer.

The system was supplied by ITT Royce Technologies. The farm owner is very satisfied with the system installed and has only encountered problems with lightning affecting the monitoring system occasionally.

3.2.2.8 Golf Courses in Ontario, Canada

A trickling filter package plant and UV disinfection system was installed by Waterloo Biofilter at each of four golf courses in Ontario in 1999. The treatment capacity for these systems ranges from approximately 15 m^3/d (4,000 gpd) to 88 m^3/d (23,000 gpd). Each system has a SCADA that is used to remotely monitor pump on times, flow meter data, pressure switches and UV intensity in real-time. There is no control of the plants remotely with the system. The plant operator calls into the SCADA system at each plant using a dedicated landline. Data from plant monitoring are stored electronically at a remote database. The monitoring system has operated well since the plants were installed.

Maintenance of the remote monitoring system is negligible and the estimated time saving for operators as a result of remote monitoring is two hours per month for each site.

3.2.2.9 Water and Sewer Systems, District of North Cowichan, British Columbia, Canada

The SCADA systems at three of the wastewater plants in the District of North Cowichan are used as hubs for collecting real-time data from water, sanitary sewer and storm sewer monitoring stations. Data are transferred to the wastewater plants from the remote facilities using radios. Data are downloaded every 10 to 60 seconds.

Data collected at the wastewater treatment plants are transferred to a central location for monitoring and data storage. In addition, on-line DO, pH, level and flow data from the wastewater plants can be monitored remotely at the central location.

Data from the SCADA system at each wastewater plant are relayed to the region's office using virtual private networks (VPN). The region installed the radio and uses the hub system as the area is very mountainous and there is no clear line of sight or cable system available.

The wastewater plants are fully manned; therefore, the remote monitoring system has not reduced labor requirements at the wastewater plants. However, the system does allow remote monitoring of the water and sewer stations. The system allows for accessing data for the water and sewer systems at the three wastewater plants, the central location or from a remote site where internet service is available.

The District has not experienced any problems with the instrumentation used at any of the facilities, which include level sensors, flow meters, chlorine sensors and pH probes. The biggest challenge with the system has been setting up the communication system, upgrading software at the wastewater treatment plants, and setting up the data management system.

3.2.2.10 Cowichan Valley Regional District (CVRD), British Columbia, Canada

The Shawnigan Beach Estates Sanitary Sewage System is an aerated lagoon plant with a microscreen drum filter and UV disinfection. The average day flow (ADF) capacity of the plant is approximately 337 m^3/d (89,000 gpd). Currently, the plant uses an on-line flow monitoring device which can be monitored in real-time. Data from the flow meter are transmitted to a SCADA system and from there are transmitted by modem to a host terminal at the CVRD office. In addition to the Shawnigan Beach wastewater plant, on-line flow monitoring data from the Lakesides Estates Treatment Station and two pump stations are transmitted to the CVRD office. Data from both facilities are stored digitally at the CVRD office.

The CVRD has been satisfied with the performance of the current system. There are occasional problems due to power outages and false alarm signals. Time savings as a result of remote monitoring are difficult to estimate for this system as the SCADA methodology is still being adjusted. The CVRD think that there will be time and cost savings in the long term as a result of remote monitoring.

3.2.2.11 Lift Stations, Langford, British Columbia

Corix Utilities provided information on thirteen lift stations in the community of Langford. Data from the pumps and flow meters at each lift station are transmitted in real-time to a central SCADA system. Eleven of the stations communicate using cable and the other two by landline. Data is stored electronically in a remote database. Issues of unnecessary alarms have been dealt with by building in a delay to the system.

Corix is in the process of developing a SCADA package for all the water and wastewater systems it is involved in operating. There are no details yet on what sensors will be used, but it is expected that the SCADA system at each facility will communicate by radio then broadband Ethernet to secure servers and the web.

3.2.2.12 Walpole, Western Australia

The on-line monitoring of the Walpole WWTP SBR plant includes levels, DO, conductivity, pump status, flow and chlorine leak detection. The treatment capacity of the plant is 200 m^3/d (53,000 gpd). The monitoring system has been in place for five years. Information from the SCADA system is communicated to a central control centre via a landline. The plant does have a full-time operator; therefore, the real-time monitoring data are typically not viewed remotely by plant operators.

The system has both localized storage files and data stored on a remote database. The implementation of the system had problems with a delay in the communication between the site and the central control centre until a broadband internet connection was installed.

3.2.2.13 Gesidra Water Distribution System, Italy

The water system within the province of Bergamo, Italy is integrated and has been using remote monitoring for the last four years. Approximately 20,000 m^3/d of water is distributed throughout the system.

On-line instrumentation includes level sensors in the well, flow and pressure monitors in the network and chlorine analyzers in the disinfection stations. The SCADA system can be accessed remotely using cell phones. A remote data acquisition system collects and stores data.

Prior to the installation of the remote monitoring system, labor for operation and maintenance of the water system was 80 hours per week (based on two full-time staff). The current operation and maintenance is carried out by one person on an as- needed basis.

Table 3-1. Summary of Case Study Information.

Facility Name and Location	Facility Type(s)	Parameters Monitored	Communication System Used	Data Storage and Access
Jerusalem and Kimages WWTPs, Charles City County, Virginia	WWTPs (SBR, filtration, UV)	LDO, ORP, pH, conductivity, nitrate	Call in to SCADA using landline	Local, electronic data
Village Growth Center, Warren, Vermont	WWTPs, pump stations, onsite treatment, STEP systems	Level, pump, float switches, flow, filter cleaning	Telemetry via landlines downloads data once a month to web, remote real-time access to control panel via local computer, alarm/alert signals sent to operators	Access using remote computer with a modem, Web-based access and storage
Cluster plants in Michigan	7 WWTPs – filtration, infiltration, storage systems	Level, pumps, flow, floats	Telemetry via landlines downloads data once a month to web, remote real-time access to control panel via local computer, alarm/alert signals sent to operators	Access using remote computer with a modem, Web-based access and storage
Piperton, Tennessee	6 WWTPs – package biological systems	Pumps, fan	Data packets sent several times per day to internet-based software program using cellular-based remote wireless telemetry with an integrated automatic dialer	Web-based access and storage
Charleston WWTP, South Carolina	WWTP – SBR and UV disinfection	Level, flow, DO, UV light intensity	Real-time data is transmitted via radio from the local SCADA system to two SCADA nodes at the control centre. Data is transferred every minute.	Temporary local data storage and long-term storage on a database at the control centre
Treatment Plants in Mobile County and Fulton, Alabama	15 WWTPs – filtration systems	Floats, level, and flow	Telemetry via landlines downloads data once a month to web, remote real-time access to control panel via local computer, alarm/alert signals sent to operators	Access using remote computer with a modem, Web-based access and storage
Miller Catfish Farm,	Fish farm ponds	DO, temperature,	Real-time data transfer to central	Electronic data stored

Table 3-1. Summary of Case Study Information.

Facility Name and Location	Facility Type(s)	Parameters Monitored	Communication System Used	Data Storage and Access
Alabama		aerator operation	location using radio and cell phone	on central computer
Ontario golf courses	4 package biological treatment plants	Pump, flow, pressure switches, UV light intensity	SCADA using a landline	Electronic data stored on remote database
Water and sewer systems, DNC, British Columbia	Multiple water, sanitary sewer and storm sewer facilities	Level, flow, chlorine, pH	Radio transfer to SCADA at 3 WWTP hubs. Sent by VPN to central facility from WWTPs.	Electronic data stored on remote database at central facility
Shawnigan Beach Estates Sanitary Sewage System, CVRD, British Columbia	WWTP - aerated lagoon, filtration, UV disinfection	Flow	Real-time monitoring using modem to a host terminal central facility	Electronic data stored on remote database at central facility
Lift Stations, Langford, British Columbia	13 lift stations	Pumps, flow	Data in real-time to a central SCADA system using cable or landlines	Data is stored electronically on a remote database
Walpole WWTP, Western Australia	SBR	Levels, DO, conductivity, pump, flow, chlorine leak sensor	Data in real-time to a central SCADA system using a landline	Data is stored electronically locally and on a remote database
Gesidra Water Distribution System, Italy	Well, water treatment plants, water distribution network	Level, flow, pressure, chlorine	Data in real-time to a central SCADA system using cell phones	Data is stored electronically on a remote database

3.3 Monitoring Needs

3.3.1 Traditional Parameters

The following is a summary of traditional parameters that can be used for monitoring decentralized wastewater treatment facilities. This is not a complete list of sensors available, but rather a list of those that are considered suitable for decentralized facilities.

- Equipment run status: the operation of pumps, blowers, clarifier drives or other mechanical equipment can be monitored to ensure that the essential equipment is operating.
- Liquid level: either on/off level switches that serve an alarm or pump start/stop function, or level sensors that monitor and report liquid level continuously.
- Pressure: for hydraulic head, typically for alarm functions. This parameter can be used to monitor the filter backwash program for example. It can also be used to monitor the air or water pressure in lines or valves to indicate problems with pump or blower operation or line blockages, or faulty valves.
- Temperature: influent, process and effluent temperature monitoring can be carried out.
- Flow: the flowrate of influent and/or effluent measurement data can be used for process control or for regulatory reporting requirements. Air flow measurement can also be used.
- Vibration: monitoring the vibration in rotating mechanical equipment may be used to indicate equipment problems.
- UV light intensity. A UV light sensor can be used to measure how much UV light is being delivered for UV disinfection processes. Over time, the intensity of a lamp will decrease and sensors are used to monitor the intensity. The sensors will also detect changes in treated water quality that affect the transmittance of UV irradiation through the water. They can be used to automatically control the amount of UV light transmitted for disinfection purposes by turning on or off banks of or individual UV lamps. The data from the sensors can be used to compute the delivered UV dose.

3.3.2 Non-Traditional Parameters

The following provides a brief description of the types of non-traditional parameters that can potentially be measured on-line in decentralized wastewater facilities. This is not a complete list of sensors available, but rather a list of those that are considered suitable for decentralized facilities.

There are three kinds of direct detection sensors that can be used for real-time monitoring of non-traditional parameters at decentralized wastewater facilities: physical, chemical and biological. Some of these sensors can also be used as event-triggered sensors (or indicator sensors), which can be used to let remote operations or management staff know that an operator should go to the site to check something or take a sample.

3.3.2.1 Physical Parameters

- Turbidity: Effluent turbidity can be used as an indicator of suspended solids or bacterial contamination. Spikes in turbidity could trigger sample collection for lab-based TSS and/or microbiological analysis. An increase in effluent turbidity detected by an on-line sensor signal would also inform remote operations or management staff of a possible process upset.
- Sludge and/or scum depth: the level of sludge or scum in a tank can be monitored to alert plant operators when sludge or scum removal is required, to automate sludge pumping equipment or to indicate failure of sludge handling equipment.

- Soil moisture content: for effluent irrigation systems, the moisture content of the soil can be monitored to optimize the application rate.

3.3.2.2 Chemical Parameters

- Dissolved oxygen (DO): DO can be monitored for aerated biological processes or can be used for effluent monitoring where there is a permit requirement to meet a minimum DO concentration for surface water discharge.
- Ammonium: the effluent ammonium concentration may be monitored in a system that has an ammonia-nitrogen concentration limit in its permit.
- Nitrate: for nitrifying biological treatment plants (i.e., those converting ammonia-nitrogen to nitrate-nitrogen), the measurement of nitrate in the effluent indicates how well nitrification is operating and can alert a plant operator to upset conditions. It can also be used for effluent monitoring for those plants that have a nitrate limit in their permit.
- Phosphorus: can be used for effluent monitoring for those plants that have a phosphorus limit in their permit.
- BOD_5: can be used for influent or effluent BOD_5 monitoring.
- COD: can be used for influent or effluent COD monitoring.
- Chlorine: for plants that are chlorinating, total chlorine may be monitored to determine if the minimum and/or maximum levels permitted are being met in the effluent discharge.
- Metals: for effluent that is used for irrigation, the concentration of metals may be monitored. However, the concentration of metals is unlikely to change significantly in decentralized wastewater facilities, therefore real-time monitoring would only be used in the case where the influent has a variable metal concentration (for plants receiving a significant flow from certain industries, e.g. metal plating).
- Oxygen Uptake Rate (respirometry): used to provide an indication of the condition of the biomass in a biological treatment process or of possible toxicity in the raw wastewater.
- pH: Can be used to monitor influent or effluent pH. It can also be used in pH control for nitrifying biological treatment plants and for chemical phosphorus removal processes. It is particularly important if the influent pH is very variable.
- Hardness: may be used where regenerant water from water softeners is treated in a decentralized treatment facility.
- Alkalinity: may be used where regenerant water from water softeners is treated in a decentralized treatment facility.
- Sodium: may be used where return water from water softeners is treated in a decentralized treatment facility.
- Fats, oils and grease (FOG): may be used where plants receive restaurant waste.

3.3.2.3 Biological Parameters

Effluent toxicity: biosensors can be used to indicate a possible process upset (e.g., high ammonia, high chlorine).

3.4 Identification of Sensor Capabilities

3.4.1 Physical Measurement

This research project identified several instruments that are used to measure physical parameters for applications in decentralized wastewater treatment systems. The measurements of pressure, decentralized facility equipment alarm status and UV light intensity are physical measurements that are described herein. The various technologies of pressure and UV light intensity are outlined in tabular format and categorized by traditional and non-traditional technologies, as defined by this research project. Note: The physical measurements of equipment alarm status and UV light intensity only provide one instrument technology and therefore are considered traditional.

3.4.1.1 Decentralized Facility Equipment Alarm Status

Decentralized facility equipment alarm status for critical equipment (such as pump run status, wet well level, and power loss) utilize a single relay contact to transmit signals to the SCADA systems. Typically, SCADA systems display process and system status received from a programmable logic controller (PLC) located at a decentralized facility. Each status signal is mechanical or a solid state relay input to the PLC (on/off or opened/closed contacts). The inputs to the PLC originate at the individual mechanical equipment or instruments (motor starters; level, pressure, and temperature transmitters; and analyzers). For example, high wet well level status (hydrostatic pressure instrument or ultrasonic level transmitter) and station power failures (mechanical auxiliary relay contacts on the facility electrical power switchgear) are usually high priority status alarms. The following provides a typical list of status signals transmitted to SCADA systems for wastewater pump stations:

- Starter Panel Power Failed
- Generator Failed
- Pump 1 Run Failure
- Pump 2 Run Failure
- Wet well level high
- Wet well level low
- Pump 1 over temperature
- Pump 2 over temperature
- Pump 1 seal failure
- Pump 2 seal failure
- Pump 1 overload tripped
- Pump 2 overload tripped
- Pump station communication failed

The following is list of typical alarms for water well sites:

- Booster pump 1 failed to run
- Booster pump 1 failed to stop
- Booster pump 2 failed to run
- Booster pump 2 failed to stop
- Well pump failed to run
- Well pump failed to stop
- Discharge pressure low
- Chlorine level low
- Chlorine level high
- Main power loss
- Local tank high level

- Local tank low level
- Generator Failed

3.4.1.2 Liquid Level

There are numerous instrument technologies that measure liquid level. Liquid level instrument technologies are categorized by this research project's definition of traditional (available and in wide-spread use for many years) and non-traditional (not in wide-spread use) sensors for wastewater treatment systems, as they pertain to decentralized wastewater treatment systems.

Some of the more traditional liquid level instruments available for decentralized systems are:

- bubbler systems
- capacitance probes
- conductive
- differential pressure
- float switches
- hydrostatic pressure
- radio frequency (RF) admittance
- site gauge
- thermal
- ultrasonic

Non-traditional liquid level instrument technologies include:

- acoustic wave
- interface level
- laser
- magnorestrictive
- microwave
- radar

Each liquid level instrument technology is described and summarized by cost of ownership and monitoring capabilities in tabular format in Table 3-2. When considering liquid level measurement, the finer points of level design are sometimes overlooked. For example, operating ranges for level control of pumps in tanks, basins, pump stations and wet wells can be set to a level that can compensate for any abnormal conditions that might occur (i.e. grease and rag build-up). In addition, some designers specify the installation of redundant level controls which can improve level measurement reliability.

Liquid level instrument principles of operation and specifications are provided in Appendix C.

Table 3-2. Liquid Level Sensor Technologies.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay Contacts	4-20 mA and/or 0-5 VDC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Bubbler Systems	Avensys		x		x		x		x		x		x	x			x
	Campbell Scientific		x		x		x		x		x	x					
	Motor Protection Electronics, Inc.		x			x	x		x			x					
	Sutron		x		x			x	x					x			
Capacitance Probes	Clark-Reliance Jerguson Magne-Sonics (continuous level)			x	x		x		x	x		x	x				
	Endress + Hauser (continuous level)			x	x		x		x	x		x	x			x	
	Level Controls (point level)			x		x	x		x	x		x					
	Lumenite Control Technology, Inc. (continuous level)			x	x		x		x	x		x	x				
	Pepperl+Fuchs (point level)			x		x	x		x	x		x					
Capacitance Probes	Sapcon (continuous level)			x	x		x		x	x		x	x				

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay Contacts	4-20 mA and/or 0-5 VDC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	Siemens (continuous level)			x	x		x		x	x		x	x			x	
	Vega Vegacap (continuous level)			x	x		x		x	x		x	x				
Conductive	Endress + Hauser (one to five point level)			x		x	x		x	x		x					
	Pepperl+Fuchs (two point level)			x		x	x		x	x		x					
	Sapcon (one to four point level)			x		x	x		x	x		x					
	Vega Vegakon (one to four point level)			x		x	x		x	x		x					
Differential Pressure	ABB			x	x		x		x		x		x			x	
	Endress + Hauser			x	x		x		x		x		x		x	x	
	Invensys Foxboro			x	x		x		x		x		x			x	
	Honeywell			x	x		x		x		x		x		x	x	
	Rosemount Emerson Process Management			x	x		x		x		x		x		x	x	
Float	Clark-Reliance Jerguson (one to three point level)		x			x		x		x		x					
	Invensys Foxboro Eckhardt (continous level)			x	x			x		x		x	x		x	x	

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	**Medium**	**Low**	**Accurate**	**Fairly Accurate**	**Reliable**	**Fairly Reliable**	**Pipe mount or wall mount**	**In-situ (in the process)**	**Auxiliary Equipment Required**	**Relay Contacts**	**4-20 mA and/or 0-5 VDC**	**RS-232, RS-422, RS-485**	**Field-Bus or Profibus**	**HART**	**Ethernet**
	Krohne (continuous level)			x	x		x			x		x	x		x	x	
	Pepperl+Fuchs (one to three point level)		x			x		x		x		x					
	Varec (continuous level)			x	x		x			x		x	x			x	
Hydrostatic Pressure	Ametek / Drexelbrook			x	x		x			x			x				
	Emerson Process / Mobrey			x	x		x			x			x				
	Endress+Hauser			x	x		x			x			x		x	x	
	GE			x	x		x			x			x				
	Global Water Instrumentation, Inc.			x	x		x			x			x				
	Pepperl+Fuchs			x	x		x			x			x		x	x	
	SensorTechnics			x	x		x			x			x		x	x	
	Siemens /Sitrans			x	x		x			x			x				
Hydrostatic Pressure	Vega			x	x		x			x			x		x	x	
Radio Frequency (RF) Admittance	Ametek / Drexelbrook			x	x			x		x		x					
	HACH / GLI			x		x		x		x		x	x				
	Hawk			x	x		x			x		x	x		x		

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay Contacts	4-20 mA and/or 0-5 VDC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	Sapcon			x	x			x		x		x					
Site Gauge	Clark-Reliance / Jerguson		x			x		x		x		x					
	PLT-Process Level		x			x		x		x		x	x				
	Quest-Tec Solutions		x			x		x		x		x	x			x	
Thermal	FCI			x		x	x			x		x	x				
	Kayden			x		x	x			x		x	x	x			
Ultrasonic	Accu-Gage CTI Manufacturing, Inc. (single point)			x		x		x		x		x	x				
	Ametek / Drexelbrook (single point)			x		x	x			x		x					
	Clark-Reliance / Jerguson			x	x		x			x			x			x	
	Cosense			x		x	x			x			x				
	Endress+Hauser			x	x		x			x		x	x		x	x	
Ultrasonic	Global Water Instrumentation, Inc.			x	x		x			x		x	x				
	HiTech Technologies, Inc.			x		x	x			x		x					
	KAB Instruments Ltd. K-Tek Corporation			x	x		x			x			x				

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay Contacts	4-20 mA and/or 0-5 VDC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	Krohne			x	x		x			x			x			x	
	LevelControls			x	x		x			x		x	x	x			
	Mobrey Emerson Process Management			x	x		x			x		x	x			x	
	Pepperl+Fuchs			x	x		x			x			x		x	x	
	Rosemount Emerson Process Management			x	x		x			x		x	x			x	
	Siemens / Milltronics and Sitrans			x	x		x			x		x	x		x	x	
Non-Traditional																	
Acoustic Wave	Hawk			x	x		x			x		x	x		x	x	x
	Sapcon			x	x		x			x			x	x		x	
Interface Level	Ametek			x		x		x		x		x	x				
	Dynatrol			x		x		x		x		x					
	Entech			x	x		x		x	x		x	x				
	Hawk			x	x		x		x	x		x	x		x	x	
	Markland			x		x	x		x	x		x	x	x			

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay Contacts	4-20 mA and/or 0-5 VDC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	Mobrey / Emesrson Process			x	x		x		x	x		x	x	x			
	Pulsar Process Measurement Ltd.			x		x	x		x	x		x	x	x			
	Royce Technologies			x	x		x		x	x		x	x				
Laser	K-Tek Corporation USA Laser Measurements (Pty) Ltd			x		x	x			x		x	x	x			
	Optech			x		x	x			x		x	x	x		x	
Magnorestrictive	Ametek Drexelbrook			x	x		x			x			x				
	MTS, Inc.			x	x		x			x			x			x	
Microwave	Hawk (single point)			x	x		x			x		x					
	Krohne			x	x		x			x			x			x	
Microwave	K-Tech Corporation KAB Instruments (Pty) Ltd,			x	x		x			x			x			x	
	Pepperl+Fuchs			x	x		x			x			x		x	x	
	Vega / Vegaflex			x	x		x			x			x		x	x	
Radar	Ametek Drexelbrook			x	x		x			x			x			x	
	Global Water			x	x		x			x			x	x			

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay Contacts	4-20 mA and/or 0-5 VDC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	Instrumentation, Inc.																
	Krohne			x	x		x			x			x			x	
	Rosemount Emerson Process Management			x	x		x			x			x			x	
	Siemens / Sitrans			x	x		x			x			x		x	x	
	Varec Radar Tank Gauging			x	x		x			x			x		x	x	
	Vega / Vegaplus Radar			x	x		x			x			x		x	x	

3.4.1.3 Liquid Flow

There are numerous instrument technologies that measure liquid flow. Liquid flow instrument technologies are categorized by this research project's definition of traditional (available and in wide-spread use for many years) and non-traditional (not in wide-spread use) flow meters for wastewater treatment systems, as they pertain to decentralized wastewater treatment systems.

Some of the traditional liquid flow instruments available for decentralized systems are:

- area-velocity
- magnetic
- open channel
- Venturi

Non-traditional liquid flow instrument technologies include:

- Doppler
- insertion magnetic
- transit-time
- ultrasonic
- v-element / v-cone
- wedge

Each liquid flow meter technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-3. Flow instrument principle of operation descriptions are extracted from the following ITA publications: Flowmeters for System Applications Designer Checklist, DC99FM-002, Area/Velocity Flowmeters for Wastewater Collection System Applications Performance Evaluation Report, PER98FM-001 and Optimal Flow Measurement Understanding Selection, Application, Installation and Operation of Flowmeters Workshop Proceedings, WK02FM-002. Rotameters, flumes and weirs were not evaluated for this project even though they are in widespread use because they do not typically connect to a SCADA system directly. However, ultrasonic level instruments are in common use to measure the water level for flumes and weirs and these instruments are connected to SCADA systems for reporting flow measurements and are discussed in the level section.

Flow instrument principles of operation and specifications are provided in Appendix D.

Table 3-3. Liquid Flow Sensor Technologies.

Traditional and Non-Traditional

Traditional and Non-Traditional Sensor Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Sensor Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Area Velocity (electromagnetic and ultrasonic)	ADS Environmental Services, Inc. (ultrasonic)		x			x		x		x				x			
	Greyline Instruments, inc.		x			x		x		x			x	x			
	Hach / Sigma (ultrasonic)		x			x		x		x			x	x			
	Hach-Marsh-McBirney (electromagnetic)		x			x		x		x			x				
	SensorProducts (ultrasonic)		x			x		x		x		x	x	x			
Magnetic	Endress+Hauser			x	x		x			x			x	x	x	x	
	Foxboro			x	x		x			x			x		x	x	
	Honeywell			x	x		x			x			x				
	Onicon Inc.			x	x		x			x			x				
	Rosemount Emerson Process Management			x	x		x			x			x			x	
	Sparling			x	x		x			x			x	x		x	
Magnetic	Yokogawa			x	x		x			x			x				
Open Channel (ultrasonic)	Accusonic			x		x	x			x		x	x	x	x		x

Traditional and Non-Traditional Sensor Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Sensor Monitoring Capabilities**												
					Accuracy		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Note: Area Velocity flowmeters can also be used for open channel flow	Avensys/ Teledyne Isco, Inc.			x	x		x			x				x			
	Thermo Scientific			x		x	x			x			x	x			
Venturi	FlowMaxx Engineering		x			x		x		x			x				
	Fox Venturi Products		x			x		x		x			x				
	Primary Flow Signal		x			x		x		x			x				
	Racine Flow meter Group / Preso		x			x		x		x			x				
Non-Traditional																	
Doppler	Dynasonics			x		x		x		x		x	x	x			
	Emco Flow Systems			x		x		x	x			x	x				
	EESiFlo			x		x		x	x			x	x				
	Greyline Instruments Inc.			x		x		x	x			x	x				
	Micronics Ltd			x		x		x	x			x	x				
	Pulsar Process Measurement Ltd.			x		x	x		x			x	x				
	Thermo Scientific / Polysonics			x	x			x	x			x	x	x			
Insertion Magnetic	Dynasonics			x	x		x		x	x			x	x			
	Georg Fischer Signet +GF+ Signet			x		x		x		x			x	x			
	McCrometer, Inc.			x	x			x		x		x	x				

Traditional and Non-Traditional Sensor Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Sensor Monitoring Capabilities**												
					Accuracy		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	MSR Magmeter			x		x		x		x		x	x	x			
	SeaMetrics, Inc.			x	x			x		x		x	x				
Transit-Time	Accusonic			x	x		x		x	x		x	x	x			
	Dynasonics			x	x		x		x				x				
	Endress+Hauser			x	x		x		x	x		x	x	x	x	x	
	EESiFlo			x	x		x		x					x			
	GE Sensing / Panameterics			x		x	x		x			x	x	x	x		x
	Hedland			x	x		x		x				x				
	Sierra Instruments			x	x		x		x	x		x	x				
V-Element / V-Cone	McCrometer (VCone)			x	x		x			x			x				
Wedge	Ametek			x	x		x			x			x				
	Preso			x	x		x			x			x				
Wedge	Primary Flow Signal, Inc.			x	x		x			x			x				

3.4.1.4 Pressure

Pressure instrumentation is commonly referred to as pressure transducers or pressure transmitters. The three most common types of pressure instruments are absolute, gauge, and differential. Field configurations provide the distinction between the different types of pressure instrumentation. Traditional types of pressure transducers/transmitters utilize a capacitance, Piezoresistive, or strain-gauge technology. Non-traditional technologies include micro-electro-mechanical systems (MEMS) piezoresistive.

Each pressure instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-4.

Pressure instrument specifications are provided in Appendix E.

Table 3-4. Pressure Instrumentation Technologies.
Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and /or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus	HART	Ethernet
								Traditional									
Capacitance	Rosemount, Emerson Process Management			x	x		x			x			x		x	x	
	Endress+Hauser			x	x		x			x			x		x	x	
	Invensys/ Foxboro			x	x		x			x			x		x	x	
	ABB			x	x		x			x			x		x	x	
Piezoresistive	Ashcroft			x		x	x			x			x				
	Honeywell			x	x		x			x			x		x	x	
Strain Gauge	GP:50			x	x		x			x			x			x	
								Non-Traditional									
MEMS Piezoresistive	Honeywell			x	x		x			x			x		x	x	

3.4.1.5 UV Light Transmission

When wastewater is to be disinfected by Ultra-Violet (UV) radiation transmission, the amount of UV radiation transmitted through the wastewater is affected by the particulates and dissolved matter in the wastewater and results in the range of from 40% to 60% reduction of UV transmission per 1 cm of layer of water thickness. This means that 40% to 60% of the applied UV radiation is absorbed by a water layer having a thickness of as little as 1 cm (for comparison: pure drinking water has a transmission in the range of from about 90% to 98%, and the absorption losses are only from 2% to 10% per 1 cm of water layer thickness). The effect of the poor UV transmission is that only relatively thin layers of the wastewater around the UV radiation tube sleeve can be effectively disinfected. For wastewater layers located further away from the tube sleeve, the UV radiation time needs to be longer, and may require a reduced flow velocity past the UV disinfection equipment.

In addition, the effect of the aging process of UV tubes is that the radiation output power decreases over time even though the power consumption remains approximately the same. This requires regulating the power applied to the UV tubes in order to maintain constant UV radiation output. The UV transmission meter measures the radiation power actually being output by the UV tubes. This information can be used to regulate the amount of electrical power delivered to the UV tubes over time.

UV light transmission instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-5.

UV light transmission instrument specifications are provided in Appendix E.

Table 3-5. UV Light Intensity.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and /or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus	HART	Ethernet
Traditional																	
Optical	HF Scientific		x		x		x		x			x	x	x			
	Dr. Gröbel UV-Elektronik GmbH Ettlingen			x		x	x			x			x				
	Ziegler Electronic Devices GmbH			x		x	x			x			x	x			
Non-Traditional																	
Not Applicable																	

3.4.2 Analytical Measurement

Analytical instruments measure the chemistry and biology of the process. For the purposes of this research project, treatment process quality parameters measured in decentralized systems include the analytical instruments that measure ammonia-nitrogen, biochemical oxygen demand (BOD_5), chlorine residual, dissolved oxygen, nitrate-nitrogen, pH, phosphate, respirometry, and turbidity. These analytical instruments used for monitoring decentralized systems are listed in tabular format in Tables 3-6 to 3-18 and are categorized by traditional and non-traditional technologies with assessed cost of ownership/maintenance requirements and instrument monitoring capabilities.

Analytical instrument specifications are provided in Appendix F.

3.4.2.1 Ammonia-Nitrogen

Analytical instruments that measure ammonia-nitrogen include the traditional technologies of colorimetric, gas selective and ion-selective electrodes. Non-traditional instrument technologies use ultraviolet (UV) absorbance to measure ammonia-nitrogen. Ammonia nitrogen instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-6.

3.4.2.2 Biochemical Oxygen Demand (BOD_5)

Analytical instruments use a primary traditional technology of biological media to measure the biochemical oxygen demand (BOD_5). BOD_5 instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-7.

3.4.2.3 Chemical Oxygen Demand (COD)

COD analyzers utilize ultraviolet, high temperature catalytic oxidation and ozone oxidation technologies. COD instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-8.

3.4.2.4 Chlorine Residual

Total chlorine residual analyzers used for monitoring the disinfection process of decentralized wastewater treatment systems include the traditional technologies of amperometric and colorimetric and the non-traditional technologies of iodine gas sensor or gas phase sensing and ion-selective electrodes. Chlorine residual instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-9.

3.4.2.5 Dissolved Oxygen

Dissolved oxygen analyzers used for remote monitoring of aerated biological systems in decentralized systems utilize the traditional instrument technologies of galvanic and polarographic sensors and utilize the non-traditional instrument technology of optical fluorescence. Dissolved oxygen instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-10.

3.4.2.6 Nitrate-Nitrogen

Analytical instruments that measure nitrate-nitrogen include the traditional technologies of colorimetric and ion-selective electrodes. Non-traditional instrument technologies use advanced oxidation process using hydroxl radicals and ultraviolet (UV) absorbance to measure nitrate-nitrogen. Nitrate nitrogen instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-11.

3.4.2.7 pH

The primary traditional instrument technology for measuring pH utilizes the electrometric method. Non-traditional pH measurement would include ion-selective field effect transistor technology. pH instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-12.

3.4.2.8 Oxidation Reduction Potential (ORP)

ORP analyzers utilize electrometric technologies. ORP instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-13.

3.4.2.9 Conductivity

Conductivity analyzers utilize electrode technologies. Conductivity instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-14.

3.4.2.10 Alkalinity

Alkalinity analyzers utilize colorimetric, titrimetric and ion-selective electrode technologies. Alkalinity instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-15.

3.4.2.11 Phosphate

Phosphate analyzers use the traditional technology of photometric and the non-traditional technology of advanced oxidation process using hydroxyl radicals. Phosphate instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-16.

3.4.2.12 Respirometry (Oxygen Uptake Rate)

Respirometry measures the respiration rate of raw samples of wastewater by providing a continuous record of oxygen use. Respirometry instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-17.

3.4.2.13 Turbidity

Turbidity measurement is a regulatory reporting requirement in the United States. The traditional technology for turbidity measurement is optical using nephelometric, per the U.S. EPA Method 180.1. The nephelometric measurement can vary by light source (either white light or infrared) and/or by type of scatter (side-scatter at 90 degrees or transmissive light and receiver at 180 degrees apart). Turbidity instrument technology is described and summarized by principle of operation, cost of ownership and monitoring capabilities in Table 3-18.

Table 3-6. Ammonia-Nitrogen.
Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Colorimetric	Applikon	x				x		x	x		x	x	x	x			
	Endress+Hauser	x			x			x	x		x	x	x	x			
	Hach	x			x			x	x		x	x	x	x			
	Severn Trent	x				x		x	x		x	x	x	x			
	Systea Scientific	x			x			x	x		x	x	x	x			
	Tytronics	x			x			x	x		x	x	x	x			
	Waltron	x			x			x	x		x		x	x			
Gas Selective Sensor	Jumo		x			x		x		x		x	x	x	x		
	Hach																
	Wedgewood Analytical	x				x		x	x		x	x	x	x			
Ion-Selective Electrode (ISE)	Applikon	x				x		x	x		x	x	x	x			
	Hach																
	NEXTChem	x			x			x	x		x	x	x	x	x		
	Murtac	x				x		x	x		x	x	x	x			

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
	Severn Trent	x				x		x	x		x	x	x	x			
	Systea	x			x			x	x		x	x	x	x			
	Tyco Greenspan	x				x		x	x		x	x	x	x			
	Tytronics	x				x		x	x		x	x	x	x			
	Waltron	x				x		x	x		x	x	x	x			
	Wedgewood Analytical	x				x		x	x		x	x	x	x			
	WTW (AmmoLyt)	x				x		x		x		x	x	x	x		
	WTW (TresCon)	x			x			x	x		x	x	x	x			
Non-Traditional																	
UV	AWA			x		x		x	x		x	x	x	x			
	ChemScan	x				x		x	x		x	x	x	x			

Table 3-7. Biochemical Oxygen Demand (BOD_5).

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Biological media	Endress+Hauser			x		x		x	x		x		x				
	LAR		x			x		x	x		x		x	x			

Table 3-8. Chemical Oxygen Demand (COD).

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Instrument Monitoring Capabilities**												
					Accuracy		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
High temperature catalytic oxidation	Endress+Hauser	x			x			x	x		x		x				
Ozone oxidation	Endress+Hauser	x			x			x	x		x		x				
UV	AWA	x			x			x	x		x		x				

Table 3-9. Total Chlorine Residual.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Amperometeric	Hach, Sigma			x		x	x			x		x	x	x			
	Rosemount Analytical Emerson Process Mgmt		x			x		x	x		x	x	x			x	
	Severn Trent		x		x			x	x		x	x	x	x			
	Wallace & Tiernan		x		x			x	x		x	x	x				
Colorimetric	Hach		x			x		x	x		x	x	x				
Non-Traditional																	
Iodine Gas Sensor or Gas Phase Sensing	ATI		x		x		x		x		x	x	x				
Ion-Selective Electrode	Thermo Scientific			x		x		x		x		x	x				

Table 3-10. Dissolved Oxygen.
Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Instrument Monitoring Capabilities**												
					Accuracy		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Galvanic	ABB		x		x			x		x		x	x	x			
	IC Controls		x		x		x			x		x	x	x			
	Hach																
	Royce Technologies		x		x		x			x		x	x	x			
Polarographic	Hach, GLI		x		x		x			x		x	x	x	x	x	
	Endress + Hauser		x		x		x			x		x	x		x	x	
	Foxboro		x			x	x			x		x	x				
	WTW		x		x		x			x		x	x	x	x		
Non-Traditional																	
Optical Fluroescence	Insite IG			x	x		x			x		x	x	x			
	Hach			x	x		x			x		x	x	x	x	x	

Table 3-11. Nitrate-Nitrogen.
Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Instrument Monitoring Capabilities** — **Accuracy**		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Colorimetric	Applikon	x				x		x	x		x	x	x	x			
Ion-Selective Electrode (ISE)	Applikon	x				x		x	x		x	x	x	x			
	Bran + Luebbe	x				x		x	x		x	x	x	x			
	Murtac	x				x		x	x		x	x	x	x			
	Myratek	x				x		x	x		x	x	x	x			
	Severn Trent	x				x		x	x		x	x	x	x			
	Tytronics	x				x		x	x		x	x	x	x			
	WTW			x		x		x		x		x	x	x	x		
Non-Traditional																	
Advanced Oxidation Process Using Hydroxyl Radicals	BioTector	x				x		x	x		x	x	x	x	x		x
UV	AWA			x		x		x	x			x	x	x			

Traditional and Non-Traditional Instrument Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Instrument Monitoring Capabilities**												
					Accuracy		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	**Medium**	**Low**	**Accurate**	**Fairly Accurate**	**Reliable**	**Fairly Reliable**	**Pipe mount or wall mount**	**In-situ (in the process)**	**Auxiliary Equipment Required**	**Relay contacts**	**4-20 mA and/or 0-5 V DC**	**RS-232, RS-422, RS-485**	**Field-Bus or Profibus**	**HART**	**Ethernet**
	Bran + Luebbe			x		x		x		x		x	x				
	ChemScan	x			x		x		x		x	x	x	x			
	Endress + Hauser			x	x		x			x		x	x	x			
	Hach, Nitrataxsc			x	x		x			x		x	x	x	x		
	S::can Messtechnik GmbH			x		x	x			x		x	x	x	x		x
	Tytronics	x			x		x		x		x	x	x	x			
	Wedgewood Analytical			x		x		x		x		x	x	x			
	WTW			x		x		x		x		x	x	x			

Table 3-12. pH.
Traditional and Non-Traditional

Traditional and Non-Traditiona Instrument Technologies	**Manufacturers**	**Cost of ownership / Maintenance Requirements**			**Instrument Monitoring Capabilities**												
					Accuracy		**Reliability**		**Installation Requirements**			**Interface with SCADA Systems**					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Electrometric	ABB			x	x		x			x		x	x		x	x	
	ATI			x	x		x			x		x	x				
	Endress+Hauser			x	x		x			x		x	x		x	x	
	Foxboro			x	x		x			x		x	x			x	
	Hach, GLI			x	x		x			x		x	x	x	x	x	
	Honeywell			x	x		x			x		x	x		x		
	Krohne			x	x		x			x		x	x		x		
	Rosemount / Emerson			x	x		x			x		x	x		x	x	
	Royce Technologies /ITT			x	x		x			x		x	x	x			
Non-Traditional																	
Ion-sensitive field effect transistor	Endress+Hauser			x	x		x			x		x	x		x	x	

Table 3-13. Oxidation Reduction Potential (ORP)
Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Electrometric	Siemens Stranco			x		x	x		x	x		x	x				
Electrometric	ATI			x		x	x		x	x		x	x				
Electrometric	Endress+Hauser			x		x	x		x	x		x	x		x	x	x
Electrometric	Hach			x		x	x		x	x		x	x		x		
Electrometric	Royce Technologies			x		x	x		x	x		x	x				

Table 3-14. Conductivity.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Electrode	ATI			x	x		x		x	x		x	x				
Electrode	ATI			x	x		x		x	x		x	x				
Electrode	Hach			x	x		x		x	x		x	x		x		
Electrode	Endress + Hauser			x	x		x		x	x		x	x		x	x	x

Table 3-15. Alkalinity.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
titrimetric and colorimetric	Hach	x			x			x	x		x	x	x		x		

WERF

Table 3-16. Phosphate.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities: Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Photometric	ABB		x			x		x	x		x	x	x		x		x
	Endress + Hauser	x			x			x	x		x	x	x				
	Hach, 5000	x				x		x	x		x	x	x				
	Hach, Phosphax sc		x		x			x	x		x	x	x	x	x		
	Rosemount / Emerson Process	x			x			x	x		x	x	x	x			
Non-Traditional																	
Advanced Oxidation Process using Hydroxyl Radicals	BioTector	x			x			x	x		x	x	x	x	x		x

Table 3-17. Respirometry (oxygen uptake rate).

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Volume of Oxygen Used	Respirometry Plus, LLC		x		x			x	x		x		x				
	Challenge Technology		x			x		x	x		x						

Table 3-18. Turbidity.

Traditional and Non-Traditional

Traditional and Non-Traditional Instrument Technologies	Manufacturers	Cost of ownership / Maintenance Requirements			Instrument Monitoring Capabilities												
					Accuracy		Reliability		Installation Requirements			Interface with SCADA Systems					
		High	Medium	Low	Accurate	Fairly Accurate	Reliable	Fairly Reliable	Pipe mount or wall mount	In-situ (in the process)	Auxiliary Equipment Required	Relay contacts	4-20 mA and/or 0-5 V DC	RS-232, RS-422, RS-485	Field-Bus or Profibus	HART	Ethernet
Traditional																	
Optical (Nephelometric)	ATI			x		x	x		x		x	x	x				
	ChemTrac			x	x		x		x		x	x	x	x			x
	Endress + Hauser			x	x		x		x		x	x	x	x			
	Hach, 1720 Low range			x	x		x		x		x	x	x	x	x		
	Hach, GLI			x	x		x		x		x	x	x		x	x	
	Hach, Solitax			x	x		x			x		x	x	x	x		
	Hach, surface scatter			x		x	x		x		x	x	x		x		
	HF Scientific			x	x		x		x		x	x	x	x			

3.5 SCADA Capabilities

3.5.1 SCADA System

There are numerous options when it comes to implementing a SCADA system. The implementation of a SCADA system for the purpose of monitoring and controlling decentralized wastewater treatment facilities would involve the selection of software and equipment that meets the requirements of the system being monitored and controlled.

The SCADA system equipment must meet the input/output (I/O) requirements of the process and be able to communicate this information to a centralized location or to a mobile operations team when it is used at a decentralized wastewater treatment location. The system can be a simple paging system that alerts the operator to an abnormal condition, or it can be more complex providing an operator interface complete with graphics and real-time process parameters, historical data storage and reporting. Each plant or group of plants must assess the operational and regulatory requirements prior to selecting the SCADA equipment for their application.

The inputs and outputs can be separated into four main types, defined as digital input, digital output, analog input and analog output. The digital data type is known as Boolean data that is either True or False or electrical contacts as either open or closed. The analog data type has the ability to read in a real numeric value and set an output value. A common means to monitor analog data is through a voltage or current signal that is proportional to the data being monitored. An instrument with this capability sends data to a controller that is proportionally relative to the parameter it is measuring. These four signal types allow for complete monitoring and control of equipment and instrumentation at a facility. Additionally communication protocols can be used to integrate equipment with the controller, thus allowing larger quantities of data to be obtained from smart instruments, starters, or other field devices.

The purpose of the SCADA system is to monitor all input signals and control all output signals that are wired between the field devices and the SCADA equipment. In order to automate the control of a decentralized wastewater treatment facility the SCADA system would require inputs and outputs as well as programming that functions to control the process based on the feedback received from the plant instrumentation. The monitoring of all input signals can be done independently of any output signals. The input and output signals monitored will vary by location, depending on the type of decentralized wastewater treatment facility, treatment process employed, and field equipment, as well as the level of monitoring and control implemented.

3.5.2 Wireless Communication Methods

SCADA systems in a decentralized wastewater environment will employ various media for communications between sites and to operational staff. These communication links are required to relay the information between the facility and an operator, or between the decentralized facility and a centralized control location. The communications mechanism is a major factor in the overall reliability of the SCADA system.

One factor in determining the method of communications is the amount of data that is required to be transmitted and received over the communications network. The quantity of data as well as the acceptable communications delay will help determine which type of communications network to employ for the decentralized wastewater treatment system. Any process requirements that rely on the timely annunciation or display of alarming and data for operations must be defined prior to the selection of a communication methodology and considered when selecting a technology.

Due to the nature of the decentralized wastewater treatment systems which are typically located in more remote or rural areas, or are implemented for small subdivisions, this section will focus on three major methods of wireless communication for remote, decentralized facilities: Wireless Radio Networks, Cellular Systems and Satellite Communications. The assumption is that other communication media such as fibre optic cabling, managed networks, and localized networks are not available in these remote or rural locations. In addition a discussion on fibre optic, managed networks and localized networks is also provided for those areas where this infrastructure is available.

3.5.2.1 Radio Networks

Industrial Wireless Network communication over wireless radio networks employs a point-to-point or point-to-multipoint form of communication. Radio communication can be transmitted over the unlicensed Radio Frequency (RF) spectrum and includes the 900MHz, 2.4GHz, and 5.8 GHz bandwidths among others. Additionally, licensed frequencies can be purchased for exclusive use by a government entity[1]. The 4.9 GHz range has been set aside by the Federal Communications Commission (FCC) for Public Safety use and may be a suitable frequency range for use in municipal applications as it is less likely to become saturated due to its dedicated use. Annual fees are typically associated with a licensed frequency. An advantage to using a licensed frequency is that it reduces the likelihood of another user in the area using that same frequency thus minimizing the shared bandwidth. This helps to reduce communication problems caused by interference from other systems in close proximity.

Wireless radio networks can also be of different forms such as completely privately owned networks by the end user, whereby they are responsible for the upkeep and maintenance of the network to third party suppliers who provide the wireless connections to the end user and maintain the infrastructure.

Industrial wireless networks require an endpoint communications device at each end of the communication link. This could be one end point at each end for a total of two devices or one end point at each remote site and one end point at the remote monitoring facility, depending on the number of remote sites on the wireless radio network. Wireless Network communications speeds are based largely on the equipment and hardware selection. Serial communications over wireless networks can support traditional serial communications speeds from 300bps to 57.6kbps. Ethernet communications over wireless networks can support Ethernet speeds of 1Mbps to 270Mbps depending on the technology deployed across the network.

A radio network path study should be conducted to determine the antenna heights required for successful communications between the two endpoints of the communications link. There could be local limitations on antenna height (such as airplane traffic or aesthetic bylaws) that could limit the successful use of a wireless radio solution. This radio network path study would also determine the signal strength based on the radio transmission distance and path. Typically, line of sight between two locations will be required to support radio communications.

[1] FCC rules, Subpart Y in 47CFR part 90.

Industrial Wireless Networks are private networks that do not rely on the public switched network. This has its own benefits in that the operator of the network has direct control over its usage and security. The type of radio network equipment will dictate what security methods can be used. Some radio equipment follows the 802.11 wireless Ethernet protocols that offer Wireless Encryption Protocol (WEP) and MAC Address filtering; others use a wireless network ID as a unique code to limit access. If secure Ethernet is required and the radio network equipment does not offer security, Virtual Private Network (VPN) hardware should be placed in the network to provide the security. For serial data communications over the wireless network, the serial network is considered secured by obscurity. The serial network is secure based upon the use of specialized tools, knowledge and software. One factor in the selection of radio network equipment should include what level of wireless security is required on the radio network.

3.5.2.2 Cellular Systems

Cellular communications systems employ the use of cellular telephony mechanisms. There are two major forms of cellular communications deployed across North America today and they are Code Division Multiple Access (CDMA) and Global System for Mobility (GSM)[2]. Both of these network implementations allow for both voice and data transmissions over the cellular network. With respect to SCADA communications and decentralized wastewater facilities, this TM will focus on data communications.

Cellular data connections can support communications speeds of up to 400kbps on the latest version of North America's leading 3G digital implementation[3]. With data compression, this speed can reach a peak of 1.8Mbps. This is an estimate of the typical transmit speed from the decentralized facility to the remote monitoring facility.

The selection of a cellular network data provider should be made based on system availability in the location of the decentralized wastewater treatment facility. This means contacting the local cellular providers to enquire as to available coverage. Figure 3-1 illustrates cellular network coverage for the United States from a large, national U.S. cellular provider. Similar coverage maps are available for Canada and other parts of the world.

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[2] IEEE Standards Glossary: www.ieee.org/web/education/standards.glassary.html

[3] Based on Telus Mobility wireless 3G rev A standard.

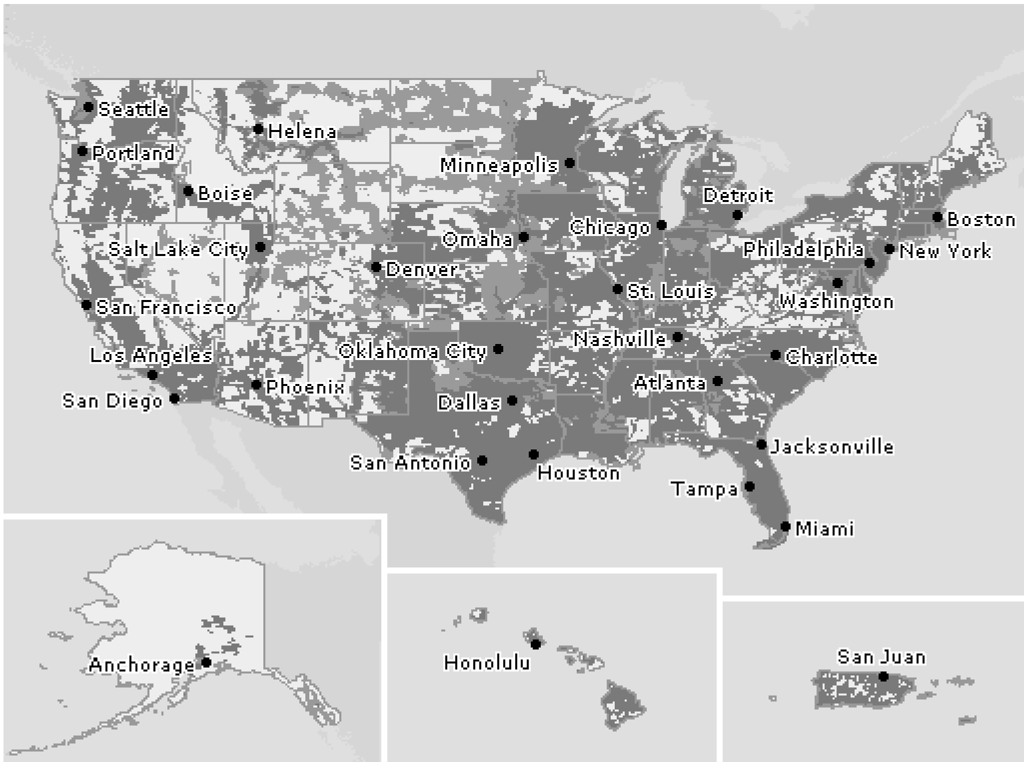

Figure 3-1. Cellular Data – Coverage Map.

Regardless of carrier, the carrier should be able to provide a cellular data modem that will be used to gain access to the cellular network. The operator of a centralized monitoring facility can either be on the same cellular network or any other publicly switched telephone network including another cellular provider.

There are two methods of connecting a decentralized wastewater treatment facility with a centralized monitoring facility over cellular, either by direct dial or by accessing the public internet. In the case of direct dial, there is a direct one-to-one link formed between the two sites with one site initiating the call and the other site answering the call. Direct dial can also be used for annunciation of alarms through an alarm dialer or notification via a paging system. In the case of the public internet, a VPN must be used for both security and routing purposes as these sites both access the public internet to complete the connection.

The use of VPN to secure the data transmission between the decentralized wastewater treatment facility and the centralized monitoring site will adversely affect data throughput due to VPN overhead. The direct dial connection is only suitable for connections with a one-to-one relationship.

3.5.2.3 Satellite Communications

Satellite communications can be employed as the means of communication where radio networks or cellular coverage are not available. The satellite coverage map is shown in Figure 3-2. Traditional data communications over satellite will result in a transfer rate between approximately 2.4kbps and 64kbps. With data compression and acceleration, the data transfer rate can approach 512kbps.

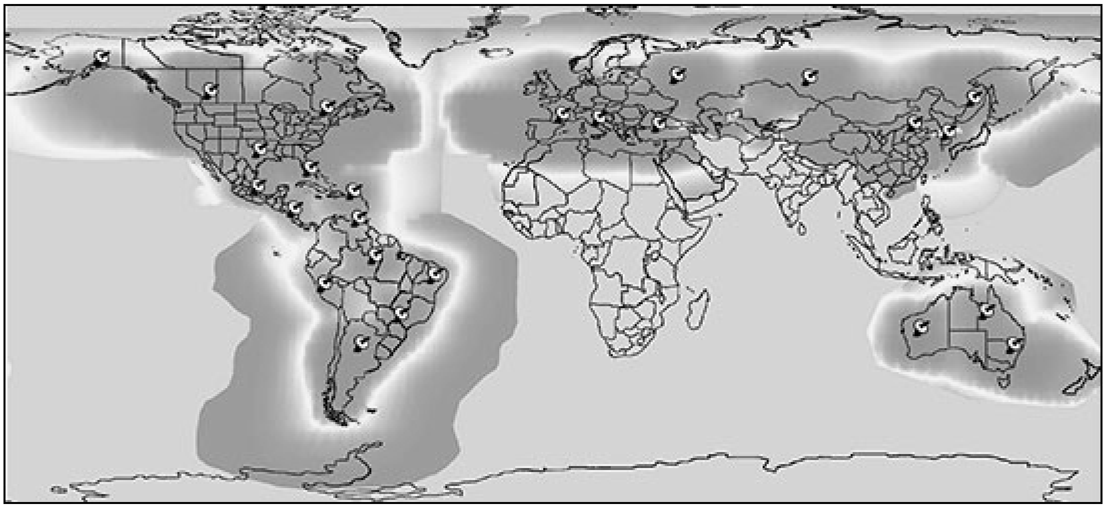

Figure 3-2. Satellite Data – Coverage Map.

Satellite communications provides connectivity to the decentralized wastewater treatment facility in a similar manner to cellular communications. The Satellite service provider will provide the required equipment to get onto the network. Network access can be through direct dial or by accessing the public internet. In the case of direct dial, there is a direct one-to-one link formed between the two sites with one site initiating the call and the other site answering the call. Direct dial can also be used for annunciation of alarms through an alarm dialer or notification via a paging system. In the case of the public internet a VPN must be used for both security and routing purposes as these sites both access the public internet to complete the connection.

The use of VPN to secure the data transmission between the decentralized wastewater treatment facility and the centralized monitoring site will adversely affect data throughput due to VPN overhead. The direct dial connection is only suitable for connections with a one-to-one relationship.

3.5.3 Wired Communications Methods

In the event that the decentralized wastewater treatment facility is located in a major urban centre, the likelihood of an available more reliable, faster communications mechanism (such as broadband internet) over wired communications is quite high and could be considered as an alternative. Wire line communication involves various types of connections from leased line to cable, fibre optic, and telephone based Broadband connections.

3.5.3.1 Leased Line Modem

Leased line connections provide a direct connection between two locations. The local telephone operating company provides the hardware and the switching to ensure that the link between the two sites is made. The use of special hardware modems is required and these modems must support the type of leased line installed. Once the modems are installed and can go on-line with each other to form a communications link, information can then be transmitted across the communication link. Leased line modem connections can support communication data rates of up to 56kbps although this is dependent on the quality of the leased line. A lower quality line will result in a decreased data rate.

3.5.3.2 Dialup Modems

Dialup modems are the traditional type of telephone system communications. These types of modem can call either another modem or call an internet service provider. The modem to modem call forms a direct link between two SCADA devices while the modem to internet link will require another internet connection to get an additional SCADA device onto the network. When using the public internet for SCADA communications, a VPN must be used for routing and security. Dialup modems can support data rates of up to 56kbps; however, this value can vary based on telephone line noise.

Dialup modems are also used for dialer alarm annunciation systems. These alarm dialers place a voice call to a notification device like a cellular telephone or pager. In order for an alarm dialer to place this call and not affect the dialup SCADA communications, a second dialup line should be used for alarming.

3.5.3.3 DSL/Broadband

Broadband Internet is available from both telephone and cable TV providers. The mechanism for communications varies however the protocols and transport medium are similar and for the purpose of this report can be considered simply as High-speed Internet. High-speed Internet connections involve transporting data over the public internet and as such, a VPN must be used for routing and security. A second internet connection is required at the centralized monitoring facility.

High-speed Internet connection speeds vary based on the distance between the SCADA location and the internet service provider central office. Typical speeds are on the order of 600kbps for transmission from the decentralized facility to the remote monitoring site.

3.5.3.4 Fiber Optic

Fiber Optic cable networks are becoming readily available in major centres and provide a dedicated network connection to the public internet with high level of data throughput and capacity. Typical Fiber Optic network access is based on usage (capacity) and the cost of the access increases as capacity increases. Bandwidth is based on data throughput that you subscribe for and your bandwidth is capped at that value. Typically the higher the bandwidth implemented, the higher the cost to the user. Current providers typically offer both public and private solutions where the fibre optic network is either shared with other users or dedicated to a specific user. This solution can also be implemented by the owner to create a dedicated private network.

As with any communications over public internet, a VPN must be used for routing and security. And a second internet connection is required at the centralized monitoring facility.

3.5.4 Case Studies

A summary of the SCADA capabilities for each case study that was presented in Section 3.2.2 is shown in Table 3-19.

Table 3-19. Case Study – SCADA System Summary.

Location	SCADA Equipment	Communications
Charles City County, Virginia	Hach SC1000	Dialup modem
Warren, Vermont	Orenco Vericomm	Internet and wireless radio
Seven Cluster Treatment Plants, Michigan	Orenco Systems	Telephone land lines
Piperton, Tennessee	Aquapoint telemetry with Allen-Bradley PLCs	Air2App cellular modem
Charleston, South Carolina	Allen-Bradley	MDS iNet radio network
Mobile County and Fulton, Alabama	Orenco T-Com	Telephone land lines
Miller Catfish Farm, Alabama	ITT Royce Technologies	Radio and cellphone
Various Golf courses in Ontario	Control Microsystems	Telephone land lines
Water and Sewer Systems, District of North Cowichan, British Columbia	Allen-Bradley	Radio and VPN
Cowichan Valley Regional District (CVRD), British Columbia	Control Microsystems	Dialup Modem
Lift Stations, Langford, British Columbia	In development	Radio and High-speed internet
Walpole, Western Australia	Schneider Electric & Serck Controls	DSL

As shown in the case study examples, various solutions both for the SCADA system solution and the communication network can be effectively implemented. Based on the information received none of the case study respondents identified any issues with their current system.

3.6 Research Needs

3.6.1 Technology and Technology Transfer

3.6.1.1 Instrumentation

Critical to the success of real-time monitoring of decentralized wastewater systems is the reliability of sensors and the required frequency of cleaning and calibration. Based on the literature study and case study review, there are limited data on these aspects for decentralized wastewater systems. It is important to note that sensors that are currently being used at centralized plants can also be used at decentralized plants, and therefore data for these sensors are transferable.

The Identification of Sensor Capabilities, the results of which are presented in Section 3.3, reviewed the availability and characteristics of real-time sensing equipment for on-line monitoring of the parameters of concern in decentralized wastewater systems. This review provided an assessment of real-time sensing equipment maintenance requirements through a cost of ownership analysis and demonstrated instrument monitoring capabilities by evaluating and reporting accuracy, reliability, installation requirements and determining the ability of these instruments to interface with SCADA systems. ITA has also carried out previous sensor studies that provide information on sensor capabilities for a range of wastewater monitoring parameters (www.instrument.org). The ITA database is regularly updated as new instruments become commercially available and older instruments become obsolete. Therefore, owners/operators are encouraged to access the ITA's Instrument Specification Database to obtain updated information on the manufacturers/suppliers of the identified technologies.

Although the Identification of Sensor Capabilities part of this study provides a good basis for selecting sensors for real-time monitoring of decentralized facilities, it is likely that uncertainties regarding reproducibility and reliability of monitoring and perceived problems of excessive maintenance costs as well as complicated and time-consuming calibration procedures exist within the decentralized wastewater industry. Field testing of sensors for real-time monitoring would provide data on sensors that is directly relevant to decentralized facilities, which could change perceptions of these technologies. Sensors to be tested in the field should include the parameters presented in Table 3-20.

Table 3-20. Summary of Parameters for Monitoring of Decentralized Wastewater Treatment Plants.

Physical Measurement	Analytical Measurement
Flow	Alkalinity
Level	Ammonia-nitrogen
Power	BOD_5
Pressure	Chlorine Residual
Pump Run Status	COD
UV Light Intensity	Conductivity
	DO
	Nitrate-Nitrogen
	ORP
	pH
	Phosphate
	Respirometry (oxygen uptake rate)
	Turbidity

Sensors currently available for some of these parameters are considered to be well established and would be less of a priority for field testing. Physical measurements typically use sensors that are robust and require little maintenance and would therefore require less testing compared to other parameters. Table 3-21 presents a proposed priority list of parameters for field testing of sensors.

Priority 1 includes parameters that can be used as an early indicator of process conditions, and currently have limited use in decentralized wastewater treatment systems. They also have a relatively proven sensor technology in centralized treatment plants and are considered to have a reasonable cost of ownership. Turbidity is included in this list as it can be correlated with BOD_5 and TSS data for a plant and use of turbidity sensors in large decentralized facilities and drinking water plants is well established.

Priority 2 parameters are those more likely to be specific to permit requirements and those that may be required to monitor plants with a variable influent flow or load. Priority 3 parameters are those considered to be reasonably well established in decentralized wastewater treatment systems.

Table 3-21. Proposed Priority List of Parameters for Field Testing.

Priority	Measurement	Rationale
1	Ammonia-nitrogen DO Nitrate-nitrogen Turbidity	Good as early indicator of process conditions. May be used for monitoring to meet regulatory requirements (ammonia-nitrogen, DO) or be used as an equivalent (turbidity for TSS and/or BOD_5 monitoring). Have sensors that are considered to be robust and well established in centralized wastewater treatment and/or water treatment plants.
2	Alkalinity BOD_5 Chlorine Residual COD Conductivity ORP pH Phosphate Respirometry	May be used for monitoring to meet regulatory requirements (BOD_5, pH, phosphate). May be used to monitor variability in influent flow or load. Typically sensors are considered to be less robust than for Priority 1 parameters.
3	Flow Level Power Pressure Pump Run Status UV Light Intensity	Reasonably well established in decentralized wastewater treatment systems. Have sensors that are considered to be robust.

A significant issue for on-line monitoring of remote plants is keeping on-line sensors clean and calibrated over long periods of time to minimize required site visits. Research and development of methods to minimize sensor maintenance and calibration in the field may be required to improve the reliability and reduce the maintenance costs of these sensors in decentralized wastewater facilities where operational and maintenance attention is infrequent. The issue of O&M requirements for sensors could be addressed by increasing the length of time between cleaning and calibration through sensor improvements and also the option of cleaning and calibration at a central laboratory. In addition, sensors that use auto-cleaning and auto-calibration would be very useful for decentralized facilities and further work could be carried out on this if field testing indicates an issue with existing technologies. These types of sensors would require a self-diagnosing system to validate that they are operating correctly. Information on what sensor types require further work to minimize maintenance and calibration frequency would be determined from field studies. Self-powered sensors (e.g., solar-powered) are also worth further investigation for monitoring at decentralized wastewater treatment facilities.

Another approach to improving acceptance and use of real-time monitoring equipment by decentralized wastewater facilities is to establish standard testing protocols for existing and new sensors. Such protocols could aid in the development of sensors with improved maintenance and calibration requirements. Standard testing protocols should be developed collaboratively with decentralized facility owners and operators, sensor manufacturers and regulating authorities.

3.6.1.2 SCADA

The review of SCADA capabilities indicates that there are three main criteria that are likely to increase the acceptance of a telemetry or SCADA system for remote monitoring of decentralized wastewater treatment systems, namely good access to permanently stored data, using software that is commonly available, and affordability of the system.

Data should be stored and made available in a format that is reliable and easy to use. Permanent or long-term electronic storage is preferred to allow historical data to be retrieved for use in reports, for recording alarm conditions, and for monitoring trends and the long term performance of the treatment system. There are no data on best practices for data storage for the decentralized wastewater industry, which is likely to have different requirements to large-scale wastewater treatment plants as there will typically be less data and different reporting requirements.

The software for any telemetry or SCADA system should be commonly available and non-proprietary to allow access from remote computers and/or the web. This will reduce the need to customise software for site specific conditions (which would increase the cost of the system), and also reduces the need for users to upgrade software programs on their computers (as proprietary software has more chance of becoming obsolete quickly). Open architecture would also allow single sites to use multiple vendor platforms. The use of vendor-supplied control systems and integration would also make the use of a telemetry or SCADA system more attractive to decentralized facility owners and/or operators. There are no data on best practices for the types and applications for open architecture SCADA software for the decentralized wastewater industry, which may have different requirements to large-scale wastewater treatment plants. In addition, the use of a mesh network concept should be investigated as a means to reduce the cost of control wiring and implementation costs, as this system uses multiple sensors communicating wirelessly with each other and only one of the sensors wired to SCADA. A review of alternatives to identify the best practice for SCADA protocol standards and networking for decentralized wastewater treatment plants is therefore recommended.

The issue of security regarding SCADA systems for large-scale wastewater facilities is currently an important topic, as well as other industries such as power generation and oil production. A study of this issue for the decentralized wastewater industry is recommended to determine its importance and to identify what, if any, best practice measures are required to enhance SCADA security for the decentralized wastewater industry.

3.6.2 Costs

The main issue regarding the use of real-time monitoring of decentralized wastewater treatment plants is likely to be cost and benefit. The capital costs of installing sensors and data transfer/storage, operation and maintenance (O&M) costs associated with the monitoring technology, and monthly costs associated with data transfer and servicing must produce a measurable benefit to the owner/operator in terms of reduced labor, power and chemical costs, and improved system reliability, robustness or performance. There are limited data on these costs and benefits for decentralized wastewater systems. Further work is necessary to determine the actual cost-benefit of different types of on-line monitoring systems at decentralized wastewater systems.

A thorough examination of cost of ownership would necessitate a life-cycle cost analysis. A life cycle cost analysis will specifically track the costs associated with installing, operating, and maintaining instruments and SCADA systems. The life cycle cost analysis can provide the decentralized wastewater system end-user with information that can be used to develop realistic operating budgets, and to justify procurement and installation of a real-time monitoring system.

Benefits must be documented and should include both tangible cost reductions in energy costs, chemical costs or labor costs as well as more intangible benefits such as improved reliability or robustness, and improved system performance.

Further work in this area could be carried out as part of a field-testing study to show that decentralized wastewater systems can be cost-effectively managed remotely.

3.6.3 Education and Awareness

There is the perception that sensors represent the weakest link for implementing on-line monitoring of decentralized plants is largely unfounded. The performance and reliability of many sensors have improved remarkably over the last decade. Similar sensor technologies have been successfully used in large-scale plants using many different monitoring and control strategies. Information provided from this study should be used to educate decentralized wastewater facility owners, operators and regulating authorities about the benefits of using real-time monitoring; however, there are limited data on existing decentralized facilities using these systems.

Testing and field studies to demonstrate economically sound and reliable on-line monitoring systems for decentralized wastewater facilities should gain support and interest for real-time monitoring in the industry. The information from field studies should be made available to regulating authorities, vendors, owners and operators of decentralized wastewater systems. This could be provided through papers in industry journals and/or presentations at relevant workshops and conferences.

Education and training of O&M staff for decentralized facilities is also important to ensure successful implementation of real-time monitoring. This will be needed to minimize the occurrence of inappropriate selection, installation and/or maintenance of on-line sensor equipment. Information provided in this study can be used as a basis for sensor selection training, but further work is required to review and identify the best methods for training on sensor installation and maintenance. The information provided on sensors would need to be updated regularly to ensure owners and operators have the most up to date information to help with selection.

CHAPTER 4.0

DISCUSSION AND RECOMMENDATIONS

4.1 Literature and Technical Review

4.1.1 Remote Monitoring

The key to providing good quality, affordable wastewater treatment in small communities is not the treatment technologies used, but how they are managed. Decentralized wastewater treatment plants rarely have full-time operators and plants may eventually fail due to neglect or lack of expertise. Failure of a treatment system can lead to public health risks, adverse environmental impacts and higher costs of correcting problems when left unchecked for periods of time.

Many decentralized wastewater treatment plants have a local audible/visual alarm system that notifies the owner/operator of a situation requiring immediate attention (e.g., pump failure). This system only allows owners/operators to respond to a system failure, rather than allowing proactive changes to plant operation to prevent the failure taking place. In addition, there is also the potential for an alarm to be missed or even ignored.

Remote monitoring provides opportunities for the owner to contract out the operation and maintenance of the facility to an accountable professional. Remote monitoring and interactive databases can alert operators of an alarm condition, operational parameters can be routinely checked and altered, if SCADA is used, and maintenance requirements can be effectively met.

On-line monitoring of real-time status of a plant allows issues to be detected before it becomes an event, reducing the risk of system or performance failure. Alternatives to real-time monitoring include sending data packets once or more a day, and also the relay of a monitored alarm/event to an independent service provider. The latter option does allow for better management of failure situations, but does not allow for remote monitoring of water quality or process information.

For plant operators, the use of remote monitoring allows site visits to be planned around the requirements for individual treatment sites, which can significantly reduce time. The use of a SCADA system with remote access would also allow operators to monitor and change setpoints and control equipment, allowing for proactive management of treatment systems. However, such systems would only be acceptable to operators if there is an overall time saving as a result of remote monitoring (i.e., the system does not require excessive maintenance and calibration), and if operators have confidence in the information received from the sensor equipment.

4.1.2 On-line Monitoring Parameters

Many of the decentralized systems in place and being installed today are advanced treatment systems, including sand filters, textile filters and package biological treatment processes. These types of treatment systems are more operationally complex than typical septic systems and, as a result, may require more monitoring and proactive maintenance to ensure effective treatment.

All of the systems reviewed have monitoring of mechanical and electrical parameters, such as pump operation and level sensors. Based on discussions with owners/operators that only monitor mechanical parameters, this type of monitoring was considered adequate for successful operation and management of their decentralized wastewater treatment plants.

A number of the facilities are using water quality and process monitoring parameters, such as DO, pH, flow and UV light intensity. With the exception of Charles City County, Virginia, facilities using water quality and process monitoring parameters have indicated that this type of monitoring is useful for remote management and is used to determine when non-scheduled operator visits are required for maintenance or to make process changes. It also allows operators of multiple facilities to determine where their time would best be spent that day. The two decentralized treatment plants in Charles City County have routine daily operator site visits and, therefore, are not considered to be a true remote operation. This is likely the reason that the facility operator for these two plants does not consider remote monitoring of water quality and process parameters to be necessary.

Critical to the success of on-line monitoring of decentralized systems is the reliability of sensors, the required frequency of cleaning and calibration, and their affordability. Based on the literature study and case study review, there are limited data on these aspects for decentralized systems, although it is anticipated that many of the sensors are currently being used at centralized plants and therefore these data are transferable. For the systems reviewed, the majority of facilities had no issues with the sensors used.

4.1.3 Monitoring Data Transfer and Management

The systems reviewed used a telemetry-based alarm warning system, a web-based telemetry remote monitoring system or SCADA used for remote monitoring. The telemetry systems reviewed either had real-time monitoring or a system that transferred packets of data once or more a day. A telemetry-based alarm warning system can only provide an alarm when an equipment or system failure occurs, telemetry remote monitoring allows the user to see what is happening at the plant as data is displayed, and SCADA allows the user to interact with the system to adjust setpoints and control equipment.

Web-based telemetry and SCADA monitoring systems are good risk management tools for decentralized wastewater treatment plants. However, costs are expected to be relatively higher than for centralized facilities on a per capita basis. In addition, there are limited SCADA specialists with experience of small, decentralized wastewater facilities, which could result in some systems having monitoring put in place that is unnecessary for effective operation.

A telemetry-based system providing an alarm to service providers has a lower cost than real-time monitoring of water quality and process parameters, although this level of monitoring is useful in the respect that it will identify a problem with a plant (typically a mechanical problem), enabling it to be fixed immediately when the impact may be less severe. However, this is unlikely to be suitable for all decentralized facilities, particularly those receiving seasonally variable flows and loads and plants receiving industrial wastewater. This is because closer monitoring of water quality and process changes is more likely to be needed to prevent upset conditions. In addition, telemetry or SCADA monitoring systems are more useful for plants that are one of many managed by a single service provider, as it enables an operator to view data from multiple plants on a daily basis, which helps an operator with scheduling site visits.

Available information indicates that there are three main criteria that are likely to increase the acceptance of a telemetry system for remote monitoring of decentralized wastewater treatment systems, namely good access to permanently stored data, using software that is commonly available, and affordability of the system (including maintenance costs to ensure reliability).

4.2 Monitoring Needs

Because of the increasing number and complexity of decentralized wastewater treatment systems, real-time monitoring using sensors may become a key component of treatment process management. Frequent sampling of decentralized and small-scale, onsite wastewater treatment systems may be too resource intensive and expensive to be practical. In addition, statistics such as median and average values may not be meaningful where samples are collected very infrequently.

As the treatment systems used and compliance requirements for decentralized plants will vary, there is no “one size fits all” for on-line monitoring. Each facility will have different on-line sensors needs to meet a monitoring program objective depending on the type of treatment system used, the receiving water environment, and regulatory or legal requirements, such as permit requirements. In addition, cost effectiveness and reliability are also important factors when determining what on-line sensors are used for on-line monitoring.

For decentralized wastewater facilities, the basic parameters to be monitored should include equipment status, liquid level, pressure and flow. These parameters are those considered to be critical indicators of the operational status of a plant. For some plants, monitoring additional water quality and process parameters may be a good management tool. For aerated biological treatment systems, on-line DO sensors will allow aeration to be remotely monitored and can be used to control blower operation for energy savings and process optimization. In facilities that have effluent filters, the filter headloss should be monitored using pressure sensors to assess filter operation and identify a filter blockage situation or to activate backwashes automatically. Any facilities using disinfection should monitor either UV light intensity or chlorine levels, depending on the disinfection method used.

Effluent quality parameters that could be monitored using on-line sensors include turbidity (as an indicator of high TSS concentrations and bacterial density), BOD_5, ammonia-nitrogen, nitrate-nitrogen and phosphorus. The requirement for these sensors is dependent on the discharge permit requirements and variability of influent loading to the treatment plant.

Based on the above discussion, traditional and non-traditional monitoring parameters that should be monitored include the following:

- Alkalinity
- Ammonia-nitrogen
- BOD_5
- COD
- Conductivity

- DO
- Flow
- Liquid level
- Nitrate nitrogen
- ORP
- Oxygen uptake rate or respirometry
- pH
- Phosphorus
- Power
- Pressure.
- Pump run status
- Turbidity.
- Total chlorine
- UV light intensity

4.3 Sensor Capabilities

A total of 239 on-line instruments were identified for possible application in decentralized wastewater treatment systems. The majority of these real-time sensing equipment technologies provide the capability to interface with SCADA systems for treatment system monitoring and control. The following outlines the number of instruments identified for physical or analytical measurement.

Physical Measurement

- Level (85)
- Flow (42)
- Pressure (8)
- Pump Run Status
- UV Light Intensity (3)

Analytical Measurement

- Ammonia-Nitrogen (22)
- BOD_5 (2)
- COD (3)
- Chlorine Residual (8)
- Dissolved Oxygen (10)
- Nitrate-Nitrogen (19)
- pH (10)
- ORP (5)
- Conductivity (4)
- Alkalinity (2)
- Phosphate (6)
- Respirometry, oxygen uptake rate (2)
- Turbidity (8)

Selection matrices summarize the cost of ownership and instrument monitoring capabilities for each instrument, based on the assumption of proper installation and maintenance performance in accordance with manufacturer instructions.

4.4 SCADA Capabilities

The performance of a SCADA system is based on its ability to actively control and monitor the process for which it is responsible. In a decentralized wastewater treatment environment this performance will often involve one or more communications mechanisms in order to get the information from the decentralized location to a centralized monitoring facility. One main function of a successful SCADA system is its ability to remotely monitor and alert operations staff in the event of an alarm. The benefit of a SCADA system is the data that is made available for monitoring can be collected and stored for historical analysis, trending, and reporting.

4.4.1 SCADA Control Systems

The SCADA equipment can range from highly scalable programmable logic controllers (PLC) from suppliers such as Allen-Bradley and GE-Fanuc, remote terminal units (RTU) from suppliers such as Bristol Babcock and Control Microsystems, distributed control systems (DCS) from suppliers such as ABB and Emerson, proprietary solutions from suppliers like Orenco, and also include alarming and reporting systems from suppliers like RACO Manufacturing and Engineering Co., Inc.

In addition to the SCADA equipment, the Human Machine Interface (HMI) often requires software suites from vendors such as GE-Fanuc, Wonderware, Rockwell, or the DCS supplier. These software suites can provide various features from basic control functionality through to historical data and trending functions.

The SCADA control system needs to be one that meets the operational and regulatory needs while achieving the necessary process automation and control. From the case study examples, it is evident that various types of SCADA systems are employed for the decentralized wastewater treatment facilities included in the review. There is no single solution as each site is unique and requires its own unique SCADA system solution.

It is advisable that the operator of a SCADA system standardize on a supplier for its SCADA control system as this will ensure compatibility of the equipment and enable data consolidation and communications without unnecessary requirements for translations and data manipulation.

4.4.2 Communication

Communications is a critical component in transferring the data from the decentralized wastewater treatment location to a centralized monitoring site. The communications mechanism can vary from owner operated wireless radio systems to the use of wire line communications over the public internet.

Communications must be secure and reliable in order to ensure a successful transmission of data between the decentralized site and the monitoring facility. The communication link is required to receive alarm notifications from the decentralized location and to minimize data loss when transferring data for historical storage from the decentralized location.

The selection of a communication solution will be based on what technologies are available at the decentralized wastewater treatment facility which will be unique to each location. SCADA equipment must be selected that is capable of utilizing the available communication alternatives at a facility.

The demands of the SCADA system on the communications network are dependent on the type of SCADA system that is deployed. There is less communications network traffic if the SCADA system is for alarm and monitoring only. If the SCADA system includes control of equipment and significant data collection then there is more communications network traffic. Another factor in the throughput of a communications network is the number of remote sites placed on this network. Typically, the more remote sites on the SCADA system, the higher the bandwidth required to support successful SCADA communications. In order to implement a successful communication solution, the type of communications mechanism should be factored into the SCADA system design.

Table 4-1 contains a comparison of the communications methods discussed in Section 3.5 of this report. This table helps to illustrate the communications options available at the decentralized wastewater treatment facility and an approximate typical bandwidth that can be expected for each method.

Table 4-1. Comparison of Communications Methods.

Communications Method	Bandwidth (maximum/typical)	Communications Mechanism
Leased Line	56kbps/9.6kbps	Copper Twisted Pair (2 wire or 4 wire)
Dial Up Modem	56kbps/48kbps	Copper Twisted Pair (2 wire)
DSL	7Mbps/2.5Mbps	Copper Twisted Pair or Co-axial
Fibre Optic	10Gbps/7Mbps	Single mode or Multimode Fibre switched network
Wireless Radio	5Mbps/19.2kbps	Private radio equipment, licensed or unlicensed frequencies
Cellular	21Mbps/400kbps	3G rev A implementation on GSM or CDMA architecture
Satellite	512kbps/64kbps	Open air Satellite Transceiver

4.4.3 Remote Monitoring and Alarming

A fundamental feature of a SCADA system is the ability to supervise and control a process from a Human Machine Interface. This HMI can be co-located at a decentralized wastewater treatment facility or located at a separate centralized monitoring facility. The SCADA system must be capable of remotely monitoring the required information so that it is made available to the operator of the facility.

In the decentralized wastewater treatment system, the SCADA system must be capable of alerting the operator of an alarm condition. If there is a critical alarm present in the SCADA system, the operator of the system must be able to receive this alarm. This requires either a 24 hour staffed SCADA system or an on-call operator who can receive alarm annunciation through an alarm dialer or paging system.

4.4.4 Data Collection and Storage

The data that are being displayed on the HMI for the SCADA system can be stored on an electronic storage device such as a computer hard drive for historical records. The benefit of capturing this data is that it can be used for statistical analysis and trending, and also for reporting purposes.

For the decentralized wastewater treatment facility, there could be regulations in place for the data collection and storage requirements. These regulations could stipulate the frequency at which data must be measured, recorded, collected and stored along with retention periods that must be followed. Consult the local regulating authority for the data collection and storage requirements prior to implementing a SCADA system. If the data storage is regulated, it is advisable to use a storage media that offers a level of redundancy and a maintenance schedule should be implemented to ensure data availability.

There are many data formats for storing SCADA system data. Some SCADA systems have proprietary data formats while others adopt a more open format. The SCADA system must be able to store historical data and allow for archiving and retrieval of this data for reporting and tending purposes.

The use of an historical record management system will facilitate the short and long term storage and retrieval of collected data. There are many historical systems available; most of these rely on the use of database software such as MS SQL Server. At a minimum, the most recent 365 days worth of data should be available as current data and an archive of the past eight (8) years should be available offline.

4.4.5 Historical Data Analysis and Trending

Historical data analysis and trending are important functions that can be implemented with a SCADA system. Any data that is stored on a SCADA system is data for events that occurred in the past and as such is considered historical data which can be trended and analyzed for plant performance.

The SCADA system should be developed so as to be able to display the historical data in either a report or a chart format and allow for trend analysis. The SCADA data becomes a powerful tool for the decentralized wastewater treatment system operator to help monitor the system performance, respond to alarm conditions, and improve process control through optimization based on historical data.

There are numerous reporting tools that can be added to any SCADA system. The main requirement of any reporting tool is that is capable of connecting to the historical data source(s) from the SCADA system. Once the reporting tool of the SCADA system has been implemented standard reports can be used or custom reports created to suit the end user.

4.4.6 Cost Factors

There are many factors in determining the cost of a SCADA System for the decentralized wastewater treatment facility. The type of SCADA control system employed, the method of communications and the volume of information being communicated, the amount of remote control and alarm monitoring required, type and size of the data collection and storage required and the duration of the historical and archival mechanisms all have a direct affect on the overall cost of the implemented systems.

In order to establish a cost of the SCADA system, one must determine the SCADA control system hardware requirements. This involves detailed I/O requirements to determine the actual hardware to be used. One must then determine the communications mechanism to be used and establish the purchase price of equipment and the ongoing operating cost of this communications mechanism. The next factor in cost determination is the remote control and alarming systems. These are typically software prices for the HMI packages and hardware prices for the alarm notification devices. These prices will depend on the number of data points to be monitored and controlled. Depending on the amount of data being collected, certain hardware will be required. This is typically a SCADA workstation or server based computer equipment with associated hard drive space for storage, along with the software licensing to deal with the quantity of data. The last item to factor into the cost of a SCADA system is the historical data. Again this is typically a SCADA workstation or server based computer equipment with enough hard drive space and an offsite storage mechanism along with software packages designed to hold the data in a method to allow for retrieval and display for analysis and trending.

Further to the cost of SCADA system for the decentralized wastewater treatment facility are the engineering, design and implementation costs along with the maintenance and support agreements required for some of the software licensing packages from various vendors. All of these costs will vary depending on the software and hardware being utilized.

For SCADA system implementations, the cost can be quite variable depending on the size of the system to be implemented and the level of field work that is required to install additional instrumentation, add monitoring and control functionality to starters, and implement communication links to a centralized location. For a small monitoring system with limited control, designed to provide process feedback and alarming from a decentralized plant to a centralized location a system could be implemented for under $30,000. Such a system would consist of a local control panel with approximately 16 to 24 I/O points, a local operator interface with historical data collection capabilities, and a remote workstation complete with historical data collection and graphical interface. Additional engineering costs and the implementation of a communication link would be required. The communication links identified within this report if provided by a third party provider can range in monthly costs from approximately $20 to $600[4] per month per site depending on the type of link to be used. For a wireless installation costs can be in the range of $2,500 to $25,000 per site depending on the antenna, radio, and tower required.

4.4.7 Recommendations

The SCADA system for the decentralized wastewater treatment facility should be designed to meet the regulations that are in place for the local operating authority. It is advisable that the SCADA system implementation allow for future expansion. Typically this would involve 20% spare capacity on all I/O, additional communications bandwidth, and 275% of additional storage. This would enable easier expansion and addition of future signals into the SCADA system without having to replace the existing SCADA system.

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[4] As technology evolves and competition increases it is anticipated that costs will decrease for increasing bandwidth and reliability.

4.5 Research Needs

Instrumentation and SCADA technology is proven in large-scale wastewater treatment facilities; therefore, technical feasibility is not considered to be a key issue for use in decentralized wastewater treatment facilities. Clearly, uncertainties in reliability as well as perceptions of high maintenance and calibration requirements for sensor equipment means that further work is necessary before the technology will be widely accepted and implemented.

It is recommended that a field study be undertaken to demonstrate that decentralized wastewater systems can be effectively and efficiently managed remotely without jeopardizing the environment if state-of-the-art, real-time sensors and SCADA hardware are utilized. A field study of real-time monitoring technologies would provide data directly relevant to decentralized facility owners and operators and regulating authorities. This study could also be used to identify issues with calibration and maintenance requirements for sensors. The field testing should be sufficiently long to investigate cleaning and calibration requirements, e.g. 6 to 12 months. If the demonstration study shows some sensors are not suitable for use in the decentralized wastewater industry because they require excessive calibration and/or maintenance, further research may be needed to improve this hardware and minimize calibration and maintenance requirements. This research could include developing sensors with auto-cleaning and auto-calibration capabilities and/or types that require less frequent cleaning and calibration.

There are limited data on best practices for data archiving and management, software and SCADA protocols for the decentralized wastewater industry. Further research is required to develop such protocols as there some issues that are specific to the decentralized industry, such as the amount of data generated and requiring storage due to infrequent site visits, and also a system that can identify and filter data that is suspect (e.g., due to a faulty sensor). A study of security issues for the decentralized industry is also recommended to determine the security risks in decentralized wastewater systems and to identify what, if any, best practice measures are required to enhance SCADA security for the decentralized wastewater industry.

The costs associated with real-time monitoring of decentralized wastewater treatment plants need to be estimated for typical facilities. This estimate should include capital costs of installing sensors and data transfer/storage, O&M costs associated with the monitoring technology, and monthly costs associated with data transfer and servicing. Equally important, benefits must be documented and should include both tangible cost reductions in energy costs, chemical costs or labor costs as well as more intangible benefits such as improved reliability or robustness, and improved system performance. Acceptance of real-time monitoring will only occur if it can be shown to be cost effective and have a cost benefit for decentralized facilities.

In addition to demonstrations of the effectiveness and efficiency of real-time monitoring, education and training programs should be developed for decentralized facility owners, operators and regulating authorities to ensure that decisions regarding the implementation of such hardware are based on sound technical information rather than perceptions that linger from experience with outdated, obsolete technologies. In addition, sensor and SCADA/data management vendors need to be made aware of technical issues with specific technologies or a potential market for a new technology that they can address through research and development.

The following table summarizes recommended research required to improve acceptance and use of real-time monitoring by decentralized facilities. The research needs are presented from highest to lowest priority.

Table 4-2. Summary of Research Needs.

Priority	Research Need	Description
1	Field Testing	A field testing program should be developed that will monitor the performance, maintenance and calibration requirements, and other costs. The program should use existing decentralized wastewater facilities and it is recommended that a number of facilities be included in the program to ensure all parameters identified for monitoring in this study are included.
2	Develop Sensor Standard Testing Protocols	Standard testing protocols should be developed to improve the comparability, reliability and quality of existing sensors. The protocols could be developed as part of a field testing program. Such protocols could aid in the development of sensors with improved maintenance and calibration requirements. Standard testing protocols should be developed collaboratively with decentralized facility owners and operators, sensor manufacturers and regulating authorities.
3	Cost-Benefit Analysis	Cost data from the field testing program and cost data from sensor and SCADA manufacturers/suppliers should be used to identify typical life cycle costs for real-time monitoring for decentralized wastewater facilities. These costs should be compared against potential benefits related to cost savings in labor and chemical and energy use as well as improved system performance and increased reliability or robustness.
4	Education and Training	Information from field testing should be disseminated to regulating authorities and also vendors, owners and operators of decentralized wastewater systems. In addition, education and training of O&M staff on selection, installation and/or maintenance of on-line sensor equipment should be provided. The best methods for providing education and training will need to be determined. Vendors should be made aware of potential markets within the decentralized wastewater industry that require further research and development. This information could be made available through technical papers and presentations through relevant forums.
5	Improve Cleaning and Calibration Frequency Of Sensors	If field testing of sensors identifies some critical sensors are not suitable for use in the decentralized wastewater industry due to excessive calibration and/or maintenance requirements,

Priority	Research Need	Description
		further research should undertaken to develop sensors with reduced cleaning and/or calibration requirements.
6	Develop Best Practices for SCADA Standards	This work would encompass a review of best practices for data archiving and management, software and SCADA protocols for the decentralized wastewater industry. This would involve a desk-top study of available data archiving and management systems and reviewing these to identify best practices, as well as what the experiences are for decentralized operation and maintenance organizations currently using SCADA.
7	Review SCADA Security Issues	A desk-top study of potential security issues and required measures to improve security (if required) should be carried out.

A proposed priority list of parameters for field testing of sensors was identified for field testing, which is presented in Table 4-3.

Table 4-3. Proposed Priority List of Parameters for Field Testing.

Priority	Measurement	Rationale
1	Ammonia-nitrogen DO Nitrate-nitrogen Turbidity	Good as early indicator of process conditions. May be used for monitoring to meet regulatory requirements (ammonia-nitrogen, DO) or be used as an equivalent (turbidity for TSS and/or BOD_5 monitoring). Have sensors that are considered to be robust and well established in centralized wastewater treatment and/or water treatment plants.
2	Alkalinity BOD_5 Chlorine Residual COD Conductivity ORP pH Phosphate Respirometry	May be used for monitoring to meet regulatory requirements (BOD_5, pH, phosphate). May be used to monitor variability in influent flow or load. Typically sensors are considered to be less robust than for Priority 1 parameters.
3	Flow Level Power Pressure Pump Run Status UV Light Intensity	Reasonably well established in decentralized wastewater treatment systems. Have sensors that are considered to be robust.

CHAPTER 5.0

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APPENDIX A

LCC ANALYSIS METHODOLOGY

A.1 Initial Costs (Cic) and Annual Spare Parts Costs (Crs)

Initial costs (*Cic*) include purchase price for the instrument, sampling system (if required), auxiliary equipment for operation, reagents typically provided with the purchase of the instrument and annual costs for reagents and inventory of spare parts (*Crs*).

The following table shows examples of costs for instruments used to monitor and control chlorine usage to determine *Cic* and *Crs*.

Example Instrument Costs *(All costs are provided by Manufacturers and are in U.S. Dollars)*					
Manufacturer	***A***	***B***		***C***	***D***
Model	Transmitter and ORP Electrode	Chloramine Analyzer	Total Residual Chlorine Analyzer (colorimetric)	Total Residual Chlorine Analyzer (titration)	ORP Meter and Electrode
Instrument Purchase Cost (list price)	$ 935	$9,400	$2,500	$7,300	$1,670
Sampling System Cost *[* $500 is for sample pump piping and valving supplied by end user.]*	N/A	$2,100 – micro-filter unit *$500	*$500	*$500	N/A
Auxiliary Equipment Cost Needed for Operation	Mounting and pipe $ 785 Additional cable and junction box $455	N/A	N/A	N/A	Flow thru Tee $75
Annual Reagent(s) Cost	N/A	$1280	$390	$575	ORP buffer solution, 250 ml, 427 mV $15
Annual Inventory of Spare Parts Cost *(Crs)*	Replacement Electrode ***$ 190***	***$190***	***$150***	***$220***	Replacement electrode ***$275***
Total Initial Cost *(Cic)*	***$2365***	***$13470***	***$3540***	***$8595***	***$2035***

A.2 Installation and Commissioning Costs (Cin)

Installation and commissioning costs (*Cin*) are associated with instrument installation, start-up and training which include the following key factors:

- Installation (skills, tools and equipment required to complete the installation)
- System Connections (process piping, electrical wiring, sample drains, auxiliary systems, and other utilities)
- Training (operation and maintenance personnel)

The following table shows a breakdown of key factors and a point rating system to determine the *Cin* factor.

Example Instrument Installation and Commissioning Costs *(Costs are subjective to user experiences and are in U.S. Dollars)*					
Manufacturer	***A***	***B***		***C***	***D***
Model	Transmitter and ORP Electrode	Chloramine Analyzer	Total Residual Chlorine Analyzer (colorimetric)	Total Residual Chlorine Analyzer (titration)	ORP Meter and Electrode
Skill— ***Personnel Required for Install*** *1-Electrician/ Instrument Tech* *1-Mechanic/ Utility Tech* *1-Operator*	3	3	3	3	3
Tools and Equipment Required *1-Common Tools (wrenches, pliers, drills, etc.)* *1-Special (provided by mfr w/ purchase)*	1	2	1	2	1
System Connections *1-In-situ* *1-Process Sample* *1-Analyzer Drain* *1-Electrical* *1-Auxiliary and Other Utilities*	3	4	4	4	3
Training *1-1 Hours* *2-2 Hours* *3-3 Hours* *4-4 Hours* *5-More than 4 hours*	1	5	1	1	1
Total Installation Cost Factor Points *(Cin)*	***8***	***14***	***9***	***10***	***8***

A.3 Labor Rates (LRavg and LRom)

Labor rates vary greatly depending on the size of the utility, local labor rates (union and non-union), and state mandated prevailing wages. The following table gives example labor rates, *LRavg,* and *LRom*, and are non-inclusive of overhead costs for labor.

Example Labor Rates *(Labor costs are hourly and are exclusive of overhead/benefits and are in U.S. Dollars)*	
Labor Rates for Staff Operating and Maintaining Instruments	***ITA Maintenance Benchmarking Study**** *Minimum Hourly / Average Hourly (percent reported)*
General Operations and Maintenance Personnel	$10 - 15 (53.2%) $15 - 20 (26.6%)
Instrumentation Specialist / Instrument Technician	$15 - 20 (63%) $10 - 15 (15.2%)
Electrician	$15 - 20 (67.4%) $20 - 25 (11.6%)
Contract Maintenance	Reported rate are inclusive of overhead. $30 - 50 (56.4%) $50 - 75 (21.8%)
Labor Rate Averages	***LRavg = $22.93*** ***LRom = $22.96***

**ITA's Instrumentation, Control, and Automation Staffing Maintenance Benchmarking Study reports majority and average labor (category percentages of respondents) rates not inclusive of overhead from 135 surveyed treatment facilities and are reported in from a survey conducted in Spring 1999.*

A.4 Operations and Maintenance Costs (*Com*)

Operations, maintenance and repair costs (*Com*) are associated with instrument operations, maintenance and repair and include the following key factors:

- Human exposure to injury during maintenance
- Equipment exposure to damage during normal operation
- Equipment exposure to damage during maintenance
- Frequency of cleaning and calibration
- Time required to perform maintenance and calibration
- Level of skill required to perform maintenance and calibration
- Special equipment required to perform maintenance and calibration
- Maintenance Costs
- Thoroughness and clarity of documentation normally supplied with equipment
- Availability of full documentation either as normally supplied or by additional purchase

The following table shows a breakdown of key factors and a point rating system to determine the *Com* factor.

Example Instrument Operations, Maintenance and Repair Cost Factors *(Costs are subjective to test site records and project team experiences and are in U.S. Dollars)*					
Manufacturer	***A***	***B***		***C***	***D***
Model	Transmitter and ORP Electrode	Chloramine Analyzer	Total Residual Chlorine Analyzer (colorimetric)	Total Residual Chlorine Analyzer (titration)	ORP Meter and Electrode
Human Exposure to Injury During Maintenance *0.5 – No exposure* *1.0 – Exposure*	1	1	1	1	1
Equipment Exposure to Damage During Normal Operation *0.5 – NEMA rated enclosure* *1.0 – Inadequate enclosure for exposure to elements*	0.5	0.5	0.5	0.5	0.5
Equipment Exposure to Damage During Maintenance *0.5 – No exposure to instrument during maintenance (i.e. changing reagents and cleaning instrument)* *1 – Exposure to instrument during maintenance*	0.5	0.5	0.5	1.0	0.5
Frequency of Cleaning and Calibration / Maintenance Performed *0.5 – once per month* *1 – once per week*	1	0.5	0.5	0.5	1
Time Required to Perform Maintenance and Calibration (Annual) *0.5 – 0 to 15 hrs/year* *1.0 – 15 to 25 hrs/year*	Estimated at: 1.25 hrs/mo 15 hrs/yr 0.5	Average = 1.13 hrs/mo 13.56 hrs/yr 0.5	Average = 1.83 hrs/mo 21.96 hrs/yr 1.0	Average = 1.65 hrs/mo 19.8 hrs/yr 1.0	Average = 1.56 hrs/mo 18.72 hrs/yr 1.0
Level of skill Required to Perform Maintenance and Calibration *0.5 – General O&M skills* *1.0 – Special Skills (i.e. laboratory personnel, electrician, etc.)*	0.5	0.5	0.5	0.5	0.5
Special Equipment Required to Perform Maintenance and Calibration ***0.5 – General tools*** ***1.0 – Special tools for maintenance or calibration***	1.0	0.5	1.0	1.0	1.0

Example Instrument Operations, Maintenance and Repair Cost Factors *(Costs are subjective to test site records and project team experiences and are in U.S. Dollars)*					
Manufacturer	***A***	***B***		***C***	***D***
Model	Transmitter and ORP Electrode	Chloramine Analyzer	Total Residual Chlorine Analyzer (colorimetric)	Total Residual Chlorine Analyzer (titration)	ORP Meter and Electrode
Maintenance/Repair Costs (Annual) *0.5 - $0 to $150 per year* *1.0 - $150 to $300 per year*	1.0	1.0	0.5	1.0	1.0
Thoroughness and Clarity of Documentation Normally Supplied with Equipment *0.5 – Comprehensive and clear documentation* *1.0 – Limited information and organization*	0.5	1.0	0.5	1.0	0.5
Availability of Full Documentation Either as Normally Supplied or by Additional Purchase *0.5 – 24 hour customer service hotline* *1.0 – Limited customer service support*	0.5	0.5	0.5	1.0	1.0
Total Instrumentation O&M Cost Factor Points *(Com)*	***7.0***	***6.5***	***6.5***	***8.5***	***8.0***

A.5 Calculating the Life Cycle Cost

The cost factors from the above tables for this example are summarized and are applied to the LCC equation as shown in the following table.

$$LCC = [Cic + LRavg(Cin) + LRom(Com)] + [(Crs + LRom(Com))\ n] \qquad [1]$$

Life Cycle Cost Factor Summary *(Costs are in U.S. Dollars)*					
Manufacturer	***A***	***B***		***C***	***D***
Model	Transmitter and ORP Electrode	Chloramine Analyzer	Total Residual Chlorine Analyzer (colorimetric)	Total Residual Chlorine Analyzer (titration)	ORP Meter and Electrode
Cic – *Initial Cost Factor*	$2,365	$13,470	$3,540	$8,595	$2,035
Cin *– Installation and Commissioning Costs*	8	14	9	10	8
Com – *Operations and Maintenance Cost Factor*	7	6.5	6.5	8.5	8
Crs – *Annual Reagent and Spare Parts Cost*	$190	$1,470	$540	$795	$290
LRavg – *Average Hourly Labor Rate*	$22.93				
LRom – *Average Hourly O&M Labor Rate*	$22.96				
n - *Life Expectancy of Instrument in Years*	10				
LCC - Calculated Life Cycle Cost of Instrument over a Ten Year Period	***$6,216***	***$30,133***	***$10,788***	***$18,921***	***$7,139***

A.6 Life Cycle Cost of Ownership

The LCC of ownership is only one factor in determining the choice of instrument for the end user's application. Additional factors need to be considered before making a choice of an instrument for a specific application. Accuracy, reliability, and installation are key factors also in selecting an instrument. Regulatory requirements for permitting may require the end user to choose a specific technology or measurement method, such as traditional amperometric titration of total chlorine measurement rather than non-traditional ion-selective electrode. The use of traditional and non-traditional measurement methods will also have an effect on installation requirements, operations, and maintenance costs.

For example, if the end user is considering using traditional direct measurement of total chlorine (which includes amperometric titration and colorimetric methods) versus a non-traditional inferred measurement of total chlorine (oxidation reduction potential [ORP] is an inferred measurement method for total chlorine because it does not directly measure total chlorine) then it is up to the end user to interpret the ORP data collected and convert that data into total chlorine measured in the water. ORP measures both the potential caused by the addition of chlorine to water and other unrelated potentials such as caustic addition to the water for pH control. As the amount of caustic addition varies the ORP data varies even though the amount of chlorine addition is held steady. This ORP variance in data may lead to the assumption that chlorine addition needs to be increased or decreased unnecessarily and can result in higher operational costs or inappropriate operational control actions.

APPENDIX B

CASE STUDY QUESTIONNAIRES

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Anish Jantrania, Virginia Department of Health, 07/03/08

1. Where is the plant located?	2 plants in Charles City County, 30 miles SE of Richmond
2. What type of plant is it? List all treatment processes at the facility.	Grinder pumps at each household. Each plant has Sequencing Batch Reactor, gravel filter, UV disinfection.
3. What is the plant capacity, and what is the operating capacity?	2 plants: Jerusalem - 3,500 gpd, at 60% capacity Kimages - 7,000 gpd, at 50% capacity
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (30 mg/L), TSS (30 mg/L) and fecal coliform (<200 colonies/100mL)
5. What type of on-line instrumentation is used at the facility?	Jerusalem – pH, LDO, ORP, conductivity Kimages - pH, LDO, ORP, conductivity, nitrate. Nitrate not worked for last year, due to faulty junction box.
6. What is the make/model of the instrumentation?	Hach sensors
7. What type of SCADA system is used and is information communicated by landline, cell or satellite?	Hach SC1000. Is a landline with a call-in system and computer with a modem. Dedicated phone line is used. A web browser is used to communicate.
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Localized electronic storage on the SC1000.
9. How long has automated monitoring been in place?	Since 2005
10. How many operating and maintenance staff are involved at the plant? What are their hours?	Is a full-time operator at the County that spends lot of time at each plant, but not dedicated to these 2 plants.
11. What type of O&M is carried out on monitoring equipment?	Cleaning and calibration. Probes alarm a lot, although LDO is generally stable. Typically clean/calibrate probes every 6 – 12 weeks.
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	1 hour/week for calibration of probes. Overall, think there is no time savings and the time spent on maintenance is an "add-on" for the operator in their regular O&M time.
13. Have there been any issues with the automation system, and if so, what type?	Monitoring is too intense for these small plants. Don't really need probes at these facilities, except LDO which can be used for automated blower control.
14. What is the approximate cost for the installed on-line sensors and SCADA system?	$40,000 - $50,000

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Provided by Kevin Camara, FA&A, 05/30/08

1. Where is the plant located?	Warren, Vermont, Core Village Growth Center Area
2. What type of plant is it? List all treatment processes at the facility.	**<u>Decentralized Wastewater Collection, Treatment & Disposal Systems</u>** Brooks Field Collection, Treatment & Disposal System: 2,000 l.f of gravity sewer (28 connections), 8,000 l.f. low pressure sewer (31 STEP Systems), two (2) sewer pump stations, forcemain, 50,000 gpd septic tank, two (2) dosing pump stations, twelve (12) dual alternating 5,000 gpd trench absorption fields (50% in use each year). Luce Pierce Cluster System: individual septic tanks (3), STEG collection system, dosing pump station, 2,000 gpd trench disposal absorption field. Individual Disposal Systems: Five (5) Individual onsite disposal systems. Three (3) pressurized conventional systems with dosing pump stations. Two (2) gravity conventional systems. Manage Existing Onsite Systems: Two (2) properties manage existing onsite systems, 2 dosing pump stations with one shared mound system. Warren Elementary School: 5,000 gpd system, Two (2) septic tanks, recirculation/blend tank, twelve (12) Orenco Textile Filters, Dosing Pump Station, Forcemain, Shallow gravelless disposal system
3. What is the plant capacity, and what is the operating capacity?	Brooks Field: 30,000 gpd permitted, 8,000 gpd actual average, 12,000 gpd max day actual. Luce Pierce Cluster System: 2,000 gpd, no data on actual Individual Systems: 5 systems ranging from 280 gpd to 840 gpd, no data on actual. Manage Existing systems: 1,200 gpd Warren Elementary School: 5,000 gpd permitted, 2,100 gpd actual average, 4,000 gpd actual max day

4. What parameters is the plant designed to treat and what are the permit limits?	Warren Elementary School: BOD (30 mg/L) and TSS (30 mg/L). None of the others have permit limitations as they are septic systems. The Large Brooks Field system that State water quality standards in groundwater must be met before groundwater reaches he receiving stream.
5. What type of on-line instrumentation is used at the facility?	Brooks Field- 1) Two (2) Collection system pump stations, and one (1) Disposal system dosing pump station panels communicate via radio telemetry to a master panel located at the Town Offices. This saves money on telephone charges if dialers were used individually. The master panel has a dialer which sends alarms to the operator's cell phone. The operator can access the master panel from his personal computer for data via a modem in the panel. 2) Thirty-one (31) *Orenco Vericomm* STEP system control panels. Alarms are sent to the operator's pager via homeowner's telephone line. Alarms are also sent via email to operators email via Vericomm system. The operator can access data from each panel via the WWW through Vericomm web site. Luce Pierce Cluster System: The panel at this cluster system also communicates via radio telemetry to the master control panel at the Town Office. Individual Systems 3 Vericomm Control panels. Manage Onsite 2 Vericomm Control panels. Warren Elementary School: Orenco Custom Control Panel. The panel send notifications to the operator's pager via a dialer in the panel The operator can remotely access the panel with a personal computer using a modem and Hyperterminal program.
6. What is the make/model of the instrumentation?	Brooks Field & Luce Pierce Cluster System Radio Telemetry System: Consolidated Electric Custom Radio Telemetry System STEP Systems: 31 Vericomm Control panels. Individual Systems 3 Vericomm Control panels.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Provided by Kevin Camara, FA&A, 05/30/08

	Manage Onsite 2 Vericomm Control panels. Warren Elementary School: Orenco Custom Control Panel.
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	See 4. and 5.
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	The operator uses digital files (Excel) and then paper storage for the Brooks Field Wastewater System and Luce Pierce Cluster System radio telemetry for flows, pump run times, etc. The operator uses the Vericomm remote database for data storage for the STEP and individual systems. The operator uses digital files converting text files to Excel and then paper storage for the Warren Elementary School panel for flows, pump run times, etc.
9. How long has automated monitoring been in place?	Warren Elementary School - Since 2000
10. How many operating and maintenance staff are involved at the plant? What are their hours?	The Town hired a part time contract operations firm (Simon Operation Services). Typically one person remotely checks on the system panels from their office once per week (1 hour). They physically check the pump stations every other week (4 hours every other week. They respond to alarms. Do reports once per month. They do monthly, quarterly and annual O&M tasks.
11. What type of O&M is carried out on monitoring equipment?	Weekly remote check. Every other week physical check and annual inspection
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	There is no maintenance budgeted for the remote monitoring. Time savings is about 12 hours per week total for all systems vs daily onsite checks. Cost saving for this is approx. $25,000/year, and also save $1,500/year using radio telemetry vs dedicated landlines.
13. Have there been any issues with the automation system, and if so, what type?	Brooks Field & Luce Pierce Cluster System: A couple of lighting strikes have cause panels to fail or not communicate. Communication failures have occurred. Vericomm Systems: The systems use the homeowner's telephone line. We have had

	some homeowners switch to cell phones or cable/Vonage etc. and cancel their land line phones causing non communication. The easement agreements between the homeowner and the Town require the homeowner to maintain the land line which has caused some anguish between the Town and the homeowners. Some homeowners have had their phone lines temporarily and periodically turned off by the telephone company for delinquency causing non communication. We have had some problems with the telephone lines between the panel and the telephone connection clarity thus no communication and bad lines. We initially had problems with homes with DSL phone lines. Installed DSL filters in each panel to correct. Warren Elementary School: A couple of lighting strikes have cause panels to fail or not communicate.
14. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	No

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #1

Provided by Michael Stephens, SCS Systems, 07/02/08

1. Where is the plant located?	Narrow Lake, Brookfield Twp, Springport, Michigan
2. What type of plant is it? List all treatment processes at the facility.	76 STEP collection tanks to 10 recirculating AdvanTex (AX100) filters, storage in two-aerated storage ponds of 330,000 gallons each, discharge to Battle Creek Drain.
3. What is the plant capacity, and what is the operating capacity?	25,000GPD capacity, operating at 8,000 to 10,000GPD
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (30 mg/L), TSS (40-70 mg/L), fecal coliform (200 cfu/100mL) and DO (5 mg/L).
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation includes 10 turbine pumps, 2 flow meters, 8 float inputs, 1 exhaust ventilation fan
6. What is the make/model of the instrumentation?	Pumps/floats/fan/controls – Orenco Systems Inc., flow meters – SeaMetrics
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 3 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since September 2006
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We operate the facility via contract, making regular site visits. The facility is inspected 3x/weekly, with an average of 2-3 hours/week of onsite time at the central treatment facility only. We employ 1 full-time and 1 summer employee to manage multiple facilities.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #1
Provided by Michael Stephens, SCS Systems, 07/02/08

11. What type of O&M is carried out on monitoring equipment?	The monitoring system is tested quarterly for proper input and output function. The data is downloaded each month remotely. Very little maintenance is required
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 2 hours per year and time savings 20 to 30 hours per year.
13. Have there been any issues with the automation system, and if so, what type?	There have been issues with the power and phone service suppliers. We lost 1 leg of our 3-phase power to the control panel. We have had multiple phone service interruption and quality problems. The telemetry panel has functioned extremely trouble-free
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$25,000 estimate.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #2

1. Where is the plant located?	River Rock Landing, Dimondale, Michigan
2. What type of plant is it? List all treatment processes at the facility.	23 (of 29) STEP collection tanks to 2 recirculating sand filters (in parallel) followed by 2 intermittent sand filters (in parallel), storage in seepage pond, discharge to groundwater and Grand River (only as necessary)
3. What is the plant capacity, and what is the operating capacity?	10,000GPD capacity, operating at 4,000GPD
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (25 mg/L), TSS (30 mg/L), total P (1 mg/L) and fecal coliform (200 cfu/100mL).
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation includes 4 turbine pumps, 2 chemical pumps, 8 float inputs, 3 pressure transducer inputs
6. What is the make/model of the instrumentation?	Pumps/floats/controls – Orenco Systems Inc., pressure transducers – unknown
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 12 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since 2000
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We operate the facility via contract, making regular site visits. The facility is inspected monthly, with an average of 2-3 hours/month of onsite time at the central treatment facility only. We employ 1 full-time and 1 summer employee to manage multiple facilities.
11. What type of O&M is carried out on monitoring equipment?	The monitoring system is tested quarterly for proper input and output function. The data is downloaded each quarter remotely. Very little maintenance is required
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 1.5 hours per year and time savings 15 to 20 hours per year.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #2

13. Have there been any issues with the automation system, and if so, what type?	There have been issues with consistent and reliable phone service from the supplier. We have also had some problems with a particular circuit inside the control panel, and have replaced it 3 times. We also had problems with the pressure transducers and have disconnected them altogether
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$10,000 estimate.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #3

1. Where is the plant located?	Lake Leslie, Corunna, Michigan
2. What type of plant is it? List all treatment processes at the facility.	6 (of 36) STEP collection tanks to 8 (of 16) recirculating AdvanTex (AX20) filters, discharged to an aerated storage pond, then to a non-aerated settling pond, then to an aerated storage ponds of 830,000 gallons, discharge to Coal Mine Drain.
3. What is the plant capacity, and what is the operating capacity?	10,000GPD capacity, operating at 1,000GPD
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (10-20 mg/L), TSS (30-47 mg/L), total P (1 mg/L), ammonia N (2-7.3), fecal coliform (200 cfu/100mL) and DO (4-7 mg/L)
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation includes 4 turbine pumps, 4 float inputs, 1 exhaust ventilation fan, 1 flow meter, 1 alphasonic water level sensor
6. What is the make/model of the instrumentation?	Pumps/floats/controls – Orenco Systems Inc., flow meter – Danfoss, water level sensor – FlowLine
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 12 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since February 2006
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We operate the facility via contract, making regular site visits. The facility is inspected monthly, with an average of 1 hour/month of onsite time at the central treatment facility only. We employ 1

	full-time and 1 summer employee to manage multiple facilities
11. What type of O&M is carried out on monitoring equipment?	The monitoring system is tested quarterly for proper input and output function. The data is downloaded each quarter remotely. Very little maintenance is required
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 2 hours per year and time savings 10 to 15 hours per year.
13. Have there been any issues with the automation system, and if so, what type?	There have been issues with consistent and reliable operation of the water level sensor. The telemetry panel has functioned extremely trouble-free
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$10,000 actual.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #4

1. Where is the plant located?	Milford Pointe, Milford, Michigan
2. What type of plant is it? List all treatment processes at the facility.	16 (of 30) STEP collection tanks to 16 recirculating AdvanTex (AX20) filters, discharged to a low pressure drainfield
3. What is the plant capacity, and what is the operating capacity?	10,000GPD capacity, operating at 6,500GPD
4. What parameters is the plant designed to treat and what are the permit limits?	BOD, TSS, nitrogen and fecal coliform.
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation includes 6 turbine pumps, 8 float inputs, 1 exhaust ventilation fan, 1 flow meter
6. What is the make/model of the instrumentation?	Pumps/floats/controls – Orenco Systems Inc., flow meter – SeaMetrics
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 12 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since April 2004
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We operate the facility via contract, making regular site visits. The facility is inspected quarterly, with an average of 3 hours/quarter of onsite time at the central treatment facility only. We employ 1 full-time and 1 summer employee to manage multiple facilities
11. What type of O&M is carried out on monitoring equipment?	The monitoring system is tested quarterly for proper input and output function. The data is downloaded each quarter remotely. Very little maintenance is required

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #4

12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 2 hours per year and time savings 20 to 25 hours per year.
13. Have there been any issues with the automation system, and if so, what type?	There have been issues with consistent and reliable phone service from the supplier. The flow meter has never operated correctly since construction. The telemetry panel has functioned relatively trouble-free, with the exception of a period of time where communication with the panel would be lost until the panel was powered down and reset
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$5,700 actual.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #5

1. Where is the plant located?	Summerbrooke, Owosso, Michigan
2. What type of plant is it? List all treatment processes at the facility.	4 (of 36) STEP collection tanks to 4 recirculating AdvanTex (AX100) filters, discharged to a low pressure drainfield
3. What is the plant capacity, and what is the operating capacity?	10,000GPD capacity, operating at 600GPD
4. What parameters is the plant designed to treat and what are the permit limits?	BOD, TSS, nitrogen and fecal coliform.
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation includes 6 turbine pumps, 8 float inputs, 1 exhaust ventilation fan, 1 flow meter
6. What is the make/model of the instrumentation?	Pumps/floats/fan/controls – Orenco Systems Inc
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 12 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since June 2006
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We operate the facility via contract, making regular site visits. The facility is inspected quarterly, with an average of 1 hours/quarter of onsite time at the central treatment facility only. We employ 1 full-time and 1 summer employee to manage multiple facilities
11. What type of O&M is carried out on monitoring equipment?	The monitoring system is tested quarterly for proper input and output function. The data is downloaded each quarter remotely. Very little maintenance is required

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #5

12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 1 hour per year and time savings 8 to 10 hours per year.
13. Have there been any issues with the automation system, and if so, what type?	The telemetry panel has functioned extremely trouble-free
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$10,000 estimate

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #6

1. Where is the plant located?	Brooks River Landing, Dimondale, Michigan
2. What type of plant is it? List all treatment processes at the facility.	15 STEP collection tanks to 2 recirculating sand filters (in parallel), discharge to subsurface gravity-flow trenches
3. What is the plant capacity, and what is the operating capacity?	5,600GPD capacity, operating at 2,000GPD
4. What parameters is the plant designed to treat and what are the permit limits?	BOD, TSS, nitrogen and fecal coliform.
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation includes 2 turbine pumps, 4 float inputs
6. What is the make/model of the instrumentation?	Pumps/floats/controls – Orenco Systems Inc
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 12 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since January 2001
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We operate the facility via contract, making regular site visits. The facility is inspected monthly, with an average of 1 hour/month of onsite time at the central treatment facility only. We employ 1 full-time and 1 summer employee to manage multiple facilities

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #6

11. What type of O&M is carried out on monitoring equipment?	The monitoring system is tested quarterly for proper input and output function. The data is downloaded each quarter remotely. Very little maintenance is required.
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 1 hour per year and time savings 15 to 20 hours per year.
13. Have there been any issues with the automation system, and if so, what type?	The telemetry panel has functioned extremely trouble-free
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$1,200 actual

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #7

1. Where is the plant located?	Baan Gan Aka, Williamston, Michigan
2. What type of plant is it? List all treatment processes at the facility.	7 (of 37) STEG collection tanks to a single lift station, discharge to subsurface low-pressure drainfield
3. What is the plant capacity, and what is the operating capacity?	10,000GPD, operating at 2,500 to 13,000GPD (depending on I&I from rainfall).
4. What parameters is the plant designed to treat and what are the permit limits?	No permit requirements
5. What type of on-line instrumentation is used at the facility?	On-line instrumentation consists of 2 pumps, 5 float inputs
6. What is the make/model of the instrumentation?	Pumps – Kennedy Industries, floats – Conery Mfg., controls – Orenco Systems Inc
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Custom Telemetry Control Panel – Orenco Systems Inc. which communicates via landline
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored for 12 months on the control panel circuit board, and is downloaded remotely to Excel files on our office PC. These Excel files are printed in hard copy and placed in the project file
9. How long has automated monitoring been in place?	Monitoring has been in place since 2002
10. How many operating and maintenance staff are involved at the plant? What are their hours?	There are no onsite staff. We monitor the facility via contract. No site visits are included in our contract. Others inspect the lift station annually. We employ 1 full-time and 1 summer employee to manage multiple facilities

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #7

11. What type of O&M is carried out on monitoring equipment?	The monitoring system is monitored quarterly for variances in input and output function. The data is downloaded each quarter remotely. Very little maintenance is required.
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance is about 0.5 hour per year and time savings 5 to 8 hours per year.
13. Have there been any issues with the automation system, and if so, what type?	The telemetry panel has experienced multiple circuit board failures due to voltage spikes in the area. Since the installation of surge protection, it has functioned trouble-free
14. Can you provide an estimate cost of installing the on-line monitoring and SCADA system?	$1,200 actual

OTHER TELEMETRY/REMOTE MONITORING

We also have remote monitoring panels for multiple commercial facilities listed below:

Pohl Oil (gas station, convenience store, and McDonalds)
Chosen Vision (group home for mentally disabled adults)
Island City Academy (public school)
Origami (rehabilitative facility for head injuries)
Huszti Building (multi-use professional service building)

We utilize web-based monitoring panels for almost all of our new STEP connections to community decentralized treatment facilities. The following facilities utilize a control panel tied into the phone line for each individual home connection, with the number of these panels in parenthesis following the facility name:

Brookfield Twp-Narrow Lake (76)
Lake Leslie Condo (6)
Milford Pointe (19)
River Rock Landing (16)
Summerbrooke (4)

In addition to these community facilities, we utilize the web-based panels for individual, on-lot septic systems. We monitor approximately 25 onsite systems this way.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Josh Lindell, Aquapoint, 06/18/08

1. Where is the plant located?	**Piperton, TN** *What makes this a nice case study is that Piperton's infrastructure is made up of a constantly growing network of several plants (6 currently) that are all using the same treatment technology and are tied into the same telemetry monitoring network. Telemetry allows them to operate the systems essentially as one since they can view their functionality from a single location.*
2. What type of plant is it? List all treatment processes at the facility.	*All 6 plants are Aquapoint Inc. Bioclere™ systems. Bioclere is a modified trickling filter over a clarifier (see details at www.aquapoint.com/bioclere.html) so the biological treatment process is fixed-film. Each system also incorporates flow EQ, UV disinfection and drip disposal all of which can be remotely accessed through the telemetry controls.*
3. What is the plant capacity, and what is the operating capacity?	*The six plants range from 20,000 to 80,000 gpd and the combined capacity at this point is 280,000 gpd. Each system is currently receiving very little flow (probably no more than a few thousand gpd) as the communities have been slow to build out and the systems are only a year old.*
4. What parameters is the plant designed to treat and what are the permit limits?	*BOD (45 mg/L)*
5. What type of on-line instrumentation is used at the facility?	*All facilities use cellular based remote **wireless** telemetry w/ an integrated auto dialer. Internet based software allows the operator to access each plant as long as they have a password.*
6. What is the make/model of the instrumentation?	*Aquapoint calls its telemetry control package Aqua-Alert™ but it incorporates Allen Bradley PLCs and Air2App wireless telemetry hardware.*
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	*System does not have full SCADA capability because it is not necessary. Telemetry sends data packets several times per day between control panel and software program. In other words data transmission is not in real-time. Information is transmitted via cellular.*
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	*Remote database is used to log alarm history, plant data, etc…*
9. How long has automated monitoring been in place?	*1 year for most systems*

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Provided by Josh Lindell, Aquapoint, 06/18/08

10. How many operating and maintenance staff are involved at the plant? What are their hours?	*One operator from the public works department (PWD) spends no more than 2 hours onsite at each plant per month… Biocleres are fully automated so there isn't much to do onsite but make sure things are working properly. Much of treatment plant O&M is preventative maintenance.*
11. What type of O&M is carried out on monitoring equipment?	*No typical O&M required on monitoring equipment.*
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	*The operator visits each site weekly for about 30 minutes each, which is not completely necessary for proper operation but is more for preventative maintenance (operator is public works employee).*
13. Have there been any issues with the automation system, and if so, what type?	*Unknown… Need to talk to system operator.*
14. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	*To be honest many engineers end up specifying telemetry or SCADA controls and more often than not the operator and/or owner never uses it.*

A FEW ADDITIONAL COMMENTS: As a project manager for a wastewater treatment design and manufacturing company, I get a significant amount of feedback from operators of our systems. Engineers frequently want to design start of the art equipment so we have a telemetry package available but we hear more often than not from operators that they either don't use it or that it doesn't have much value. Most decentralized plant operators are happy if they have a simple auto dialer to call them in the event of an alarm condition. The auto dialer can indicate the failure and the operator has to eventually visit the site any way to fix whatever went wrong. Why incorporate a $4,000 telemetry control system that costs $25 per month for the wireless transmission of data when a simple $400 to $500 auto dialer and a hardwire phone line can tell you when there is an alarm and what has failed. In the case of Bioclere, the process is so simple that SCADA and telemetry are overkill in most cases. We are talking about a few fractional horsepower pumps and a small fan that make up the mechanical components, it's not complex. Plus, treatment plans are living biological systems and must be touched, smelled, listened to, etc… They need a human touch and cannot be 100% operated via a computer from an office. It is my personal opinion that the real value of telemetry is when an operator has a network of many systems he/she maintains like in the case of Piperton, TN. The operator can log onto the telemetry system and look at all plants to determine where their time would best be spent that day.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Doug Klein, Charleston Water System, 06/24/08

1. Where is the plant located?	196 Pierce Street Charleston, SC 29492
2. What type of plant is it? List all treatment processes at the facility.	Aqua-aerobics Sequencing Batch Reactor. -Primary screening -Equalization tank -2 SBRs -Effluent Filtration -UV light disinfection -Aerobic Sludge Digestion -Rotary Sludge Press
3. What is the plant capacity, and what is the operating capacity?	Design Capacity: 1.0 MGD Current flow:0.65 MGD
4. What type of on-line instrumentation is used at the facility?	14 Ultra sonic level, 1 Ultra sonic flow 2 Dissolved Oxygen 6 Magnetic Flow Meter 2 Ultra Violet 7 Pressure 2 RPM Speed 1 Truck Scale
5. What is the make/model of the instrumentation?	MILLTRONICS Hydroranger MILLTRONICS Open Channel HACH SC100 HACH LDO 3-ISCO unipulse5000, 1-ISCO unimag, 2-ENDRESS& HAUSER Promag TROJANUV3000 ENDRESS& HAUSER PSI ENDRESS& HAUSER RPM SCISSON SCALE
6. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	1) Computer Professional grade. Manufacture Dell 490. 2) Software RSView 32 Manufacture Rockwell Automation. 3) Software RSLinx Communications software for local and remote communications

	Manufacture Rockwell Automation. 4) SCADA (onsite) plant communication fiber optics 10/100 MEG switches using Ethernet communications protocol TC/PIP. 5) Four (onsite) Daniel Island plant Allen Bradley Programmable logic Controllers PLCs Manufacture Rockwell Automation. 6) Two (off site remote) Daniel Island controlled influent pump stations the pump stations use two Allen Bradley Programmable logic Controllers PLC's using iNet 900 Frequency Hopping Spread Spectrum Radios using Ethernet communications protocol between Daniel Island plant and two Influent pump stations, stations are monitored at DI and PI. Manufacture Rockwell Automation. 7) Daniel Island plant and Plum Island plant SCADA (between plant site) allows remote control and monitoring from Plum Island, using Ethernet communications protocol, Manufacture MDS iNet 900 Frequency Hopping Spread Spectrum Radios
7. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	1) Digital files are compiled by Daniel Island SCADA node locally for 90 days. 2) All data from Daniel Island is transmitted via radio every minute 1440/ 24/ 7 and recorded and stored on 2 Plum Island SCADA nodes. 3) All digital files transferred to a sequel data base each night at mid night at Plum Island and archived indefinitely on historical servers
8. How long has automated monitoring been in place?	2001 / 2002 time frame
9. How many operating and maintenance staff are involved at the plant? What are their hours?	(1) 40 hr week: full time operator: does preventative maintenance. Assistance from (2) mechanics and (1) electrical tech. for corrective repairs as needed.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Doug Klein, Charleston Water System, 06/24/08

10. What type of O&M is carried out on monitoring equipment?	HMI software, communications software and hardware updates are performed Quarterly on all SCADA computers software is backed up stored off site
11. Have there been any issues with the automation system, and if so, what type?	Occasional communications failures due to radio failure our average UP TIME is 99.9%
12. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	Not at this time.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #1

Utility: Mobile County Water Sewer & Fire Authority-Theodore, AL

Operator: Stephen Cunningham interviewed

1. Where is the plant located?	1 Plant – Haskew WWTF is located in the western part of Mobile County, AL at Exit 10, I-10
2. What type of plant is it? List all treatment processes at the facility.	Packed Bed Filter/Textile Medium/Orenco's ADVANTEX
3. What is the plant capacity, and what is the operating capacity?	30,000 gpd
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (45 mg/L), TSS (45 mg/L), ammonia (10 mg/L)
5. What type of on-line instrumentation is used at the facility?	ORENCO-TComm accessed by computer at any location and onsite by use of a laptop. Option: Touch Screen
6. What is the make/model of the instrumentation?	TComm made by Orenco
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Tcomm serves as SCADA using a land/telephone line
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored in TComm unit in the Control Panel and accessed by dialing into the panel from a PC or Laptop at the site
9. How long has automated monitoring been in place?	1 1/2 years
10. How many operating and maintenance staff are involved at the plant? What are their hours?	1 part-time who averages visiting the sites 1-3 times per week unless there is an alert. Averages 5hrs. per week
11. What type of O&M is carried out on monitoring equipment?	No O&M carried out on the monitoring equipment
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Little or no maintenance required. Many of our systems are 15 – 20 miles from the treatment site, so there are considerable savings when 1 operator can oversee multiple treatment sites using computer access and to assess when site visits are necessary
13. Have there been any issues with the automation system, and if so, what type?	No Issues with the telemetry

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #2

Utility: Mobile Water & Sewer Service – Mobile, AL

Operator: Wayne Noel interviewed by William H. McLean-Dauphin Environmental Equipment, Mobile, AL

1. Where is the plant located?	1 Plant-Snow Road WWTF is located in the western part of Mobile County, AL at Collier Elementary School on Snow Road
2. What type of plant is it? List all treatment processes at the facility.	Packed Bed Filter/Textile Medium/Orenco's ADVANTEX
3. What is the plant capacity, and what is the operating capacity?	20,000 gpd
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (30 mg/L), TSS (30 mg/L), ammonia (10 mg/L)
5. What type of on-line instrumentation is used at the facility?	ORENCO-TComm accessed by computer at any location and onsite by use of a laptop. Option: Touch Screen
6. What is the make/model of the instrumentation?	TComm made by Orenco
7. What type of SCADA system is used and is information communicated by landline, cell. or satellite?	Tcomm serves as SCADA using a land/telephone line
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored in TComm unit in the Control Panel and accessed by dialing into the panel from a PC or Laptop at the site
9. How long has automated monitoring been in place?	7 years
10. How many operating and maintenance staff are involved at the plant? What are their hours?	1 part-time who averages visiting the sites 1-3 hours per week unless there is an alert
11. What type of O&M is carried out on monitoring equipment?	No O&M carried out on the monitoring equipment
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Little or no maintenance required. Many of our systems are 15 – 20 miles from the treatment site, so there are considerable savings when 1 operator can oversee multiple treatment sites using computer access and to assess when site visits are necessary
13. Have there been any issues with the automation system, and if so, what type?	No Issues with the telemetry. Panel does interface with conventional SCADA so operator can make a comparison and says he would be comfortable if he only had TComm

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE #3

Utility: South Alabama Utilities

Operator: Tim Lee interviewed by William H. McLean-Dauphin Environmental Equipment, Mobile, AL

1. Where is the plant located?	13 Plants located in the western part of Mobile County, AL
2. What type of plant is it? List all treatment processes at the facility.	Packed Bed Filter/Textile Medium/Orenco's ADVANTEX
3. What is the plant capacity, and what is the operating capacity?	J.E. Turner Elementary School (2003)-20,000 g. The Oaks (2004)-20,000 g Champion Hills (2005)-30,000 g Harmony Ridge (2005)-30,000 g Wendy Oaks (2004)-30,000 g Johnson Road (2004)-60,000 g Wilmer Elementary School (2006)-30,000 g Cambridge Place (2006)- 30,000 g Palmer Woods (2006)- 30,000 g Holley Branch (2007)- 30,000 g J.E. Turner 2 (2008)- 30,000 g Johnson Road 2 (2008)- 60,000 g
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (30 – 45 mg/L), TSS (30 - 45 mg/L), ammonia (10 mg/L) or TKN (10 mg/L)
5. What type of on-line instrumentation is used at the facility?	ORENCO-TComm accessed by computer at any location and onsite by use of a laptop. Option: Touch Screen
6. What is the make/model of theinstrumentation?	TComm made by Orenco
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Tcomm serves as SCADA using a land/telephone line
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data is stored in TComm unit in the Control Panel and accessed by dialing into the panel from a PC or Laptop at the site
9. How long has automated monitoring been in place?	1 1/2 years
10. How many operating and maintenance staff are involved at the plant? What are their hours?	2 part-time who work together and average 2 hours per week unless there is an alert
11. What type of O&M is carried out on monitoring equipment?	No O&M carried out on the monitoring equipment
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Little or no maintenance required. Many of our systems are 15 – 20 miles from the treatment site, so there are considerable savings when 1 operator can oversee multiple treatment sites using computer access and to assess when site visits are necessary
13. Have there been any issues with the automation system, and if so, what type?	No Issues with the telemetry except for occasions when telephone lines go down

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Dan Miller (Miller Catfish Farm), AL and Jim Dartez (Royce Technologies), 07/03/08

1. Where is the plant located?	Greensboro, AL
2. What type of plant is it? List all treatment processes at the facility.	Is a catfish farm with 60 ponds (each approx. 10 – 15 acres)
3. What is the plant capacity, and what is the operating capacity?	N/A
4. What type of on-line instrumentation is used at the facility?	DO, temperature, aerator operational status and electrical current
5. What is the make/model of the instrumentation?	Royce
6. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Data is collected in the analyzer at the pond bank and relayed in packets of data to a central office within 10 miles via radio or cell phone. Data is collected into a computer software program that can present graphical and numerical data constantly.
7. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Data stored electronically in central office.
8. How long has automated monitoring been in place?	Started in 1995
9. How many operating and maintenance staff are involved at the plant? What are their hours?	1 man on farm responsible, as part of other work
10. What type of O&M is carried out on monitoring equipment?	Minor maintenance required
11. Have there been any issues with the automation system, and if so, what type?	No problems with the radio system. Motherboards on computers in the field need to be replaced occasionally
12. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Evelyn Allen, Waterloo Biofilter Systems Inc., 07/08/08

1. Where is the plant located?	4 plants in South Central Ontario
2. What type of plant is it? List all treatment processes at the facility.	Golf courses. Waterloo Biofilter and Trojan UV treatment systems at each
3. What is the plant capacity, and what is the operating capacity?	15 – 88 m3/d
4. What parameters is the plant designed to treat and what are the permit limits?	Compliance parameters: BOD (30 mg/L), TSS (30 mg/L), ammonia (2.5 mg/L), TP (2 – 2.5 mg/L), E.coli (100 cfu/100mL)
5. What type of on-line instrumentation is used at the facility?	Monitor only, no control - UV light intensity, pressure switches, pumps, flow meter
6. What is the make/model of the instrumentation?	
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Control Microsystems. SCADA adds up the number of events for the day and time pumps have been on. Dedicated landlines are used and call in to check the plant data. When an alarm, send message to operator's pager and operator looks up the site on the computer.
8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Remote data storage.
9. How long has automated monitoring been in place?	Since 1999
10. How many operating and maintenance staff are involved at the plant? What are their hours?	1 staff for all sites, with 2 hours/week at each site
11. What type of O&M is carried out on monitoring equipment?	None so far. No issue with false alarms.
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Maintenance was negligible and time savings about 2 hours per month on travel time per site when there were alarms
13. Have there been any issues with the automation system, and if so, what type?	No
14. Can you provide an estimated cost for the on-line sensor and SCADA system?	$25,000 to $30,000 total for all 4 plants (Canadian $, 1999 prices)

Decentralized System Case Study Questionnaire

Provided by Clay Reitsma, DNC, 07/04/08

1. Where is the plant located?	3 wastewater plants in 3 parts of region, separated by mountains: Chemainus, Crofton and Joint Utility Board (JUB). Each plant is used as a hub for collecting data from water, sanitary sewer and storm sewer stations. Data is transferred from wastewater plants to central location at municipal hall. A fourth treatment plant (Maple Bay Marina STP) will be commission in the fall of 2008. It will also be a hub plant for other systems.
2. What type of plant is it? List all treatment processes at the facility.	Chemainus STP has screening, degritting, biological treatment, secondary clarification, aerobic digestion, dewatering. Crofton STP has screening, degritting, biological treatment, secondary clarification, aerobic digestion. JUB STP has screening, degritting, complete mix aeration biological treatment cell, partial mix biological treatment cell, 2 facultative treatment cells/settling cells, chemical addition for phosphorus removal, chlorination, dechlorination. MBM STP has screening, flow equalization, anoxic treatment for nitrogen removal, biological treatment with ammonia conversion, chemical addition for phosphorus removal, membranes for solids separation, UV disinfection.
3. What is the plant capacity, and what is the operating capacity?	Chemainus: 2,000 m3/d Crofton: 1,200 m3/d JUB: 16,500 m3/d MBM: 350 m3/d Average Annual Flow basis.

Decentralized System Case Study Questionnaire

Provided by Clay Reitsma, DNC, 07/04/08

4. What type of on-line instrumentation is used at the facility?	Chemainus/Crofton: DO probes, ultrasonic level sensor, magnetic flow meters. JUB Lagoons: Ultrasonic flow meters. MBM: Ultrasonic level sensors, magnetic flow meters, pH probes, DO probes. Water Stations: Typically have ultrasonic level sensors, magnetic flow meters, free chlorine probes, pH probes, temperature probes, turbidity meters. Storm Sewer Stations: Typically have level sensor and ultrasonic or bubbler (pressure) type flow meters. Sanitary Sewer Stations: Typically have level sensors and ultrasonic or bubbler (pressure) type flowmeters.
5. What is the make/model of instrumentation?	Fisher-Porter, Endress & Hauser.
6. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Alan Bradley PLC and Rockwell software for HMIs. Use radios to communicate from water/sewer systems to wastewater pants and VPN networks from wastewater plants to municipal hall. Use radio and hub system due to mountainous area, so no clear line of sight or cables available.
7. Do you use localized data storage (digital files), paper files or a remote database for data storage?	Use localized digital storage at wastewater plants and central database at municipal hall. STP hubs store locally but all data also forwarded to SCADA server at municipal hall.
8. How long has automated monitoring been in place?	Since 1998 at wastewater plants. Water and sewer systems connected to wastewater plants since 2007. Not all water/storm sewer/sanitary sewer system stations connected yet.

Decentralized System Case Study Questionnaire

Provided by Clay Reitsma, DNC, 07/04/08

9. How many operating and maintenance staff are involved at the plant? What are their hours?	All three wastewater plants are manned. MBM STP will also be fully manned. The system has not reduced labour requirements, but allows for accessing of data at remote locations (hubs), at the muni hall, or via laptop from any other location where internet service is available. Also will be installing aircard into some laptops to access information over a high speed cellular network.
10. What type of O&M is carried out on monitoring equipment?	Alarming and diagnostics of the network alerts operations to communication errors so that action can be taken.
11. Have there been any issues with the automation system, and if so, what type?	No problems with instrumentation. Biggest challenge has been setting up the communication system, upgrading MMI software at the wastewater plants and setting up data management system. Download data every 10 – 60 seconds, so a lot of information and need to figure out how can manage so can pick fields and create queries to look at specific things and do data rollups. All took about 1.5 years.
12. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	

C·V·R·D

COWICHAN VALLEY REGIONAL DISTRICT
Engineering Services

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Shawnigan Beach Estates Sanitary Sewage System
Provided by Alina Lintea, CVRD, 07/04/08

1. Where is the plant located?	Block of District lot 11E&N, Shawnigan District
2. What type of plant is it? List all treatment processes at the facility.	Class A –High quality secondary after sub-surface denitrification beds; The system comprises: an aerated Lagoon, an unaerated lagoon with alum addition for phosphorous removal and flow equalization, a microscreen drum filter, an ultraviolet disinfection system, pressure ground disposal to 36 infiltration beds (18 pairs) with a reserve area large enough for 18 basins
3. What is the plant capacity, and what is the operating capacity?	Max Daily flow: 591m3/d Average Daily Flow 337 m3/day
4. What parameters is the plant designed to treat and what are the permit limits?	BOD (10 mg/L), TSS (10 mg/L), turbidity (5 NTU), total N (20 mg/L), nitrate N (10 mg/L), total P (1 mg/L), fecal coliform (14 cfu/100 ML)
5. What type of on-line instrumentation is used at the facility?	Flow Recording device Proposed UV Units and Drum Filter monitoring devices
6. What is the make/model of the instrumentation?	Flow Recording Device through Wet Well Geometry transmitted to SCADA PACK 32
7. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	CLEAR SCADA software with a Host Terminal at the CVRD office; Transmission by Modem from remote sites to the host

C·V·R·D

COWICHAN VALLEY REGIONAL DISTRICT
Engineering Services

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Shawnigan Beach Estates Sanitary Sewage System
Provided by Alina Lintea, CVRD, 07/04/08

8. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Digital files and paper files
9. How long has automated monitoring been in place?	1 Year
10. How many operating and maintenance staff are involved at the plant? What are their hours?	One operator 2 hours per day
11. What type of O&M is carried out on monitoring equipment?	Regular Servicing Daily monitoring of host
12. What are the estimated time requirements for maintenance of the remote monitoring system and the estimated time savings as a result of using the system?	Hard to estimate as we are continuously adjusting the SCADA methodology. We hope in long term to see time and cost savings.
13. Have there been any issues with the automation system, and if so, what type?	Power outages caused disruptions False signals
14. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	Cowichan Bay Sewer Pump Station; Shawnigan Beach Estates-Dosing Pump Station for Disposal Fields; Lakeside Estates Treatment Station (the on-line instrumentation for these systems has never been fully functional)

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Paul Nicholls, Corix Utilities, 07/03/08

1. Where is the plant located?	Langford, BC
2. What type of plant is it? List all treatment processes at the facility.	13 lift stations
3. What is the plant capacity, and what is the operating capacity?	n/a
4. What type of on-line instrumentation is used at the facility?	PLC to cable; 2 are on landlines
5. What is the make/model of the instrumentation?	Mostly Allen-Bradley & Milltronics, plus a scatter of other suppliers.
6. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	Unknown; 11 on cable; 2 on landline
7. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	Remote data storage at a secure location.
8. How long has automated monitoring been in place?	2.5 years
9. How many operating and maintenance staff are involved at the plant? What are their hours?	2 FTE
10. What type of O&M is carried out on monitoring equipment?	Normal O&M checking and cleaning operations
11. Have there been any issues with the automation system, and if so, what type?	Unnecessary alarm callouts, trouble shooting annoyance alarms, build in delays to avoid unnecessary alarms
12. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	Corix is in the process of developing a SCADA Package for all of its water and wastewater systems. VTS SCADA Package by Trihedral Systems; Control Microsystems SCADAPAC 32 PLC, communicate by radio then broadband Ethernet to secure servers and on the web.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Dean Puzey, Water Corporation, 06/30/08

1. Where is the plant located?	Water Corporation of WA, Walpole Wastewater Treatment Plant, Walpole, Western Australia (approximately 450km South of Perth).
2. What type of plant is it? List all treatment processes at the facility.	Wastewater Treatment plant. Inline ‘muncher’ (for cutting of rags etc), cylindrical bioselector/grit chamber, cylindrical IDEA basin, submerged tubular aeration diffusers, lever arm decanter system, separate digestor, sludge drying beds. Final effluent pumped to storage dam and filtered / chlorinated before irrigation to woodlot.
3. What is the plant capacity, and what is the operating capacity?	200 m3/day of raw inflow. Plant currently operating at approximately 60% capacity.
4. What type of on-line instrumentation is used at the facility?	Level sensors, dissolved oxygen meter, conductivity probes, pump status, motor status, pump station status, valve status, alarm status, magflow meters, variable speed controllers, differential pressure switches, chlorine leak sensor / alarms.
5. What is the make/model of the instrumentation?	HACH dissolved oxygen probe with SC100 controller, TRAFAG 8838.21 level elements, Q6M level switch, Foxboro IDP10 differential pressure switch, Danfoss VLT5000 variable speed controller, level switch ATO-11-S-I/H-ATO actuating rod.
6. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	CITECT and SCX-6 systems (dual at present). Information communicated to central control centre via landline (ADSL).
7. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	CITECT uses localised data storage files. SCX-6 used remote database.
8. How long has automated monitoring been in place?	5 years.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Provided by Dean Puzey, Water Corporation, 06/30/08

9. How many operating and maintenance staff are involved at the plant? What are their hours?	One district operator, one district electrician and one district mechanical fitter. Nominal hours are 0730 to 1630 each weekday. These personnel are on call in order to attend breakdowns and emergency repairs.
10. What type of O&M is carried out on monitoring equipment?	Routine maintenance in line with manufacturers' requirements and breakdown maintenance as required.
11. Have there been any issues with the automation system, and if so, what type?	Implementation of SCX-6 was troublesome due to delay in communication between site and central database system (prior to ADSL broadband installation).
12. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	N/A.

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE

Provided by Alberto Casiraghi, Endress+ Hauser, 09/11/08

1. Where is the plant located?	The plant is located in Cologno al Serio, Bergamo county in Italy, and it cover 10 villages around that.
2. What type of plant is it? List all treatment processes at the facility.	It's a potable water distribution plant that control from one side the water abstraction from the well, the disinfection by chlorine, and the distribution in the cities
3. What is the plant capacity, and what is the operating capacity?	They are covering 60.000 thousand domestic and some hundred of industrial users, distributing 20.000 cubic meter per day
4. What type of on-line instrumentation is used at the facility?	On-line instrumentation include level in the well, flow and pressure transmitter in the network and chlorine analyzer in the disinfection stations
5. What is the make/model of the instrumentation?	Instrumentation is mainly E+H since the plant and the distribution schemes were constructed in different phases, before Scada supply.
6. What type of SCADA system is used and is information communicated by landline, cell, or satellite?	The Scada type used is HEIDI and collect the remote data using GSM cell lines. Heidi is not software product but a service center that provides remote control functionalities to small water customer, avoiding them to make investment into IT technology, having full Scada functionality through a WEB remote service center where the water customer are connected through the internet.
7. Do you use localized data storage (digital files), paper files, or a remote database for data storage?	The remote data acquisition system collect and store datas in a remote databases that are transferred centrally on a periodic time base

DECENTRALIZED SYSTEM CASE STUDY QUESTIONNAIRE
Provided by Alberto Casiraghi, Endress+ Hauser, 09/11/08

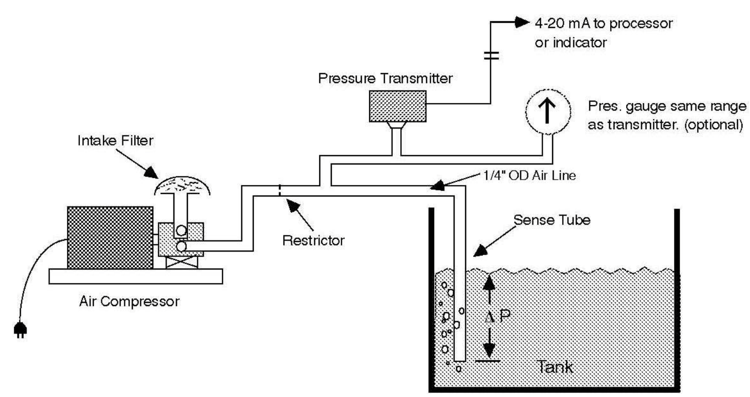
8. How long has automated monitoring been in place?	It's working since 4 year
9. How many operating and maintenance staff are involved at the plant? What are their hours?	Before the SCADA installation 2 people on 5 days / week on 8 hours. After that only 1 person is running the operation and the maintenance on demand.
10. What type of O&M is carried out on monitoring equipment?	There are periodic preventative maintenance checks scheduled on time base, and corrective activities scheduled automatically by data acquisition fault
11. Have there been any issues with the automation system, and if so, what type?	No
12. Can you provide an estimate of the capital cost of the installed instrumentation and SCADA system?	Only the Scada system supply was 75.000 $ without cabling and installation that has been provided directly by the customer.
13. Do you know of any other facilities that we could use as potential case studies? Please provide contact details.	No

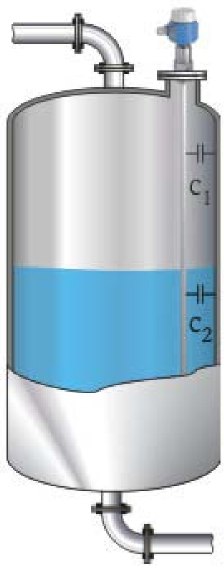
APPENDIX C

LIQUID LEVEL INSTRUMENTATION

Liquid Level

There are numerous instrument technologies that measure liquid level. Liquid level instrument technologies are categorized by this research project's definition of traditional (available and in wide-spread use for many years) and non-traditional (not in wide-spread use) sensors for wastewater treatment systems, as they pertain to decentralized wastewater treatment systems. The following tables provide level instrument technology descriptions and specifications.

<table>
<tr><th colspan="2">Traditional and Non-Traditional Liquid Level Instrument Technology Descriptions</th></tr>
<tr><th>Traditional and Non-Traditional Instrument Technologies</th><th>Instrument Description</th></tr>
<tr><td colspan="2">Traditional</td></tr>
<tr><td>Bubbler Systems</td><td>Bubbler systems are comprised of a source of compressed air, air flow restrictor, sensing tube and pressure transmitter. The bubbler system sensing tube is installed directly in the process or basin and is connected to the pressure transmitter and air supply through the flow restrictor which can be located in a remote location or protected area. The depth of fluid is determined by the pressure required to displace the liquid and is measured by the fluid depth above the open end of the sensing tube. If an application of measuring liquid level for only the top part of a tank or basin, the sensing tube does not need to extend to the bottom of the tank or basin. Instead, a shorter sensing tube and lower ranged pressure transmitter can improve the resolution and accuracy of the bubbler system. However, if the liquid level is above the air-supply and pressure transmitter, then installing a check valve at the high point in the air line will prevent siphoning of the fluid back to the transmitter and air compressor if there is a power failure. A typical bubbler system configuration is provided courtesy of Kele & Associates (22).

</td></tr>
</table>

Traditional and Non-Traditional Liquid Level Instrument Technology Descriptions	
Traditional and Non-Traditional Instrument Technologies	Instrument Description
	Bubbler systems can accomplish more precise level control than float switches but can be subject to grease plugging and air leaks. In addition, bubbler systems require auxiliary equipment such as compressors, purging valves, and rotameters to control air flow.
Capacitance Probes	The principle of capacitive level measurement is based on the capacitance change of a capacitor. The capacitance probe system uses an oscillator at one end of the probe (ground potential) to impresses a sinusoidal voltage in series with the probe.  An insulated electrode makes the tank a capacitor whose capacitance is dependent on the amount of product inside the tank, an empty tank has a lower capacitance and a filled tank a higher capacitance. The measurement is independent of the dielectric constant (DK) as long as the liquid inside the tank has a conductivity of 100 µS/cm or more. In this way, various liquids can be measured, figure courtesy of Endress+Hauser (23).
Conductive	The Conductive Level Technology method of liquid level measurement is based on the electrical conductance of the measured material, which is usually a liquid that can conduct a current with a low-voltage source (normally <20 V). One, two or more electrodes are arranged above the conductive fluid that is to be detected. If the filling material reaches the electrodes and makes contact, the circuit between the electrodes is closed and a switching signal is triggered. Such probes are generally used for point level detection, and the detected point can be the interface between a conductive and nonconductive liquid (24).
Differential Pressure	The differential pressure (DP) detector method of liquid level measurement uses a DP detector connected to the bottom of the tank being monitored. The higher pressure, caused by the fluid in the tank, is compared to a lower reference pressure (usually atmospheric). This comparison takes place in the DP detector (25).

Traditional and Non-Traditional Liquid Level Instrument Technology Descriptions	
Traditional and Non-Traditional Instrument Technologies	Instrument Description
Float Switches	Float switches are used to measure level in tanks, wells, and sumps to control pumps and have many configurations. Single or multiple switch configurations can be installed to accomplish pump control. Float switches are prone to fouling especially with rags.
Hydrostatic Pressure	Another type of level measurement employs a submerged pressure transducer. A pressure transducer is suspended from a cable, similar to a float switch, and is submerged in the process. The pressure transducer measures the actual water head of the wet well, tank, or sump and converts the pressure reading to a level measurement signal that in turn is typically used by a pump controller to turn pumps on and off.
Radio Frequency (RF) Admittance	RF Admittance employs a radio frequency signal. A change in RF admittance indicates either the presence or absence of material or how much material is in contact with the sensor, making it highly versatile and a good choice for a wide range of conditions and materials for point or continuous level measurement (26).
Site Gauge	Liquid in a tank or vessel is connected to the site gauge glass by a suitable fitting, and when the tank is under pressure the upper end of the glass must be connected to the tank vapor space. Thus the liquid rises to substantially the same height in the glass as in the tank, and this height is measured by suitable scale (27).
Thermal	Thermal dispersion technology for level measurement uses the temperature difference between the two RTDs which is greatest in the absence of liquid and decreases when the level element is submerged, cooling the heated RTD. An electronic control circuit converts the RTD temperature difference into a DC voltage signal. Both signals are provided at output terminals to drive two adjustable-setpoint alarm circuits (28).
Ultrasonic	Ultrasonic level systems are not required to be installed within the treatment process and therefore can provide an advantage over bubbler systems and float switches for level measurement. Since the ultrasonic level sensors do not have contact with the process, the level instrument can avoid fouling from grease or rags. However, installations of ultrasonic level systems must consider interference from sidewalls of the station wet wells and other protrusions into the wet well, tank, or sump walls such as rails for submersible pumps. These interferences can cause false signals to be transmitted to an ultrasonic level system and therefore cause erroneous level measurements.
Non-Traditional	
Acoustic Wave	A high powered acoustic wave transmit pulse is transmitted which is reflected from the surface of the material being measured. The reflected signal is processed using specially developed software to enhance the correct signal and reject false or spurious echoes. The transmission of high powered acoustic waves ensures minimal losses through the environment where the sensor is located. Due to the high powered emitted pulse, any losses have far less effect than would be experienced by traditional ultrasonic devices. More energy is transmitted hence more energy is returned (29).
Interface Level	Interface level measurement equipment includes sensors and meters for detection and measurement of interface levels between different media, such as oil/water interfaces and liquid/solid interfaces. Some interface level measurement equipment can measure the interface between a liquid and a settled bed of solids. Other interface level measurement equipment can detect the interface between a liquid and a floating bed of solids. Yet other interface level measurement equipment can measure the interface between liquid phases of significantly different viscosities. Interface level measurement equipment is also sometimes referred to as oil water analyzers, water oil analyzers, liquid solid

Traditional and Non-Traditional Liquid Level Instrument Technology Descriptions	
Traditional and Non-Traditional Instrument Technologies	Instrument Description
	analyzers, or oil level measurement equipment, depending upon the application (30).
Laser	Single point laser instruments are designed & manufactured for use in level control & position measurement. Narrow beam divergence allows for accurate measurement within a vast range of applications ranging from straight forward silo monitoring, hazardous area applications, hygienic environments to high speed crusher control. Distances varying from 0.5m to 1400m can be measured with impressive accuracy (31).
Magnorestrictive	Magnetostrictive uses an electric pulse from ferro-magnetic wire to detect the position of a float with embedded magnets. As the pulse intersects the magnetic field from the float, a second pulse is reflected back to an electric circuit that accurately reads the level (26).
Microwave	Microwave level sensors use microwave beam focusing technology that reduces interference noise. Similar to ultrasonic level systems, microwave level sensors also avoid fouling because they are not required to be in contact with the treatment process.
Radar	Radar measurement technology measures the time of flight from the transmitted signal to the return signal. From this time, distance measurement and level are determined. Unlike ultrasonic measurement, radar technology does not require a carrier medium and travels at the speed of light (300 000 000 m/s). Most industrial radar devices operate from 6 to 26 GHz. Pulse radar emits a microwave pulse from the antenna at a fixed repetition rate that reflects off the interface between the two materials with different dielectric constants (the atmosphere and the material being monitored). The echo is detected by a receiver and the transmit time is used to calculate level. FMCW (Frequency Modulated Continuous Wave) radar devices send microwaves to the surface of the material. The wave frequency is modulated continuously. At the same time, the receiver is also receiving continuously and the difference in frequency between the transmitter and the receiver is directly proportional to the distance to the material. Guided Wave Radar combines TDR (time domain reflectometry), ETS (equivalent time sampling) and modern low power circuitry. Time Domain Reflectometry (TDR) uses pulses of electromagnetic (EM) energy to measure distances or levels. When a pulse reaches a dielectric discontinuity (created by media surface), part of the energy is reflected. The greater the dielectric difference, the greater the amplitude (strength) of the reflection (32).

C.1 Bubbler Systems

Bubbler Systems												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
meters, ft	Bubbler System	Avensys	BB-400 Intelligent Bubbler System	BB-400	pressure to measure level measurement in remote areas of surface water and ground water.	Ex-situ	0 to 20 meters		±0.1% FS	Refreshing rate: 60 seconds or less		Purge rate: 1 to 30 times a month; Purge duration: 1 to 10 seconds each tube
psi, ft	Bubbler System	Campbell Scientific	DB1	DB1	detects level by measuring the pressure required to force nitrogen bubbles from a pair of submerged tubes.	In-Situ	Three models: 0 to 5 psi (0 to 11.5 ft); 0 to 15 psi (0 to 34.5 ft), 0 to 30 psi (0 to 69 ft.)		Accuracy: ±0.05% of Full Scale Range			Self-calibrating system

Bubbler Systems												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
meters, ft	Bubbler System	Motor Protection Electronics, Inc.	BS2000	BS2000	fully automatic dual compressor bubbler system	Ex-situ	Field Calibration range: from 10ft/H2O up to 20ft/H2O					Automatic Bubbler Tube Purge and Air Tank Moisture Dump Cycle, Performed Every 6 Hours.
psi, ft, meters	Bubbler System	Sutron	Accubar Constant Flow (CF) Bubble Gauge	Accubar Constant Flow	device for measuring water levels and consists of a pump, tank, manifold, control board, display/keypad & enclosure.	Ex-situ	0-22 psi, 0-50 ft.	Resolution: 0.0001 psi	0-25 ft. 0.02% FSO; 26-50 ft. 0.05% of reading			

C.2 Capacitance Probes

Capacitance Probes													
Units	Technology	Manuf Name	Model	Sensor Model	Measure-ment Method	Sensor Location	Measure-ment Range	Measure-ment Uncertainty	Accurac y	Measuremen t Interval	Respons e Time	Calibration Frequency
m, ft, mm, in	capacitance	Bindicator	VRF Series	VRF 1000 & 2000	variable radio frequency	in-situ for dry bulk level measure ment	0 to 45 ft (13.71 mm) or 540 in (13716 mm)				Dip-switch selectabl e for 1, 4, 8 or 15 seconds	push-button, intelligent re-calibration
mete rs, ft	Capacitanc e	Endress + Hauser	Liquicap T FMI21	FMI21	used in conductive liquids (as of 30 µS/cm) for continuous level measuremen t	In-Situ						preconfigur ed from factory 0 %...100 % to probe length ordered
mete rs, ft	Capacitanc e	Endress + Hauser	Liquicap M FMI51 (rod probe), FMI52 (rope probes)	FMI51 (rod probe), FMI52 (rope probes)	The principle of capacitive level measuremen t is based on the capacitance change of a capacitor.	In-Situ	Rope probe: 0.42...12.00 0 m; Rod probe: 0.1...6 m					factory calibrated to the ordered probe length (0 %...100 %)
mete rs, ft	Capacitanc e	Endress + Hauser	Liquicap M FTI51 (rod probe), FTI52 (rope probe)	FTI51 (rod probe), FTI52 (rope probe)	The principle of capacitive level measuremen t is based on the capacitance change of a capacitor.	In-Situ	Rod length L1 max. 4 m; Rope length L1 max. 10 m					factory calibrated to the ordered probe length (0 %...100 %)

Capacitance Probes												
Units	Technology	Manuf Name	Model	Sensor Model	Measure-ment Method	Sensor Location	Measure-ment Range	Measure-ment Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	RF capacitance	Jerguson Gage and Valve, A Division of the Clark-Reliance Corporation	300 Series		radio frequency capacitance	in-situ					Output Dampening......0.1 to 10 seconds	
m, ft, mm, in	capacitance	Level Controls	Pro	pro-flush mount	capacitance; PRO series probes operate at approximately 6 kHz and do not generate radio frequencies	in-situ						Electronic stability that will firmly hold calibration.
m, ft, mm, in	Capacitance	Lumenite Control Technology, Inc.	MLST-4220		Radio Frequency	in-situ			Accuracy and repeatability to less than 0.1% of span			4-20mA, 20-4mA and 0-100% calibration
m, ft, mm, in	Capacitance	Metex Corporation, Ltd.	KENCO KRF		Radio Frequency	in-situ						
m, ft, mm, in	capacitance	Pepperl + Fuchs, Inc.	LCL Series		a metal plate at the end of the probe, within the insulation, and the	in-situ	limit level (limit value)					

Capacitance Probes												
Units	Technology	Manuf Name	Model	Sensor Model	Measure-ment Method	Sensor Location	Measure-ment Range	Measure-ment Uncertainty	Accurac y	Measuremen t Interval	Respons e Time	Calibration Frequency
					surroundings (e.g. the silo walls) combine to form the two electrodes of a capacitor							
m, ft, mm, in	capacitance	SAPcon	MPILC		The measuring electrode and the container wall (or grounding probe) form an electrical capacitor with the material as the dielectric.	in-situ	Minimum 10% of zero setting to 4500 pF		+/- 1-2% of Full Measuri ng Span			Calibration possible without completely filling and emptying the vessel
m, ft, mm, in	Capacitanc e	Siemens	SITRAN S LC300		Radio Frequency	in-situ		Non-linearity and repeatability: < 0.4% of full scale and actual measuremen t value	Transmit ter Accurac y: Deviatio n < 0.5% of actual mea-suremen t value. Temper ature stabliity:			

Capacitance Probes												
Units	Technology	Manuf Name	Model	Sensor Model	Measure-ment Method	Sensor Location	Measure-ment Range	Measure-ment Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
									0.25% of actual capacitance value.			
m, ft, mm, in	Capacitance	Siemens	Pointek CLS 100		Radio Frequency; Inverse frequency shift capacitive level detection	in-situ		Repeatability: 2 mm (0.08")				
m, ft, mm, in	Capacitance	Siemens	LC 500		Radio Frequency	in-situ			Deviation < 0.1% of measured value		1 to 60 s	
m, ft, mm, in	capacitive	Vega	Vegacap	CAL 69 twin probe for plastic/non-mettalic tanks	radio frequency	in-situ	0.2 to 6 m (0.656 to 19.69 ft)				0.5 s; 1 s in event of failure	

C.3 Conductive

Conductive												
Units	Technology	Manuf. Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	Conductive, Limit Switch	Krohne	LS 7000 Series		Electrical Resistance	in-situ	single point					
m, ft, mm, in	Conductive	Krohne	BM 500		Potentiometric;	in-situ	50 mm / 2" (configurable using keys)..... 3 m (10 ft)	Repeatability: ± 0.1% of the max. measuring rod length	± 0.5%		T66 10 ms	
m, ft, mm, in	Conductive, Limit Switch	Pepperl + Fuchs	LKL Series		Electrical resistance	in-situ	up to 4 switch points (can detect conductive & non-conductive interface layers)	Repeatability: ± 5 % at 100 Ohms...100 k Ohms	measuring error: ± 10 % at 100 kOhms; ± 5 % at 1k Ohms			
m, ft, mm, in	Conductive, limit switch	SapCon	SLW Series		Electrical Resistance;	in-situ	up to four point switching				0.5 second	
m, ft, mm, in	Conductive, Limit Switch	Solinst	101		Electrical Resistance;	in-situ	point meas; The 101 Mini is available in 65 ft and 20 m lengths.					
m, ft, mm, in	Conductive	Vega	Vegakon		Electrical resistance	in-situ						

C.4 Differential Pressure

Differential Pressure												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Re-sponse Time	Calibration Frequency
mbar, psi	capacitive	Endress + Hauser	Deltabar S PMD75	PMD75	Differential pressure	in-situ	Measuring range: from -10...+10 mbar to -40...+40 bar	Turn down 100:1, higher on request	Reference accuracy: up to 0.075% of the set span, PLATINUM version: 0.05% of the set span.			
mbar, psi	capactive	Endress + Hauser	Deltabar S PMD70	PMD70	Differential pressure	in-situ	Measuring range: from -25...+25 mbar (-10 to +10 in H20) to -3...+3 bar (- 43 to +43 psi).	Turn down 100:1, higher on request	Reference accuracy: up to 0.075% of the set span, PLATINUM version: 0.05% of the set span			

Differential Pressure													
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Re-sponse Time	Calibration Frequency
mbar, psi	capacitive	Endress + Hauser	Deltabar S FMD76	FMD76	Differential pressure	in-situ	Measuring range: from -100...+100 mbar (40 in H2O to + 40 in H2O) to -3...+3 bar (-45 psi to +45 psi)	Turn down 100:1, higher on request	Reference accuracy: up to 0.075% of the set span, PLATINUM version: 0.05% of the set span			
m, ft, mm, in.	capacitive	Foxboro	IDP Series		differential pressure	in-situ						
m, ft, mm, in	capactive	PMC, Process Measurement & Controls, Inc.	Dip Stick Level Probe		hydrostatic pressure	in-situ	Ranges: 0 to 5" WC through 0 to 300 PSI (vacuum & absolute)		static accuracy: +/- 0.25% of full scale			
m, ft, mm, in	capacitive	Rosemount Emerson Process	2024 Differential Pressure Transmitter		pressure	in-situ	0 - 50 to 0 - 1,000 in H2O; 5:1 rangeability	stability: +/- 0.25% of upper range limit for six months	0.25%			
m, ft, mm, in	capactive	Yokogawa	EJX110A Differential Pressure Transmitter		pressure	in-situ						

C.5 Float

Float													
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	buoyancy (based on Archimedes buoyancy principle)	Foxboro	Eckardt		positive displacement	in-situ						
m, ft, mm, in	float	Jerguson Magne-Sonics, Clark-Reliance	Float Displacer		positive displacement	in-situ						
m, ft, mm, in	float switch	Pepperl + Fuchs	LFL Series		positive displacement	in-situ						
m, ft, mm, in	float and tape	Varec	2500		postive displacement	in-situ	0 to 60 ft (18 m) Extended range 0 to 96 ft (29 m); Product gravity range: 0.7 to 1.9 g/cc (700-1900 kg/m³)					

C.6 Hydrostatic Pressure

Hydrostatic Pressure												
Units	Technology	Manuf. Name	Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Re-sponse Time	Calibration Frequency
m, ft, mm, in	capacitive	Ametek Drexelbrook	750 Series		hydrostatic pressure via its sensing element, an ion implanted silicon semiconductor chip with integral Wheatstone Bridge circuit.	in-situ	up to 690 ft		"+0.25% full scale, +0.50% full scale (6 psi range only)"			0 to 3 psi or 0 to 0.2 bar (0 to 7 feet or 0 to 2.1 meters of water) to 0 to 300 psi or 0 to 20 bar (0 to 690 feet or 0 to 211 meters of water).
psi, ft	Pressure transducer	Campbell Scientific	CS431-L	CS431-L	Piezoresistive strain gage technology to measure water level in streams.	In-situ	Available pressure ranges are 5, 15, 30, 50, or 100 psig	Linearity is ±0.1% FSO, typical	Repeatability is ±0.1% FSO, typical			

Hydrostatic Pressure												
Units	Technology	Manuf. Name	Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Re-sponse Time	Calibration Frequency
mbar, psi	Hydrostatic pressure	Endress + Hauser	Deltapilot S	Deltapilot S	Hydrostatic pressure	In-situ	Measuring ranges: from -100...+100 mbar to -900...+10000 mbar; from -1.5...+1.5 psi to -13...150 psi	Maximum linearity (better than 0.1 % of the set measuring range). Minimum temperature effects (better than 0.1%/10 K).				
mbar, psi, meters, ft	Hydrostatic pressure	Endress + Hauser	Waterpilot FMX 167	FMX 167	Hyrdostatic pressure		Measuring ranges: from 1.5 to 300 psi; nine fixed pressure measuring ranges in psi, ft H2O, bar and m H2O	Long-term stability: ± 0.1% of Full Scale per year	± 0.2% of Full Scale, Pt 100 (optional): max. ± 0.7 K			s nine permanently calibrated measuring ranges from 0.1 bar to 20 bar (1.5 psi to 300 psi)
m, ft, mm, in	capacitive	GE Sensing	1830/1840 Series		hydrostatic pressure	in-situ	Ranges from 0.75 m H2O to 600 m H2O (1 to 900 psi)		+/- 0.06% full scale (FS) best straight line (BSL)			

Hydrostatic Pressure												
Units	Technology	Manuf. Name	Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Re-sponse Time	Calibration Frequency
m, ft, mm, in	capacitive	Global Water	WL 450		hydrostatic pressure	in-situ	0 to 3 ft; 0 to 900 ft		total error band: +/- 0.1%; 16 bit digital error correction			
m, ft, mm, in	capacitive	Mobrey	9700	flush mounted ceramic sensor	hydrostatic head	in-situ	up to 200 m / 656 ft H2O; 10:1 rangeability	Stability: +/- 0.1% URL per 6 months	+/- 0.1% of calibrated span	Over range limit: 5X range up to a max 600 m / 1968 ft H2O		
m, ft, mm, in	capacitive	Pepperl + Fuchs	LGC Series		hydrostatic head;	in-situ	Nine permanently calibrated measuring ranges from 0.1 bar to 20 bar					
m, ft, mm, in	capacitive	Sensor Technics	KTE/KTU 6000		hydrostatic pressure	in-situ	0 to 6000 psi					
m, ft, mm, in	capacitive	Siemens	Sitran S P MPS		piezzo-resistive sensor	in-situ	standard: 2, 4, 6, 10 and 20 m; on request: from 1 to 200 m H2O (3 to 600 ft H2O)		< 0.3%; long-term stability < 0.2% / 12 months			
m, ft, mm, in	capacitive	Vega	Vegabar 6072		hydrostatic pressure	in-situ			0.1%			

C.7 Radio Frequency (RF) Admittance

Radio Frequency (RF) Admittance													
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	RF Admittance	Ametek Drexelbrook	IntelliPoint RF (Line Powered)		capacitance and resistance	in-situ					Less than 1 second	
m, ft, mm, in	RF Admittance	HAWK	Gladiator		capacitive and resistive;	in-situ	0.2 pF - 100 nF		0.05 pF			
m, ft, mm, in	RF Admittance	SAPcon	SLA M Series		capacitive and resistive	in-situ					0.2 Seconds	

C.8 Site Gauge

Site Gauge												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	Site Gauge	Jerguson, Clark-Reliance	Magnicator II		visual observation	In-situ						
m, ft, mm, in	Site Gauge	Jerguson, Clark-Reliance	Jerguson Gage and Valve		Visual Inspection	in-situ						
m, ft, mm, in	Site Gauge	PLT	MAG-GAGE 281-332 MAG1 (6241)		Visual inspection	in-situ						
m, ft, mm, in	Site Gauge	PLT, Process Level Technology, Ltd	C-Flo-360 Magnetic Site Flow		Visual Observation	in-situ						
m, ft, mm, in	Site Gauge	PLT, Process Level Technology, Ltd	Mag-Gage		Visual Observation	in-situ						
m, ft, mm, in	Site Gauge	Quest-Tec Solutions	Level-Trac		Visual Observation	in-situ						
m, ft, mm, in	Site Gauge	Quest-Tec Solutions	Magne-Trac		Visual Observation	in-situ						
m, ft, mm, in	Site Gauge	Quest-Tec Solutions	Level-Trac		Visual inspection	in-situ						
m, ft, mm, in	Site Gauge	Quest-Tec Solutions	Magne-Trac		Visual inspection	in-situ						

C.9 Thermal

Thermal												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
in., mm	thermal dispersion	FCI	FLT93	Models, S and F, L, C	temperature difference between the two RTDs is greatest in the absence of liquid and decreases when the level element is submerged	in-situ		Repeatability: ± 0.125 inch [± 3.2 mm]	For Level/Interface Service: ± 0.25 inch [± 6.4 mm] ; For Temperature Service: ± 2° F [± 1° C]		As low as 3 seconds	Factory Application-Specific Set-up and Set-point Calibration
in., cm	thermal dispersion (calorimetric principle)	KAYDEN	CLASSIC^(tm) 800 Series	810 thru 832	The thermal dispersion (calorimetric principle) is based on two temperature sensors which are in close contact with the process	in-situ	user specified	Repeatability: ±0.125 inch (±0.32 cm)	±0.25 inch (±0.64 cm)		0.5 to 30 seconds. Actual response time can vary due to fluid type, direction of change and specific application.	

Thermal												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
Level Switch: Switch on level change of 0.03 inch	Thermal	Sierra Instruments, Inc.	Innova-Switch		Level detection is accomplished by using a high-resolution thermal differential technique.	in-situ	Level Switch: Switch on level change of 0.03 inch	Repeatability: +/- 1% of setpoint (Flow) or 1/32" (0.8mm) Level	Stability: Drift <0.5% from calibrated setpoint over a range of +/- 50F. Temperature compensated through entire range.		Level Switch: 0.1 to 1 second (media dependent).	

C.10 Ultrasonic

Ultrasonic												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mm, m, in., ft	Ultrasonic	Endress + Hauser	Prosonic T FMU230	FMU230	Non-contact level measurement in liquids using the Time-of-Flight principle.	Ex-situ	FMU 230 up to 2 m / 6.6 ft in liquids up to 4 m / 13.1 ft					
meters, ft	Ultrasonic	Endress + Hauser	Prosonic S - Transducer FMU90	FMU90	Non-contact level measurement in liquids using the Time-of-Flight principle.	Ex-situ	Measuring range up to 70 m (depending on sensor and material measured).					
meters, ft	Ultrasonic	Endress + Hauser	Prosonic M FMU40	FMU40	Non-contact level measurement in liquids using the Time-of-Flight principle.	Ex-situ; Non-contact measurement method, therefore almost independent of product properties.	FMU 40, 5 m in fluids					

Ultrasonic													
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
meters, ft	Ultrasonic	Campbell Scientific	SR50A	SR50A	The sensor is based on an electronic transducer that determines the distance to a target	Ex-situ	Measurement range 0.5 to 10 meters. 1.6 to 32.8 ft (0.5 to 10 m)	Beam Acceptance: ~30°; Resolution: 0.01" (0.25 mm)	Accurate to one centimeter or 0.4 percent of distance to target (whichever is greater); requires external temperature.		Less than one second measurement time	
meters, ft	Ultrasonic	Endress + Hauser	Prosonic S - Sensors	FDU91	Non-contact level measurement in liquids using the Time-of-Flight principle.	Ex-situ	FDU91/91F: 10 m in fluids					

C.11 Acoustic Wave

Acoustic Wave												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft	ultrasonic	Hawk	234		high powered acoustic waves	in-situ	0 - 182 m (597 ft)	Resolution: 1 mm (0.04") 5-50 kHz; 4 mm (0.2") 4-9 kHz	+/- 0.25% of max range			

C.12 Interface Level

Interface Level												
Units	Tech-nology	Manuf. Name	Model	Sensor Model	Measure-ment Method	Sensor Lo-cation	Measure-ment Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Response Time	Calibration Frequency
m, ft, mm, in	ultrasonic	Ametek Drexelbrook	CCS 4000		ultrasonic echo	in-situ	max. tank depth 30 ft (9.14 m); max. span 29 ft (8.84 m); near zone 1 ft (0.3 m); dead zone 3 inches (76 mm) from tank bottom		1% of tank depth or 1.0" (25 mm) whichever is greater transducer			

Interface Level												
Units	Tech-nology	Manuf. Name	Model	Sensor Model	Measure-ment Method	Sensor Lo-cation	Measure-ment Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Response Time	Calibration Frequency
m, ft, mm, in	vibrating probe	Dynatrol	CL-10DJI Interface Level Detector		mechanical oscillations;	in-situ						
feet or meters	Ultrasonic	Entech Design	BinMinder 9300™	Wiper Transducer	Underwater acoustic (ultrasonic)	In-Situ	0 to 328 ft. / 0 to 100 m		+ / - 0.5% of measurement range or 0.5 in., whichever is greater			
inches, feet or meters	Ultrasonic	Hach	OptiQuant Sludge Level Monitor	OptiQuant SLM	ultrasonic pulse	In-Situ	7" - 19.7' (0.2-6.0 m)	Resolution: 1" (0.03 m) Stability (per 24 hr period) <0.33 ft	Accuracy: +/- 0.33 ft Measurement Deviation: 3.25" (0.1 m)		6 seconds Response Time User selectable from T90 in 9 seconds to 600 seconds	Automatically performs self-testing and calibration daily. Calibration: 6 months
m, ft, mm, in	optical	Markland Specialty	602		infrared LEDs	in-situ	48 in (max) 122 cm		+/- 2 cm (=/- 1 in)			
ft or m	Ultrasonic Sonar	Mobrey formerly Solartron Mobrey	MSL600 Sludge Blanket Level Monitor	MSL600 Sludge Blanket Level Monitor	sonar principle	In-Situ	Operating range 7m/32ft	Sensitivity or Resolution 1” Repeatability ± 0.25%	± 1.38”		1 second minimum, site adjustable	No Calibration required.
m, ft, mm, in	ultrasonic - single	Pulsar	sludge finder		acoustic sensor	in-situ	0.3 to 50 m		0.03 m (30 mm)			

Interface Level												
Units	Tech-nology	Manuf. Name	Model	Sensor Model	Measure-ment Method	Sensor Lo-cation	Measure-ment Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Response Time	Calibration Frequency
	beam											
Feet/Meters, %, mg/L	Optical	Royce Technologies	711	71	Optical	Portable	25 feet				Instantaneous	None
feet or meters	Ultrasonic	Royce Technologies	2501A		Underwater acoustic (ultrasonic)		0 to 100 feet or 0 to 33 meters		0.1 feet			
m, ft, mm, in	optical	Scientific Software Group	mini REEL E-Z oil / water interface meter		infra-red refraction	in-situ						
m, ft, mm, in	guided wave radar	Siemens	SITRANS LG200		TDR - time domain reflectom-etry	in-situ	0.15 to 22.5 m (0.5 to 75 ft)					

C.13 Laser

Laser												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	optical	KTEK	Model LM200 & LM200C		reflector	in-situ	Long range to 394 ft./ 120 m on level & 1150 ft./ 350 m on reflector		+/- 1 in (25 mm)			
m, ft, mm, in	Optical	Optech	Sentry SR		Infrared (IR) 905 nm wavelength	in-situ	up to 25 meters		2-4 cm			

C.14 Magnorestrictive

Magnorestrictive												
Units	Technology	Manuf. Name	Instr. Model	Sensor Model	Measure-ment Method	Sensor Lo-cation	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Response Time	Calibration Frequency
in., ft., mm	magnorestrictive	AMETEK	7250V	7250V	magnorestrictive	in-situ		Repeatability: Equal to Resolution; Linearity: Probes 193" to 600": ± 0.01% of span or ± 0.039", whichever is greater.				
m, ft, mm, in	Magnorestrictive	Ametek Drexelbrook	DM330		Magnorestrictive	in-situ	up to 40 ft		0.1% accuracy of measurement ranges up to 40 ft. or 0.050" (1.27 mm) whichever is greater			

Magnorestrictive												
Units	Technology	Manuf. Name	Instr. Model	Sensor Model	Measure-ment Method	Sensor Lo-cation	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Response Time	Calibration Frequency
in., ft, mm	magnorestrictive	MTS	MC420		Magno-restrictive timed pulse Measured Variable: Product level / interface depending on float selection	in-situ	18 to 216 in. (457 mm to 5486 mm)	Non-linearity: 0.02% Full Scale (F.S.) (independent BSL) or 1/32 in. (0.794 mm) whichever is greater	Repeatability: 0.005% F.S. or 0.005 in. (0.127 mm) whichever is greater		Time Constant: 1 second	Calibration is accomplished by positioning the float and then placing an MTS supplied calibration magnet in the “Zero” or “Span” indentation on underside of housing.

C.15 Microwave

Microwave												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	microwave beam	K-Tek, Kab Instruments	Chute Master		potentiometric point level detector	ex-situ	10 m			Delay time: 100 mS to 30 Sec	100 mS	
m, ft, mm, in	Guided microwave	Pepperl + Fuchs	LTC Series		Pulscon guided radar transmitters		up to 65 ft					
m, ft, mm, in	TDR technology	SICK	LFT			in-situ	3 mm to 2 m (1 to 4 swtich points)					
m, ft, mm, in		Vega	Flex 62									

C.16 Radar

Radar												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	Radar, K-band FMCW 26 GHz	Ametek Drexelbrook	DR7000		TDR	in-situ	0.5 to 40 m (1.5 to 131 ft); dead zone: antenna length + 0.1 m (4")		+/- 3 mm (+/- 0.12 ")			
meters, ft	Radar	Endress + Hauser	Micropilot M FMR230	FMR230	Radar - continuous, non-contact level measurement of liquids, pastes, and slurries	In-situ	Max. measuring range: 20 m (67 ft)					
meters, ft	Guided Radar	Endress + Hauser	Levelflex M FMP40	FMP40	Radar - continuous	In-situ	Measuring range: rope probe: 1...35 m (40...1378"); rod or coax probe: 0.3...4 m (12...178")					
meters, ft	Guided Radar	Endress + Hauser	Levelflex M FMP45	FMP45	Guided level radar measurement using the Time-of-Flight principle.	In-situ	Rod and coax probes up to 4 m (157"), rope probes up to 35 m (1378")					

Radar												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
meters, ft	Radar	Endress + Hauser	Micropilot M FMR240	FMR240	Radar - continuous	In-situ - Non-contact measurement: Measurement is almost independent from product properties.			±3 mm.			
meters, ft	Radar	Endress + Hauser	Micropilot S FMR531	FMR531	Radar - continuous	In-situ	Max. measuring range: 20 m (67 ft), 10 m (33 ft) with custody transfer approvals		0.5 mm accuracy (2ó value). Inventory Control Version with reduced accuracy (3 mm) available for all instrument types.			

Radar												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
meters, ft	Radar	Endress + Hauser	Micropilot S FMR532	FMR532	Radar - continuous	In-situ	Max. measuring range: 38 m (127 ft), 22 m (73 ft) with custody transfer approvals		0.5 mm accuracy (2ó value). National approvals (NMi, PTB) for custody transfer. Inventory Control Version with reduced accuracy (3 mm) available for all instrument types.			
meters, ft	Radar	Endress + Hauser	Micropilot M FMR231	FMR231	Radar - continuous	In-situ - Non-contact measurement:	Max. measuring range: 20 m (67 ft)					
m, ft, mm, in	Pulse Radar	Global Water	WL 900		TDR	in-situ, non-contact measurement	10" to 50'		±0.25% of maximum sensor range (in air)			push-button calibration

Radar												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	Radar	Krohne	Optiflex 1300 C		Time Domain Reflectometry (TDR)	in-situ	4 - 35 m (13 to 115 ft)		+/- 3mm (+/- 0.12") when distance < 10 m (33 ft); +/- 0.03% of measured distance, when distance > 10 m (33 ft)			
m, ft, mm, in	Guided Wave Radar (GWR)	Rosemount, Emerson Process Management	Rosemount 5300 Series		Time Domain Reflectometry (TDR)	in-situ	Up to 164 ft. (50 m)		Reference Accuracy: ± 0.1 in. (± 3 mm) or ± 0.03% of measured distance, whichever is greatest			

Radar												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
m, ft, mm, in	guided wave radar	Rosemount, Emerson Process Management	Rosemount 3300 Series		TDR (Time Domain Reflectometry)	in-situ	77 ft (23,5 m) from upper reference point		± 0.2 inch (5 mm) for probes ≤ 16.4 ft (5 m); ± 0.1% of measured distance for probes > 16.4 ft (5 m)			
ft, meters	Radar	Sutron	RLR-0001-1 Radar Level Recorder	RLR-0001-1	Radar Type: UWB Pulse-Echo Operating at 5.8 GHz for unrestricted, unlicensed operation.	In-Situ	60 feet (18.3 meters)	Resolution: 0.001 ft (3 mm); Beamwidth: 17 degrees	Accuracy: 0.01 ft.	Recording Intervals: User-selectable	every 15 minutes	
m, ft, mm, in	Radar	Varec	7200 Series		TDR	in-situ			±3...10 mm accuracy			
m, ft, mm, in	Radar	Vega	VegaPuls 68		TDR	in-situ	70 m					
m, ft, mm, in	Radar	Vega	VegaPuls 65		TDR	in-situ	30 m		Accuracy +/- 10mm			
m, ft, mm, in	Radar, K Band - high frequency	Vega	VegaPuls 62		TDR	in-situ	35 m		+/- 3 mm			

APPENDIX D

FLOW INSTRUMENTATION

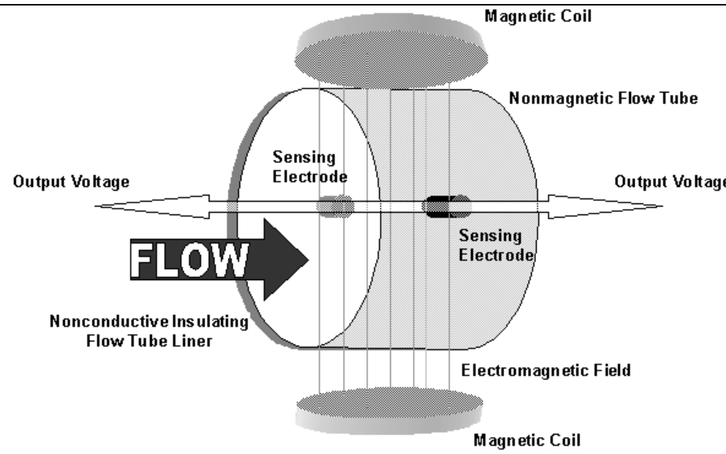
Liquid Flow

There are numerous instrument technologies that measure liquid flow. Liquid flow instrument technologies are categorized by this research project's definition of traditional (available and in wide-spread use for many years) and non-traditional (not in wide-spread use) flow meters for wastewater treatment systems, as they pertain to decentralized wastewater treatment systems. The following tables provide liquid flow instrument technology descriptions and specifications.

Traditional and Non-Traditional Instrument Technologies	***Instrument Description / Principle of Operation***
Traditional	
Area-velocity	Area/velocity flowmeters measure both the level and velocity to obtain a flow value that is based on the continuity equation: Q (flow) = V x A, where V is the average velocity and A is the cross-sectional area of the flow. Area/velocity flowmeters generally consist of three basic components: 1. a level sensor; 2. a velocity sensor; and 3. an electronics module. The level measurement is converted to fluid area based on the geometry of the pipe. The velocity measurement is converted to a mean velocity. Area/velocity flowmeters use electronic modules to calculate flow from measured level and velocity sensor values. The technique for measuring velocity and converting the sensed velocity to a mean velocity is different for the different types of area/velocity flowmeter configurations. Area/velocity flowmeter configurations vary by differing level and velocity sensors. Manufacturers of area/velocity flowmeters offer various combinations of level and velocity sensors. Area/velocity flowmeter level sensors include but are not limited to pressure and ultrasonic technologies. Area/velocity flowmeter velocity sensors include but are not limited to Doppler/reflective, electromagnetic probe; and transmissive sonic technologies. Pressure and ultrasonic level measurements are converted to a fluid area based on the geometry of the pipe. Doppler and electromagnetic velocity measurements are used to calculate a mean velocity and multiply the mean velocity by the pipe cross-sectional area. Transmissive sonic velocity measurements are integrated over the pipe cross-sectional area. Manufacturers offer different combinations of pressure and ultrasonic level sensors individually with one of the three different types of velocity sensors (Doppler/reflective, electromagnetic probe, and transmissive sonic). The electronics module and software used to operate area/velocity flowmeters are proprietary to each flowmeter configuration and manufacturer. Area/velocity flowmeters can be portable or fixed systems. Fixed systems require AC power, while portable units typically use battery power. Various mounting adapters are available for custom applications. Some area/velocity flowmeters require installation, calibration, and maintenance in an enclosed or confined space that has restricted entry and contains known or potential hazards. Area/velocity flowmeters are typically used to measure open-channel and/or closed circular pipe gravity flow, such as partially filled pipe or channel flow, river flows, stream gauging, wastewater collection system flows, storm drain flows, monitoring of inflow/infiltration (I/I), and monitoring of wet weather flows such as combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs). Area/velocity flowmeter wetted materials are typically constructed of corrision-resistant materials such as polyvinyl chloride (PVC); chlorinated polyvinyl chloride (CPVC); 316 stainless steel; and marine grade aluminum. Area/velocity flowmeters can operate over a general range of the following process characteristics: • Velocity Sensor Range: -5 to 20 ft/sec (-1.52 to 6.1 m/s) • Level Sensor Range 0.1 to 12 ft (0.03 to 3.66 m) • Temperature 32 to 160oF (0 to 60oC) Area/velocity flowmeters operate linearly with respect to the volume flowrate. If Reynolds numbers above 10,000 are used, the flowmeter will experience minimum affects from changes in viscosity. Flowmeter manufacturers should be contacted to verify their respective process characteristics, operating ranges, or to discuss other special process considerations. Area/velocity flowmeters' accuracy and repeatability vary with manufacturer and operating conditions. Typical accuracies have been reported by manufacturers as +/-2% of the flowmeter reading. Repeatability information can be obtained by reading ITA's 1998 Area/Velocity Flowmeters for Wastewater

Traditional and Non-Traditional Instrument Technologies	Instrument Description / Principle of Operation
Traditional	
	Collection System Applications performance evaluation report (PER98FM-001). Area/velocity flowmeters require periodic maintenance and calibration. Liquid level sensor readings need to be periodically checked to ensure that sensors are reading actual liquid depth. Verification of actual liquid depth typically requires entering the pipe or channel and taking physical measurements. Actual physical measurement of the liquid level depth determines whether the level sensor needs to be recalibrated. All portable area/velocity flowmeters require periodic battery replacement. In addition, the following area/velocity flowmeter sensors require the following maintenance practices: • ultrasonic level sensors may become coated with grease and require periodic cleaning; • pressure level sensors require periodic replacement or recharging of the desiccant for use on the ambient air reference tube; and • velocity sensors may be impaired or covered by heavy silts or debris and require periodic cleaning. The following lists some of the advantages and limitations of area/velocity flowmeters. Advantages • flowmeters are portable and • flowmeter software provides flowmeter readings into a downloadable format for general computer use. Limitations • confined space requirements for installation, maintenance, and calibration of flowmeters; • flowmeter readings can be affected by upstream/downstream flow blockages; • flowmeters can be affected by silt or debris buildup around the level and velocity sensors; • flowmeter software is proprietary; • area/velocity flowmeters with doppler/reflective velocity sensors may be more appropriate for pipe sizes less than 3 ft (0.91 m) diameter; • area/velocity flowmeters with transit time (or transmissive sonic) velocity sensors may be more appropriate for pipe sizes larger than 3 ft (0.91 m) diameter; and • area/velocity flowmeters with an electromagnetic probe velocity sensor may require a velocity profile for calibration.
Magnetic and Insertion Magnetic	Magnetic flowmeters are based on Faraday's principle of electromagnetic induction. Electromagnetic induction (Faraday's principle) occurs when an electrical conductor (anything that conducts electricity such as water, copper wire, etc.) passes through a magnetic field (typically generated by a magnetic coil) and a voltage is produced at right angles to the magnetic field and the conductor's path. Magnetic flowmeters generally consist of four basic components: 1. a nonmagnetic stainless steel flow tube; 2. magnetic coils; 3. sensing electrodes; and 4. nonconductive insulating flow tube liner. Magnetic flowmeters use the principle of electromagnetic induction to generate a small electrical signal. As a conductive fluid flows through a magnetic induction field generated by magnetic coils on a magnetic flowmeter, the fluid flow or velocity acts as a moving electrical conductor. The fluid flow (moving electrical conductor) induces a voltage that is received by magnetic flowmeter electrodes. Output of the magnetic flowmeter electrodes are proportional to the velocity of the fluid flow. Magnetic flowmeters use electronic modules to calculate flow from measured voltage created by magnetic induction. The following figure (courtesy of ITA) displays the basic components of a magnetic flowmeter.

Traditional and Non-Traditional Instrument Technologies	Instrument Description / Principle of Operation
Traditional	



All magnetic flowmeters are basically constructed using the same configuration, with the exception of the differing voltages applied to the magnetic coils and frequency of the coil excitation. Space limitations and other piping considerations often require the mounting of flowmeters in less than ideal configurations. Certainly the most often abused is maintaining the desired upstream and downstream distances from pipe fittings and other obstacles that will impact the velocity profile. Even where the ideal installation is possible, there is still no guarantee that the installation will produce ideal conditions for flow measurement.

A means of calibration should be developed for magnetic flowmeter acceptance testing and periodic calibration for each installation. Magnetic flowmeters are used in pressurized pipe flows and may provide flow measurements for the following water and wastewater flows:

- influent;
- raw sewage;
- chemicals;
- pumping stations;
- filtrate;
- sludges;
- slurries;
- effluent;
- return activated sludge; and
- waste activated sludge.

Magnetic flowmeter liners are typically constructed of

- butyl rubbber;
- ceramic;
- kynar;
- Neoprene;
- PFA;
- polyurethane;
- Teflon; and
- Tefzel.

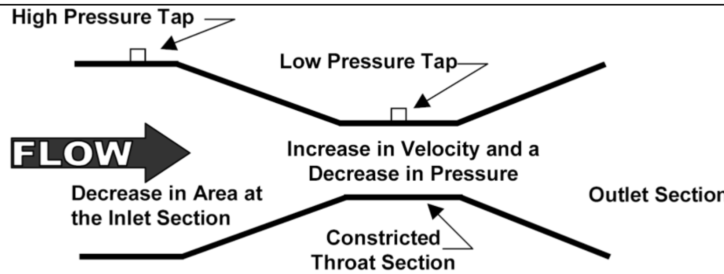
Magnetic flowmeter flow tubes are typically constructed of nonmagnetic 316 stainless steel.

Magnetic flowmeter electrodes are typically constructed of

- 316 stainless steel;
- Hastelloy C;
- monel (for salt water applications);
- platinum;
- tantalum; and

Traditional and Non-Traditional Instrument Technologies	Instrument Description / Principle of Operation
Traditional	
	• titanium. Magnetic flowmeter magnetic coils are typically constructed of copper. Magnetic flowmeters can operate over a general range of the process characteristics are: Conductivity: 10 to 5000 uS/cm (microsiemens per cm) Velocity: 1 to 30 ft/sec (0.3 to 9 m/s) Pressure: Less than 75 psig (500 kPa) Temperature: 32 to 100oF (0 to 38oC) Flowmeter manufacturers should be contacted to verify their respective process characteristics, operating ranges, or to discuss other special process considerations. If prudent design, application, and installation practices are followed, the accuracy of a magnetic flowmeter will be in the range of 0.5 to 2% of total flow. Magnetic flowmeter repeatability is generally 0.5% of full-scale. Magnetic flowmeters typically require the following periodic maintenance: • calibration of flowmeter and • cleaning of electrodes to prevent fouling. Some manufacturers offer proprietary calibration verification tools. The following lists some of the advantages and limitations. Advantages • can measure a wide range of flow with minimal pressure drop or disturbance of the process stream; • requires little maintenance; • can measure a variety of process flows; • direct-buried magnetic flowmeters avoid the cost of installing a chamber/vault; • no moving parts; • relatively unaffected by non-conductive films or coatings inside spools; and • can measure corrosive liquids and slurries. Limitations • measured fluid must contain sufficient conductivity; • direct-buried magnetic flowmeters may require contingency funds for excavation of failed meters; • fluid must be grounded properly with grounding rings, grounding electrodes; and • conductive films or coatings can significantly accuracy of the magnetic flowmeter.
Venturi	G.B. Venturi, an Italian physicist, completed the basic theory for Venturi tube flowmeters in 1791. In 1887, Clemens Herschel furthering Venturi's initial work, developed the first commercially available Venturi flowmeter. Venturi flowmeters were initially designed for large pipe flow applications but are recommended for all flow applications, except partially filled pipe flow, and in some cases are used to calibrate flow standards. The Venturi flowmeter consists of a short tube with a constricted, throat-like passage that increases velocity and lowers pressure of a fluid conveyed through it. Venturi flowmeters measure flow using differential pressure. As fluid flows through the Venturi, the decrease in the area of the inlet section causes the velocity to increase through the throat section. An increase in velocity causes a drop in pressure at the throat section with respect to the pressure at the inlet section. This difference in pressure between the inlet section and the throat section is proportional to the square of the flow (dp is proportional Q^2, where dp = differential pressure and Q = flow). The Venturi flowmeter system is composed of the Venturi flowmeter tube, the differential pressure sensor, and an optional indicator that provides display readings of calculated flow rates.There are two pipe taps on the Venturi. Both pipe taps collect pressurized fluid in the Venturi and are connected to a differential pressure sensor. One tap provides a high-pressure reading (at the inlet section of the Venturi). The other tap provides a low-pressure reading and is located at the throat section of the Venturi. The following figure (courtesy of ITA) displays a typical design of a Venturi flowmeter.

Traditional and Non-Traditional Instrument Technologies	***Instrument Description / Principle of Operation***
	Traditional



All Venturi flowmeters have two pressure taps connected to a differential pressure sensor; however, each manufacturer may offer different types of pressure sensors. The type of differential pressure sensor required depends on the application of the Venturi flowmeter. For example, using a Venturi flowmeter in a raw sewage application would most likely use a "diaphragm seal" type of sensor. Application also determines Venturi installation.

The most common design of a Venturi flowmeter tube is the Classical Herschel in which the flowmeter tube is constructed of four distinct pipe sections:

- Inlet (matches incoming pipe diameter);
- Inlet section (decreasing pipe diameter);
- Throat (constant pipe diameter to match the small inlet cone and outlet cone pipe diameter); and
- Outlet section (increasing pipe diameter to match pipe discharge diameter).

Some manufacturers of Venturi flowmeter tubes offer several variations of the Classical Herschel design by increasing throat diameter and shortening inlet and outlet cone length. These proprietary flowmeters render advantages over the Classic Herschel design by decreasing head loss through the flowmeter and shortening the overall length of the flowmeter. These features not only provide better flow characteristics but also reduce installation costs.

Space limitations and other piping considerations often require the mounting of flowmeters in less than ideal configurations. Certainly, the most often abused is the upstream and downstream distance from pipe fittings and other obstacles that will impact the velocity profile. Even where the so-called ideal installation is possible, there is still no guarantee that the installation will produce ideal conditions of flow measurement. For this reason a means of hydraulic flowmeter calibration should be developed for meter acceptance testing and periodic calibration for each meter installation.

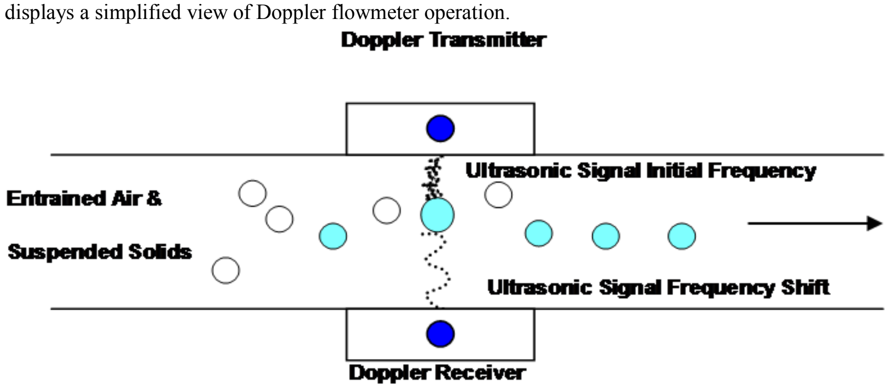
Venturi flowmeters have the following water and wastewater applications:

- custody transfer or revenue metering of clean liquids;
- water filtration plants;
- acceptance testing and periodic retesting of large hydraulic machinery such as pumps, turbines, and cooling towers;
- influent;
- raw sewage;
- filtrate;
- effluent; and
- steam.

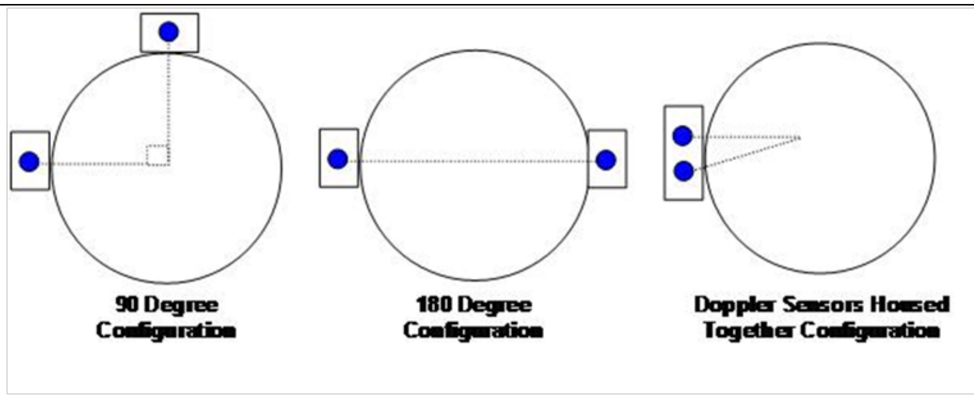
Flowmeter manufacturers should be contacted to verify their respective process characteristics, operating ranges, or to discuss other special process considerations.

Accuracy of the Venturi flowmeter is dependent on the manufacturer's predetermined accuracy of each Venturi flowmeter system component (i.e., flowmeter tube, differential pressure sensor, and indicator). Each component's individual accuracy introduces some error to the overall system flow reading. If prudent design, application, and installation practices are followed, the accuracy of the Venturi flowmeter will be in the range of 0.5 to 1% of total flow. Typically, a 1% or better accuracy is attainable for Venturi flowmeter systems. Venturi flowmeter repeatability has been report at +/-1% of actual flow.

The most important maintenance aspect of a Venturi flowmeter system is to prevent a build up of debris in the

Traditional and Non-Traditional Instrument Technologies	Instrument Description / Principle of Operation
Traditional	
	Venturi flowmeter tube pipe taps. Routine maintenance requires flushing pipe tap connections and/or pressure diaphragm seals located at the pipe taps. In addition, the Venturi flowmeter system requires the following basic maintenance and calibration procedures: • inspect and clean Venturi flowmeter pipe taps on a regular basis as determined by history, application, and per manufacturer recommendations; • perform annual testing of the Venturi flowmeter tube using a portable manometer; • inspect the inside surface of the Venturi flowmeter tube for imperfections every 2 to 3 years; • bleed Venturi tube pipe tap lines of trapped air on a routine basis as determined by history, application, and per manufacturer recommendations; • calibrate the differential pressure sensor on an annual basis using a portable manometer; and • calibrate the Venturi flowmeter indicator concurrently with the calibration of the differential pressure sensor. Advantages of Venturi flowmeters include a long history of use in many applications; a contoured design of the Venturi flowmeter prevents buildup of debris inside the Venturi; low maintenance; and a low total headloss due to head recovery in the enlarging section. Limitations of Venturi flowmeters include Venturi throat size can limit the flow range and can be costly for large installations.
Non-Traditional	
Doppler	Doppler flowmeters, named after Christian Doppler, an Austrian physicist and mathematician, who in 1842 predicted that frequencies of received waves were dependent on the motion of the source, operate on the basis of Doppler's theory. The Doppler flowmeter is composed of two sensors: an ultrasonic transmitter and receiver. The Doppler transmitter sends a signal of a known high ultrasonic frequency into the flowing fluid. As the ultrasonic signal hits suspended particles or gas bubbles in the fluid flow, the ultrasonic signal is reflected back to the Doppler receiver. The velocity of the particles and gas bubbles in the fluid flow cause the ultrasonic signal to shift in frequency. The magnitude of the shift in frequency is proportional to the velocity of the reflecting particles or gas bubbles in the fluid flow (or the components of the velocity parallel to the ultrasonic signal path). The following figure (courtesy of ITA) displays a simplified view of Doppler flowmeter operation.  Doppler flowmeter electronics are preprogrammed with assumptions to relate the particle velocity to the average axial velocity of the fluid. Doppler flowmeter electronics also calculate frequency differences, reject unwanted or stray signals, and provide correction for interposing materials such as pipe wall or transducer windows. Additionally, these electronics produce standard output signals or pulse trains for interfacing with control systems. Doppler flowmeter configurations vary by the different placements of the ultrasonic transmitter and receiver pair. Placements include 90 or 180 degrees around the pipe or near one another where the Doppler transmitter and receiver sensors are housed together. The following figure (courtesy of ITA) displays the various Doppler flowmeter configurations.

Traditional and Non-Traditional Instrument Technologies	*Instrument Description / Principle of Operation*
Traditional	



Doppler flowmeters require suspended solids particles or gas bubbles in flowing fluid. Mounting of the Doppler flowmeter ultrasonic transmitter and receiver sensors may require the use of clamps, gasket materials, or silicon gel. Doppler flowmeter ultrasonic sensors are typically mounted on the surface of a pipe but can also be mounted in a pipe when a pipe is constructed of materials that will not allow transmission of ultrasonic signals or when a more accurate flow measurement is required.

The Doppler flowmeter’s surface mounted ultrasonic transmitter and receiver sensors require a pipe that is constructed of metal or plastic that does not have the interior coated with rubber or concrete. Some Doppler flowmeter sensors may also require that a pipe's interior is not coated with coal tar epoxy.

Doppler flowmeters' ultrasonic transmitter and receiver sensors have process fluid temperature limitations. Doppler flowmeters are used in pressurized pipe flows and may provide flow measurements for the following water and wastewater flows:

- raw sewage;
- filtrate;
- primary sludge;
- digested sludge;
- slurries;
- wastewater effluent;
- return activated sludge; and
- waste activated sludge.

Surface and wetted ultrasonic sensor housings are typically constructed of corrosion-resistant materials such as

- polyvinyl chloride (PVC);
- chlorinated polyvinyl chloride (CPVC);
- 316 stainless steel; and
- aluminum (surface-mounted ultrasonic sensor housing only).

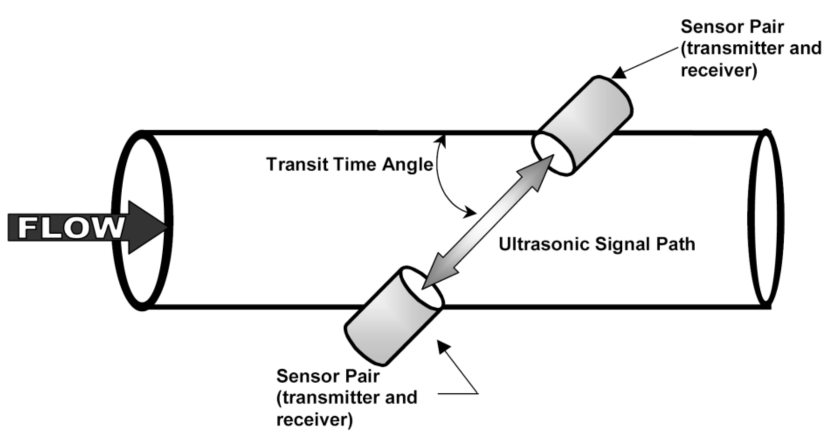
Doppler flowmeters can operate over a general range of the process characteristics described in the following table. Flowmeter manufacturers should be contacted to verify their respective process characteristics' operating ranges or to discuss other special process considerations.
Velocity: 0.1 to 30 ft/sec (0.03 to 9 m/s)
Temperature: -122 to 392oF (-50 to 200oC)
Manufacturers of Doppler flowmeters have reported accuracies of +/- 2%. Doppler flowmeters typically require the following periodic maintenance:

- replacement of mounting gaskets or silicon gel material;
- tightening of mounting clamps;
- calibration of flowmeter; and
- cleaning of wetted ultrasonic sensors.
- The following lists some of the advantages and limitations.

Advantages

- can measure a wide range of flow with no pressure drop or disturbance of process stream and
- easily mounted on existing pipe without process shutdown.

WERF

Traditional and Non-Traditional Instrument Technologies	*Instrument Description / Principle of Operation*
Traditional	
	Limitations • measured fluid must contain sufficient particles or entrained air; • flowmeter cannot be surface mounted on concrete pipe (as an alternative, the ultrasonic sensors must be installed inside a concrete pipe and will operate as a wetted sensor); • pipe cannot be lined with material that can absorb ultrasonic signals, such as coal tar epoxy, rubber, or concrete; • moving the sensors may affect flow measurements, as well as removing and re-installing the sensors immediately, at the same location; and • it may be difficult to quantify the uncertainties associated with Doppler sensors, therefore making it difficult to quantify accuracies.
Transit-Time	Transit time flowmeters were originally invented to measure clean water flows. More recently, transit time flowmeters have been used in dirty water, air, and gases. The transit time flowmeter is composed of a pair of sensors mounted at an angle to the side of the channel or pipe, 180 degrees apart. Each sensor pair contains an ultrasonic transmitter; ultrasonic receiver; and electronics module. The pair of sensors face each other and transmit and receive ultrasonic pulses upstream and downstream across the fluid flow. The upstream ultrasonic transmitter sends a signal of a known high ultrasonic frequency (approximately 1 MHz) into the flowing fluid at an acute angle (transit time angle) across the pipe. The acute angle facilitates each sensor to face each other at a known distance across the pipe. Immediately following the upstream signal, the downstream ultrasonic transmitter sends a signal of the same known frequency in the opposite direction. The transit time flowmeter measures the velocity of the process flow by measuring the difference in the time required for the upstream transmitter to send a high-frequency ultrasonic pulse to the downstream receiver (typically at a specified distance through the process flow in the same direction of the flow with respect to the transit time angle); and by measuring the time required for the downstream transmitter pulse to travel the same distance in the opposite direction to the upstream receiver. The transmission of a downstream pulse takes less travel time than a transmission of an upstream pulse. The difference in travel times for the pulses is proportional to the flow velocity. The time it takes for the pulses to travel along the ultrasonic signal path between upstream and downstream sensor pairs and the transit time angle are used to mathematically determine flow velocity. The electronics module converts the calculated velocity into a flow output reading. Sometimes the sensors are both mounted on the same side of the pipe. In such cases, the signal traverses across the pipe twice, bouncing off the far pipe wall along the way. The following figure (courtesy of ITA) displays a simplified view of a transit time flowmeter design.  Transit time flowmeters can be configured with clamp-on sensors or with wetted sensors. Wetted sensors can be either permanently mounted within the pipe or inserted through the pipe wall, using a wet tap assembly. Mounting of the transit time flowmeter sensors may require the use of clamps, gasket materials, or silicon gel. Transit time flowmeter ultrasonic sensors are typically mounted on the surface of the pipe but can also be mounted in the pipe when a pipe is constructed of materials that will not allow transmission of ultrasonic signals or when a more accurate flow measurement is required.

<table>
<tr><th>Traditional and Non-Traditional Instrument Technologies</th><th>Instrument Description / Principle of Operation</th></tr>
<tr><td colspan="2">Traditional</td></tr>
<tr><td></td><td>The transit time flowmeter ultrasonic sensors also require a pipe that is constructed of metal or plastic that does not have the interior coated with coal tar epoxy, rubber, or concrete. Transit time flowmeter ultrasonic sensors have process fluid temperature limitations.

Transit time flowmeters have the following water and wastewater applications
• custody transfer or revenue metering of clean liquids;
• water filtration plants;
• hydroelectric power plant management;
• nuclear/fossil power plant cooling water flow measurement;
• acceptance testing and periodic retesting of large hydraulic machinery such as pumps, turbines, and cooling towers;
• water resource management; and
• raw sanitary wastewater.
Surface and wetted ultrasonic sensor housing are typically constructed of corrosion-resistant materials such as
• polyvinyl chloride (PVC);
• chlorinated polyvinyl chloride (CPVC);
• 316 stainless steel; and
• aluminum (surface mounted ultrasonic sensor housing only).
Transit time flowmeters can operate over a general range of the process characteristics such as
• Velocity 0.1 to 30 ft/sec (0.03 to 9 m/s)
• Temperature -122 to 392oF (-85 to 200oC)

Flowmeter manufacturers should be contacted to verify their respective process characteristics, operating ranges, or to discuss other special process considerations. Transit time flowmeter accuracy is reported as +/- 2% for wetted sensors and +/- 5% for clamp-on sensors. Repeatability is reported as +/-1% of actual flow. Transit time flowmeters typically require the following periodic maintenance:
• replacement of mounting gaskets or silicon gel material;
• tightening of mounting clamps;
• calibration of flowmeter; and
• cleaning of wetted ultrasonic sensors.
Advantages of transit time flowmeters include:
• can measure a wide range of flow with no pressure drop or disturbance of process stream;
• easily mounted on existing pipe without process shutdown;
• bi-directional flow measurement;
• automatic signal and data testing can ensure that only accurate readings are accepted for output;
• electronics can accommodate many metered sections; and
• cost relatively independent of size.
One of the limitations of transit time flowmeters is that they cannot be surface mounted on concrete pipe. As an alternative, the ultrasonic sensors must be installed inside a concrete pipe and will operate as a wetted sensor. Surface mounted transit time flowmeters are not recommended for installation on pipes that are lined with material that can absorb ultrasonic signals.</td></tr>
<tr><td>V-Element / V-Cone</td><td>The V-Cone Flow Meter is an advanced differential pressure instrument, which is ideal for use with liquid, steam or gas media in rugged conditions where accuracy, low maintenance and cost are important. With its DP built-in flow conditioning design, the V-Cone is especially useful in tight-fit and retrofit installations in which the long runs of straight pipe required by Orifice Plates, Venturi Tubes, and other technologies are either impractical or unavailable. [4]</td></tr>
</table>

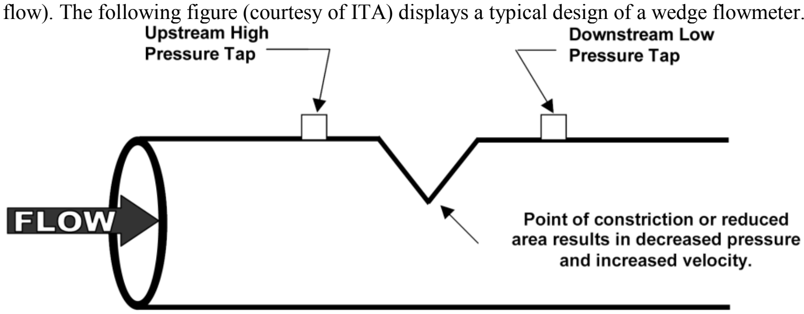
Traditional and Non-Traditional Instrument Technologies	Instrument Description / Principle of Operation
Traditional	

Picture Courtesy of McCrometer, USA

Wedge

Wedge flowmeters are based on Bernoulis principle of differential pressure and consist of two basic elements:
1. a flow tube and 2. a differential pressure sensor. The wedge flow tube consists of a straight pipe with a v-notch wedge-shaped constriction protruding from the top of the tube into the process pipe flow. A high-pressure tap is located upstream of the v-notched wedge constriction and a low-pressure tap is located downstream of the constriction.

As process fluid flows past the v-notch wedge-shaped constriction, the area is decreased, causing an increase in velocity and a decrease in pressure. The differential pressure sensor measures the difference in pressure from the upstream and downstream sections of the v-notch wedge (or across the wedge flowmeter tube). This difference in pressure is proportional to the square of the flow (dp is proportional to Q^2, where dp = differential pressure and Q = flow). The following figure (courtesy of ITA) displays a typical design of a wedge flowmeter.



Wedge flowmeters vary by size of the v-notch wedge constriction in relationship to the internal pipe diameter and use of various differential pressure sensors. Wedge elements are classified by the H/D ratio. This H/D ratio is similar to the orifice plates beta ratio. The H/D ratio is the wedge meter's opening height (H) divided by the inside pipe diameter (D). Wedge flowmeters can be used for process flows that are very viscous. Standard wedge sizes are ½ to 12 in. (1.25 to 30 cm). Larger sizes can be custom ordered. Wedge elements are available with an assortment of process connections when used with clean fluid service. Remote seals are recommended when used with slurries. Wedge flowmeters used in pressurized pipe flows may provide flow measurements for the following water and wastewater flows:

- filtrate;
- sludges
- slurries;
- return activated sludge; and
- waste activated sludge.

Wedge flowmeters are typically constructed of 316 stainless steel.
Depending on the type of differential pressure sensor used, wedge flowmeters can operate over a general range of the process characteristics such as: Pressure: less than 6000 psig (41000 kPa); Temperature: -20 to 1000oF (-30 to 540oC). Flowmeter manufacturers should be contacted to verify their respective process characteristics, operating ranges, or to discuss other special process considerations.

Traditional and Non-Traditional Instrument Technologies	*Instrument Description / Principle of Operation*
Traditional	
	Accuracy of the wedge flowmeter is dependent on the manufacturer's predetermined accuracy of each wedge flowmeter system component (i.e., flowmeter tube, differential pressure sensor). Each component's individual accuracy introduces some error to the overall system flow reading. If prudent design, application, and installation practices are followed, the accuracy of the wedge flowmeter will be in the range of 0.5 to 1% of total flow. Typically, a 1% or better accuracy is attainable for wedge flowmeter systems. Wedge flowmeter repeatability has been report at +/-1% of actual flow. The most important maintenance aspect of a wedge flowmeter system is to prevent a buildup of debris in the wedge flowmeter tube pipe taps. Routine maintenance requires flushing pipe tap connections and/or pressure diaphragm seals located at the pipe taps. In addition, the wedge flowmeter system requires the following basic maintenance and calibration procedures: • inspect and clean wedge flowmeter pipe taps on a regular basis as determined by history, application, and per manufacturer recommendations; • perform annual testing of the wedge flowmeter tube using a portable manometer; • inspect the inside surface of the wedge flowmeter tube for imperfections every 2 to 3 years; • bleed wedge flowmeter tube pipe tap lines of trapped air on a routine basis as determined by history, application, and per manufacturer recommendations; • calibrate the differential pressure sensor on an annual basis using a portable manometer; and • calibrate the wedge flowmeter indicator concurrently with the calibration of the differential pressure sensor. Some of the advantages of wedge flowmeters include: the contoured design of the v-notch wedge prevents buildup of debris inside the wedge flowmeter tube and low maintenance. One of the limitations of wedge flowmeters is the v-notch wedge constriction which limits the flow range.

D.1 Area-Velocity

Area-Velocity												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measure ment Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
fps, m/s, mgd	Electromag netic	Hach/Marsh-McBirney	Flo-Tote 3		Velocity Measure ment: Electroma gnetic (Faraday's Law); Level Measure ment:Sub merged pressure transduce r.	In-Situ	Velocity Sensor: -5 to +20 feet per second (-1.5 to +6.1m/s); Level Sensor: Standard 0.4 to 138 inches. (10mm to 3.5m) Optional 0.4 to 276 inches	Velocity sensor: Zero Stability: ±0.05 feet per second (±0.015m/sec); Resolution: 0.01 feet per second (± 0.003m/sec)	Velocity sensor: ±2% of reading,			
mgd	Ultrasonic Doppler	ADS Environmenta l Services, Inc.	one each quadredun dant ultrasonic level sensor, peak velocity sensor, and pressure depth sensor.	3500 or 3600/36 01	Ultrasonic Doppler	In-Situ				preset intervals such as 1.0, 2.0, 2.5, 5.0, 7.5, and 15 minutes.		

Area-Velocity												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mgd	Ultrasonic multiple path/channel transit-time	Accusonic Technologies, Inc.	7510	Intrinsically Safe Transducers Model 7657 (1-MHz) or 7658 (500-kHz). internal-mount transducers are designed for installation in open channels.	Up to 8 acoustic paths and 4 pipes or channels available.	In-situ		Repeatability: +/- 0.2% Full Pipe Applicaitons; +/- 0.5% Partially Full Pipe /Open Channel Applications	+/- 0.5% of flowrate for full pipes and +/- 2.0% for partially full pipes and open channels			No re-calibration required over time

Area-Velocity												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measure ment Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
Flow: GPS, GPM, GPH, LPS, LPM, LPH, MGD, AFD, CFS, CFM, CFH, CFD, M3S, M3M, M3H, M3D. Totalized Flow: gal.,ft.³, acre-ft., L, m³.	Ultrasonic	Hach	Sigma 920 AV	Sigma 920 AV	Ultrasonic Doppler sensor for direct measure ment of average stream velocity.	In-Situ	Range: -5 to 20 fps (-1.52 to 6.10 m/s).	Zero Stability: <0.05 fps. (.015 m/s).	Accuracy : ±2% of reading. to 34.6´ ft. ± .07´ ft. (.005 m - 10.5 m ± .021 m).	Monitoring Intervals: 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, 60-minutes.		
m/s, ft/s	ultrasonic	Sensor Products	Mainstream		ultrasonic		Velocity measurement range from 10 mm/S to 5 m/S. Resolution 1 mm/S		Typically better than 2% in evaluatio n trials.			

Area-Velocity												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measure ment Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
ft/s, m/s	ultrasonic	Greyline	AVFM-II		ultrasonic echo-ranging principle	in-situ	0.1 to 20 ft/sec (0.03 to 6.2 m/sec).		±0.25% of Range; ±2% of reading			calibration - built-in 3-key programmer

D.2 Doppler

Doppler												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
GPM or LPM	Ultrasonic	Essiflo	3000		Doppler Ultrasonic	ex-situ	0.3 to 10.0 m/s		±2% of FS			
GPM or LPM	ultrasonic	Greyline	DFM 4.0			ex- situ pipe from 1/2" to 180"	0.2 to 40 ft/sec (0.06 to 12.2 m/sec)		±2% of full scale			
GPM or LPM	Ultrasonic	Micronics	DFM 4.0		Ultrasonic Doppler	ex-situ	0.08m/s to 12m/s	Repeatability:- +/- 0.1%., Linearity:- +/- 0.5% of full scale.	+/-2% of full scale			

Doppler												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
GPM or LPM	Ultrasonic	Pulsar Process	500 Series		Ultrasonic Doppler	ex-situ	510 unit 0.3m/sec to 3.5m/sec		± 7.5%, application dependent			
GPM or LPM	Ultrasonic	EMCO	Sono-Trak™		Doppler Ultrasonic	ex-situ	0.1 to 50 fps (0.04 to 15.25 mps)	±0.5% of full scale, ±0.1% of full scale	Typically ±1% to ±3% of full scale		1 second or less	
ft/s, m/s	ultrasonic	Thermo Scientific	SX 40		sonic pulse	+/- 0.2 to 18 ft/s (+/- 0.06 to 5.5 m/s)			+/- 1% of total error band			
GPM or LPM	Ultrasonic	Dynasonics	DFX		Doppler Ultrasonic	ex-situ	0.15-30 FPS (0.05-9 MPS)		±2% full scale, over calibrated span			

D.3 Insertion Magnetic

Insertion Magnetic												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
GPM or LPM	Magnetic	McCrometer	Marsh Multi-Mag		magnetic	in-situ	0.3 to 40 ft/s	Zero Stability: ±0.03 ft/s (±.009 m/s), Linearity: 0.3% of range, Repeatability: 0.20% of range	Accuracy: ±1% of reading from 0.3 to +20 ft/s + zero stability			
GPM or LPM	Magnetic	MSR magmeter	Magnum	Magnum	magnetic	in-situ	min. velocity .25 inch/s, max. Velocity unlimited	precision 0.5% of velocity, repeatability 99. 5%				
GPM, LPM	Electromagnetic	SeaMetrics, Inc.	EX 100 / 200		Electromagnetic	In-situ	0.28 - 20 ft/sec (0.08 - 6.09 m/sec)		+/- 1% of full scale			
GPM or LPM	Magnetic	Georg Fischer Signet	5075 Totalizing ProPoint™ Flow Monitor	2552 Metal Magmeter Flow Sensor	magnetic	in-situ	0.05 to 10 m/s (0.15 to 33 ft/s)	±(1% reading + 0.01 m/s), ±0.5% of reading @ 25°C	±2% of measured value			

Insertion Magnetic													
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
GPM or LPM	Magnetic	Dynasonics	MFX		magnetic	in-situ	0.1 to 30 FPS (0.03 to 9 MPS)	Sensitivity ±0.005 FPS (±0.0017 MPS)	±2% of full scale		3-300 seconds, user configured, to 100% of value, step change in flow.	

D.4 Magnetic

Magnetic												
Units	Technology	Manu-facturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Cali-bration Frequency
GPM or LPM	Magnetic	SeaMetrics, Inc.	WMX101		Electromagnetic	In-situ	Gallons/Minute Gallons x 1000, Million Gallons/Day Gallons x 1000, Liters/Second Cubic Meters,Feet		"+/-1% of reading from 10% to 100% of full scale,			
GPM or LPM	Magnetic	Rosemount	8732E	8732E	magnetic	in-situ			Up to 0.15% of volumetric flow rate accuracy over 13:1 flow turndowns		50 ms from zero flow	

Magnetic													
Units	Technology	Manu-facturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Cali-bration Frequency
mgd	Magnetic	Sparling	TigerMag	TigerMag	magnetic	in-situ	Bi-directional totalization; FM626 (wafer) Available from 0.1" to 4"; FM656 (flanged) Available from 0.5" to 72"		Standard 0.5% accuracy			
gpm, lpm	magnetic	Yokogawa	AXF		magnetic	in-situ			0.35% of rate (0.2% of rate optional)			
GPM or LPM	Magnetic	Foxboro	47						±0.5% of Flow Rate			
GPM	Electromagnetic	ONICON Incorporated	F-3200 SERIES		Electromagnetic	In-situ	.3 to 180,000 GPM		± 0.2% of reading from 3.3 to 33 ft/s, ± 0.75% of reading from 1 to 3.3 ft/s			
gpm, lpm	Magnetic	Honeywell	VersaFlow Mag		magnetic	in-situ						

Magnetic												
Units	Technology	Manu-facturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Cali-bration Frequency
			4000									
m^3/h [Mgal/d]	Electromagnetic	Endress + Hauser	Promag	Promag W and 53 transmitter	Electromagnetic flowmeter for bidirectional measurement of liquids with a minimum conductivity of ≥ 50 µS/cm	Application Specific	Flow measurement up to 4,700 m^3/h [30 Mgal/d]	Maximum measured error - Current output: ± 5uA Pulse output: ± 0.5% o.r. ± 2 mm/s (o.r. = of reading)	Repeatability Max. ± 0.2% o.r. ± 2 mm/s (o.r. = of reading)	Continuous		

D.5 Open Channel

Open Channel												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measure-ment Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
gpm, lpm	ultrasonic	Pulsar	Flo-Pak	db15 transducer								
GPM or LPM	Ultrasonic	Anvensys/Isco	H-ADFM™		Ultrasonic Doppler	in-situ	±15 ft/s (±5 m/sec)		2-5% of reading			
ft/s, m/s	Ultrasonic	Thermo Scientific	Sarasota 2000		ultrasonic	in-situ	Bi-directional; Maximum depends on path length e.g., 10 m/s for 100 m path (33 ft/s for 330 ft path)		Overall accuracy typically 2% to 5% of flow reading,			
GPM or LPM	Ultrasonic	Anvensys/Isco	ADFM™ Pro20		Ultrasonic Doppler	in-situ	±30.0 ft/s (±9 m/s), 250 psi Nominal		1-2% of reading			
gpm, lpm	ultrasonic	Accusonic	7700-7720		ultrasonic	in-situ			+ or - 0.5% of true flowrate			

D.6 Transit-time

Transit-time												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measurement Interval	Response Time	Cali-bration Fre-quency
GPM or LPM	Ultrasonic	Hedland	HTTF Remote Model		transit time	ex-situ	0.1 to 40 FPS (0.03 to 12.4 MPS)		±1% of reading at rates above 1 FPS (0.3 MPS)		0.3-30 seconds, adjustable	
m/s, ft/s	ultrasonic	EESiFlo	Portalok 7S		Ultrasonic time difference correlation principle and doppler	in-situ	(0.01...25) m/s (0.003 to 82 ft/s)		Volume Flow: ± 1% ..3% of reading ± 0.02 m/s(0.06 ft/s)		1 s (1 channel)	
mps, fps	ultrasonic	Sierra Instruments	Innova-Sonic 206		ultrasonic	in-situ	bi-directional Flow range of 0 to 23 fps liquids (0 to 7 mps).		+/- 0.5% of reading.			
GPM or LPM	Ultrasonic	Endress+Hauser	Prosonic Flow Clamp On 90U		transit time	ex-situ	0 to 15 m/s with the specified measuring accuracy for Prosonic Flow W					

Transit-time												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measurement Interval	Response Time	Cali-bration Fre-quency
GPM or LPM	Ultrasonic	Dynasonics	TFXM		transit time	ex-situ	-40 to +40 FPS [-12 to +12 MPS]	Repeatability ±0.01% of reading	±0.5% of reading at rates > 1 FPS [0.3 MPS] for field calibrated systems		1-10 seconds, user configured, to 90% of value, step change in flow	
	Ultrasonic	GE Sensing	GC868 Clamp-on									
m/s, ft/s	ultrasonic	Accusonic	797		ultrasonic	in-situ	+/-65 ft/sec (+/-20 m/sec); Measures bi-directional flowrates up to +/-65 ft/sec (+/-20 m/sec)		Accuracy rate of +/- 1 to 2% of flowrate typical			

D.7 V-Cone

V-Cone												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
gpm, lpm	differential pressure flow	McCrometer	Vcone		differential pressure flow	in-situ	10:1 and greater		+/- 0.5%			

D.8 Venturi

Venturi												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measure-ment Interval	Re-sponse Time	Cali-bration Frequency
GPM or LPM	Differential Pressure	Fox Venturi Products	Fox deltaP Venturi Flowmeter	Fox deltaP Venturi Flowmeter	Differential Pressure	in-situ						
GPM or LPM	Differential Pressure	Flowmaxx		Venturi	Differential Pressure	in-situ						
gpm, lpm	differential pressure	Preso	SSL		differential pressure	in-situ			within ±1.0% uncalibrated (±0.5% calibrated)			
GPM or LPM	Differential Pressure	Primary Flow Signal		HVT-Halmi	Differential Pressure	in-situ			+/0.50% - 2 SIGMA			

D.9 Wedge

Wedge												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure-ment Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Response Time	Cali-bration Frequency
GPM or LPM	Differential Pressure	Ametek/Solatron	Wedge meters		Differential Pressure	in-situ			Calibrated ±1%			
GPM or LPM	Differential Pressure	Primary Flow Signal	PFS-WM Wedge		Differential Pressure	in-situ			+/- 0.50% of Coefficient Accuracy for the Calibrated Range			
GPM or LPM	Differential Pressure	Preso Meters	COIN Flow Meter		Differential Pressure	in-situ		repeatability of ±0.2%	±3.0% (uncalibrated) and ±0.5% (calibrated)			

APPENDIX E

PRESSURE AND UV LIGHT INTENSITY INSTRUMENTATION

Physical Measurement

Background

This research project identified several instruments that are used to measure physical parameters for applications in decentralized wastewater treatment systems. The physical measurements of pressure, decentralized facility status and UV light intensity are physical measurements that are described herein. The various technologies of pressure, decentralized facility status and UV light intensity are outlined in tabular format and categorized by traditional and non-traditional technologies, as defined by this research project. Note: The physical measurements of pressure, pump run status and UV light intensity only provide one instrument technology and therefore are considered traditional.

E.1 Pressure

Pressure instrumentation are commonly referred to as pressure transducers or pressure transmitters. The three most common types of pressure instruments are absolute, gauge, and differential. Field configurations provide the distinction between the different types of pressure instrumentation. Traditional types of pressure transducers/transmitters utilize a capacitance, Piezoresistive, or strain-gauge technology. Non-traditional technologies include micro-electro-mechanical systems (MEMS) piezoresistive.

Pressure												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
psi, bar	strain gauge	GP:50	211/311		pressure	in-situ	0-20,000 PSI		± 0.5% FSO standard			
psi, bar	pressure	Rosemount, Emerson Process Mgmt	3051T				0.3 to 10,000 psi		+ 0.065% of span			
psi, bar	pressure	Honeywell	RMA 3000		pressure	in-situ			+/- 0.5% of span			
psi, bar	pressure	ABB	265A		pressure	in-situ	0.3 to 3000 kPa abs; 2.25 mmHG to 435 psia		±0.04%			
psi, bar	pressure	Ashcroft	GC51		pressure	in-situ	0/50 to 0/7500 psig and compound to -15/50 psi					
psi, bar	pressure	Omega	PX2088S-150GI		pressure	in-situ			0.20%; Analog: ±0.25% of calibrated span			

Pressure												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
psi, bar	silicon sensor	Honeywell	PPTE		pressure	in-situ	15 to 3000 psi		Analog: ±0.12% FS Typ., ±0.24% FS Max		(1000/update rate) +1ms, minimum 17ms	

E.2 Ultraviolet Light (UV) Light Intensity

When wastewater is to be disinfected by Ultra-Violet (UV) radiation transmission, the amount of UV radiation transmitted through the wastewater is affected by the particulates and dissolved matter in the wastewater and results in the range of from 40% to 60% reduction of UV transmission per 1 cm of layer of water thickness. This means that 40% to 60% of the applied UV radiation is absorbed by a water layer having a thickness of as little as 1 cm (for comparison: pure drinking water has a transmission in the range of from about 90% to 98%, and the absorption losses are only from 2% to 10% per 1 cm of water layer thickness). The effect of the poor UV transmission is that only relatively thin layers of the wastewater around the UV radiation tube sleeve can be effectively disinfected. For wastewater layers located further away from the tube sleeve, the UV radiation time needs to be longer, and may require a reduced flow velocity past the UV disinfection equipment.

In addition, the effect of the aging process of UV tubes is that the radiation output power decreases over time even though the power consumption remains approximately the same. This requires regulating the power applied to the UV tubes in order to maintain constant UV radiation output. The UV transmission meter measures the radiation power actually being output by the UV tubes. This information can be used to regulate the amount of electrical power delivered to the UV tubes over time. [2]

Ultraviolet Light (UV) Light Intensity												
Units	Technology	Manufacturer Name	Inst. Model	Sensor Model	Measure-ment Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Re-sponse Time	Calibration Frequency
W/m2	Optical	ZED		SiC021-I	absorbance		210...380nm (with UV-C filter: 220...290nm)					
% Transmission	Optical	HF Scientific	AccUView	Ultrasonic Cleaning System	absorbance	ex-situ	0-100 %T Transmission	Repeatability: ±0.1%T; Resolution: ±0.1%T	±1.0%T	Wavelength: Ultra Violet 253.7nm	Updated at Selectable sample intervals from 10 to 60 minutes	

Ultraviolet Light (UV) Light Intensity												
Units	Technology	Manufacturer Name	Inst. Model	Sensor Model	Measure-ment Method	Sensor Location	Measurement Range	Measure-ment Uncertainty	Accuracy	Measure-ment Interval	Re-sponse Time	Calibration Frequency
% Transmission	Optical	Metex	Micro T UV Online Transmission Analyzer		absorbance	ex-situ	Auto Ranging, 0-100 %T Transmission	Resolution: ±1.0% of Reading;	±1% of Full Scale	Wavelength: Ultra Violet 253.7nm	Reading is Updated every 30 seconds	Automatic, w/Calibration periods User Selectable
% Transmittance	Optical	Metex	UVT-15 UV Portable Transmission Photometer		absorbance	ex-situ	0 - 100 %Transmittance	Resolution: 1% Transmittance	±2%; Wavelength Accuracy: 253.7nm	Path Length: 10mm	Full scale deflection in less that 2 seconds	
W/m2	optical	UV-Elektronik GmbH	RM32	UVC-SE	absorbance	in-situ	1000w/m2	selectivity: above 280 nm 4%				

APPENDIX F

ANALYTICAL INSTRUMENTATION

Analytical

Background

Analytical instruments measure the chemistry and biology of the process. For the purposes of this research project, treatment process quality parameters measured in decentralized systems include the analytical instruments that measure ammonia-nitrogen, biochemical oxygen demand (BOD_5), chlorine residual, dissolved oxygen, nitrate-nitrogen, pH, phosphate, respirometry, and turbidity. These analytical instruments used for monitoring decentralized systems are listed in tabular format and are categorized by traditional and non-traditional technologies with assessed cost of ownership/maintenance requirements and instrument monitoring capabilities. The following tables provide analytical instrument technology specifications.

F.1 Ammonia-Nitrogen

Analytical instruments that measure ammonia-nitrogen include the traditional technologies of colorimetric, gas selective and ion-selective electrodes. Non-traditional instrument technologies use ultraviolet (UV) absorbance to measure ammonia-nitrogen.

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE	Applikon	Alert Ion	Alert Ion	Dynamic Standard Addition (DSA) Method	Ex-situ	0 to 10 ppm	Repeatability: +/- < 3% of full scale reading	Inaccuracy: +/- < 5% of full scale reading	5 min.	5 min.	Automatic, Program-mable
mg/L	Colorimetric	Applikon	Alert Colorimeter	Alert Colorimeter	Differential Absorbance Colorimetry (DAC) Method	Ex-situ	0 to 10 ppm	Repeatability: +/- < 3% of full scale reading	Inaccuracy: +/- < 5% of full scale reading	Ammonia: 5 min.	Ammonia: 5 min.	Automatic, Program-mable
mg/L	UV	AWA	CX1000-4000 series	1000 - 4000 series	UV light absorption spectrum of ammoniac gas NH3 in equilibrium with dissolved ammoniac gas in the water sample.	Ex-situ	0 – 100 mg/l NH4+ or (0 – 4000 mg/l on request)	Repeatability +/- 0.05 mg/l NH4+ or +/- 3% of reading (whichever is greater)		5 min. to 12 hours (configurable)	5 min.	Calibration check: every 6 months

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	UV	ChemScan	UV-2150	2150	UV Multiple Wavelength Absorbance Detection	Ex-situ	0.2 to 25 mg/L as N		accuracy 2 to 5% of range	3–9999 min.	3 to 5 min.	Calibrated to plant lab or reference at startup, thereafter automatically zeroed against deionized water standard at operator set intervals.
mg/L	Colorimetric	Endress + Hauser	Stamo-Lys CA 71 AM	Micro Ultra Filtration System StamoClean CAT 430	Photometric – Indophenole blue method	Ex-situ	0.02-5 mg/L (AM-A) 0.2-15 mg/L (AM-B) 0.2-100 mg/L (AM-C)	+/- 2% maximum measured error of measuring range end		0 to 120 min, = ~ 8 min	3 min	0 to 72 h at ambient temps

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE Std Addition	Global Measurement Technologies, Inc.	IonChem 2005	2005	Ion-Selective Electrode	Ex-Situ	Trace to Saturation	2%		User defined	2 min	Automatic
mg/L Ammonia Ammonium	ISE	Hach	AMTAX	sc	Expulsion method with photometric pH indication	Ex-situ	0.2–1200 mg/L NH₄-N		Accuracy: ± 2.5 % of the measured value or +/- 0.2 mg/L, whichever is greater	13, 15, 20, or 30 minutes (selectable)	13, 15, 20, or 30 minutes (selectable)	Auto-calibration, self-priming. Every 8, 12, or 24 hours (selectable) One-point automatic calibration with standard.
mg/L	ISE	Murtac	OMT20-SX / DXN-NH4	DXN-NH4	Ion-Selective Electrode (gas method)	Ex-situ	0,05 - 30mg/L NH4-N	+/- 3% scale end		5 min	3 min	1/day (free programmable)
mg/L	ISE	Myratek	AD-2000	AD-2000	Ion-Selective Electrode (ISE)	In-Situ	0.1– 99.9 ppm	Resolution: 0.1 ppm Reproducibility: within 5%	Accuracy: +/- 5 % of measurement or +/- 0.5 ppm (larger)	10 min or greater	5 min	Automatic: Default is every 6 hours – Adjustable to 1 hour or greater

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE	NEXTChem	Mini Chem Plus / Mini Chem / Omni Chem	Mini Chem	Ion-Selective Electrode (ISE) standard addition method	Ex-situ	0-20 ppm		Accuracy: +/- 2%	2 to 10 minutes	5 min avg	1 month
mg/L	ISE	Severn Trent	AZTEC A1000	A1000	ISE	Ex-situ	Auto Ranging 0.05–1000 mg/L as NH_3		Accuracy: 5% of reading (or ± 0.02 mg/L NH_3 whichever is greater)		5 min	Automatic 1 /day
mg/L	Colorimetric	Severn Trent	Aztec Am1000	Am1000	Colorimetric Color absorbance Salicylate method	Ex-situ	Auto Ranging 0–6 mg/L as NH_3 (0–5 mg/L as NH_3-N)		Accuracy: Typically 2–5% of reading	10–60 min		Two point, automatic calibration, with optional manual initiation. Selectable from 4 x's / day to once / week

WERF

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE	Tytronics	Tytronics Sentinel AMM-ISE	Tytronics Sentinel AMM-ISE	ISE Direct or using single known addition method	Ex-situ	0-10 ppm to 0–1000 ppm	+/- 5% of reading or +/- 5% of full scale (whichever is greater)		5 min	5 min	Weekly / User program-mable
mg/L	Colorimetric	Tytronics	Tytronics Sentinel Ammonia-WW	Tytronics Sentinel Ammonia -WW	Colorimetric Modified Berthelot method	Ex-situ	0–1 ppm to 0-25 ppm	+/- 2% of reading or +/- 2% of full scale (whichever is greater)		12 min	12 min	Weekly / User program-mable
mg/L	ISE	Waltron	uAI-8232	uAI-8232	Ion Selective Electrode	Ex-situ	0.05 to 5,000 ppm	+/- 5% of reading		0 to 1000 ppm	5 minutes	Automatic calibration 2 point user program-mable recommend ed once per week
mg/L	Colorimetric	Waltron	AI-9046	AI-9046	Colorimetric Dual-beam with silicon detector	Ex-situ	0 to 7.5 ppm	+/- 2% of reading		0 to 700 ppb, 0 to 7 ppm by auto-dilution	8 minutes	Automatic calibration 2 point user program-mable recommend ed once per week

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE / GSE	Wedgewood Analytical	PBS 1 - Process Buoy STIP	Process Buoy STIP	Ion-Selective Electrode / Gas Selective Electrode	In-situ	0.1 to 50 mg/L NH4-N	5%		3 to 5 min	5 min.	Automatic calibration (programmable)
mg/L	ISE / GSE	Wedgewood Analytical	GENION 1 (NH4)	GENION 1 (NH4)	Ion-Selective Electrode / gas-selective electrode (GSE)	Ex-situ	0.3 to 1,000 mg/L NH4-N	5%		5 min. lag continuous	5 min. excluding sample preparation	Automatic calibration (programmable)
mg/L	ISE	WTW	IQ Sensor Net AmmoLyt 700IQ	AmmoLyt 700IQ	Ion-Selective Electrode	In-Situ	0.1 to 100 mg/L	+/- 10 % of Measured Value Resolution 0.1 mg/L		Continuous	< 3 minutes	Manual

Ammonia-Nitrogen												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measureme nt Range	Measurement Uncertainty	Accuracy	Measureme Interval	Response Time	Calibration Frequency
mg/L	ISE	WTW	TresCon Module OA 100	TresCon Module OA 100	ISE Gas Sensitive	Ex-situ	0.1 to 10 mg/L and 10 to 100 mg/L	Coefficient of variation for method +/- 3% Resolution 0.1 mg/L Coefficient of variation for method +/- 4% Resolution 0.1 mg/L		Continuou s or Adjustable	< 3 Minutes	Automatic every 6, 12 and 24 hours

F.2 Biochemical Oxygen Demand (BOD_5)

Analytical instruments use a primary traditional technology of biological media to measure the biochemical oxygen demand (BOD_5).

BOD, Biochemical Oxygen Demand												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/l	Biological Media	Endress + Hauser	BIOX-1010	1010	true continuous biological with dilution procedure	ex-situ	20 - 1,200 mg/l BOD; 5 - 1,200 mg/l BOD; 20 - 100,000 mg/l BOD			3 - 15 min		
mg/L		LAR	BioMonitor	BioMonitor		Ex-situ	user - adjustable between 1 - 50 and 1 - 200.000 mg/l BOD			every 3 - 4 minutes		

F.3 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) analyzers indirectly measure the amount of organics in wastewater or surface water by determining the amount of oxygen consumed. COD analyzers utilize ultraviolet, high temperature catalytic oxidation and ozone oxidation technologies.

Chemical Oxygen Demand (COD) Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/l	High temperature catalytic oxidation	Endress + Hauser	PHOENIX-termcat	Thermcat	Combustion into CO2 and IR detection	Ex-Situ	4 - 1000 mg/l COD; 40 - 4000 mg/l COD; 100 - 10.000 mg/l COD		Reproducibility: 4% Resolution: 0.1 mg COD/L		T90 time: 3 - 15 minutes	Automatic calibration daily using two COD standards (two point calibration)
mg/l	Ozone oxidation	Endress + Hauser	PHOENIX-1010	1010	oxidation with ozone - dilution procedure	Ex-Situ	10 - 1,500 mg/l COD; 10 - 100,000 mg/l COD				3 - 15 min.	

Chemical Oxygen Demand (COD) Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
ppm Abs/m	UV	AWA	CX1000-3000	CX1000-3000	UV light absorption by unsaturated organic molecules at 254nm according to the Beer-Lambert law	Ex-Situ	0 - 2000 Abs/m The instrument is pre-calibrated for river water on the low range and for urban wastewater on the high range.					

F.4 Chlorine Residual

Total chlorine residual analyzers used for monitoring the disinfection process of decentralized wastewater treatment systems include the traditional technologies of amperometric and colorimetric and the non-traditional technologies of iodine gas sensor or gas phase sensing and ion-selective electrodes.

Chlorine Residual Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
ppm	Iodine Gas Sensor or Gas Phase Sensing	ATI	A15/79	A15/79	Iodine Gas Sensor or Gas phase iodine sensor.	Ex-Situ	Programmable for ranges of either 0-2.000 PPM or 0-20.00 PPM	Repeatability: ± 0.01 PPM; Linearity: 0.1% of F.S.; Zero Drift: < 0.01 PPM per month	± 0.01 PPM		95% in 3 Minutes	
mg/L or ppm free chlorine	Amperometric	Emerson / Rosemount Analytical	54eA Analyzer	499A Amperometric Sensor	Amperometric - membrane-covered amperometric sensor consisting of a porous membrane stretched tightly over a platinum cathode.	Ex-situ	0 to 10 ppm (mg/L) as Cl_2. For higher ranges, consult the factory.		Accuracy depends on the accuracy of the chemical test used to calibrate the sensor.		22 sec to 95% of final reading at 25°C	the sensor must be calibrated against the results of a laboratory test run on a grab sample of the process liquid

Chlorine Residual Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L or ppm	Amperometric	Hach	Sigma Residual Chlorine Monitor Model 8450	Model 50 Probe	Amperometric membraned probe	In-Situ	0.00 to 20.0 ppm (selectable)	Repeatability ±0.5%; Linearity ±0.5%;	Displayed Precision 0.01, 0.1, 1	Sampling Interval 1-90 minutes, selectable intervals	Damping Time Constant: 0 - 300 seconds	
mg/L	Colorimetric	Hach	CL17	CL17	Colorimetric DPD chemistry method of measurement using DPD indicator and a buffer solution.	Ex-situ	0 to 5 mg/L free or total residual chlorine. Minimum Detection Limit: 0.035 mg/L	Precision: ±5% or 0.005 mg/L as CL2, whichever is greater.	Accuracy: ±5% or ±0.035 mg/L as CL2, whichever is greater.		Cycle Time: 2.5 minutes	

Chlorine Residual Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L or ppm	Amperometric Electrode Cell plus pH reagent solution	Severn Trent	Aztec CL1000	Aztec CL1000	Amperometric Electrode Cell plus pH reagent solution.	Ex-situ	0-60 mg/L		Manufacturer's Quoted Accuracy 1% of reading or +/- 0.002 PPM, whichever is greater for residuals below 20PPM 0. 5% of reading for residual levels between 20-60PPM (see sample limitation).		Four (4) seconds from sample entry to display indication. 90% of full scale response within 1-1/2 to 2 minutes.	
ppm	Ion-Selective Electrode	Thermo Scientific	Orion 1770 Total Residual Chlorine Monitor	Orion 1770 Total Residual Chlorine Monitor	ISE - Ion-Selective Electrode iodometric method for total residual chlorine.	Ex-Situ	0.001-10 ppm total residual chlorine 4-decade scale standard. Other ranges available.		± 10% of reading	10 min	90% within 2 min	2 point calibration

Chlorine Residual Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	Amperometric Electrode Cell	Wallace & Tiernan	Micro 2000	Micro 2000 Three Electrode Measuring Cell	Amperometric Electrode Cell which continuously measures and indicates free or total Chlorine residual	Ex-situ	0-0.1 to 0-50 mg/l free or total Chlorine residuals, Chloride Dioxide or Potassium Permanganate residual.	Sensitivity: 0.001 mg/L or 1% of full scale, whichever is greater. Repeatability: 0.001 mg/L or 1% of full scale, whichever is greater. Stability: Under favorable conditions +/- 1% of full-scale for 1 month.	Accuracy is 0.001 mg/l or 1% of full scale whichever is greater.		90 sec. with 2 rpm pump motor. 180 sec. with 1 rpm pump motor. (Sample is pumped to cell via an internal peristaltic pump.)	Long term stability of calibration that is unaffected by varying water quality, changes in turbidity or conductivity

F.5 Dissolved Oxygen

Dissolved oxygen analyzers used for remote monitoring of aerated biological systems in decentralized systems utilize the traditional instrument technologies of galvanic and polarographic sensors and utilize the non-traditional instrument technology of optical fluorescence.

Dissolved Oxygen Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure ment Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
mg/L	Galvanic	ABB	4642	9408-762E	Galvanic	In-Situ	Programmable 0-200% saturation, 0 to 20 mg/l	Sensitivity or Resolution 0.1%	1% saturation , 0.1 ppm		20 Seconds for 90% at 20 Deg C	Calibration Method: In air for span or 5% sodium sulphate for zero if required.
mg/L	Polarographic	Endress + Hauser	Liquisys M COM 253	COS 41	Membrane covered amperometric sensor	In-Situ	0 - 20 ppm (mg/l) / 0...200 %SAT / 0...400 hPa	Repeatability Max. 0.2 % of measuring range.	Max. 0,5 % of measuring range (display). Sensitivity or Resolution 0.01 ppm (mg/l) / 0.1 %SAT / 1 hPa			One point slope calibration: |1) in air 2) in air saturated water 3) in process by means of reference measurement (handheld, Winkler titration etc).

Dissolved Oxygen Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure ment Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
mg/L or ppm	Polarographic	Foxboro	873DO Electrochemical Analyzer	871DO-C Sensor	Polarographic Clark Cell with a composite membrane enclosing four electrodes in potassium chloride (KCl) electrolyte.	In-Situ		Repeatability: ±2% of span; Drift: Less than ±1% of measurement span per day in nonmembrane fouling conditions			Nominal 90% of step response in less than one minute at 25oC (77oF).	Air calibration.
mg/L	Polarographic	Hach	GLI D53	5500 Clark Series Electrode	Polarographic Clark Cell technology that includes a three-electrode system: gold cathode, silver anode, and silver reference electrodes.	In-Situ	0.0-40.00 ppm	Sensitivity: ± 0.05% of span. Repeatability : ± 0.05% of span	± 0.1% of span		1-60 seconds to 90% of value upon step change. Response Time (20°C): 130 seconds to 90% of value upon step change.	Calibration Method: Comparison Sample Cal to Laboratory instrument or winkler method Air Cal Saturation Cal

Dissolved Oxygen Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure ment Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
ppm	Optical Fluorescence	Hach	LDO	LDO	The sensor is an optical type sensor that measures the fluorescence and quenching reactions	In-Situ	0-20 ppm	Hach	Above 1 ppm: ±0.2 ppm			
mg/L ppm	Galvanic	IC Controls	855-8-32-52	802-1-3-94 Sensor	Galvanic reduction of oxygen to directly produce mA current	In-Situ	0 to 20 ppm and -5 to 105 oC	Repeatability ±2% of Reading; Sensitivity or Resolution: Standard deviation ±2% of reading or 2 digits; Stability (per 24 hr period): ±2 of Reading	Standard deviation ±2% of reading or 0.1 ppm, whichever is a greater Dissolved Oxygen		90% within 5 minutes (default), function of flow	One point, in air, ½ inch over surface of water with zero check using A1100193 Zero DO standard
mg/L or ppm	Optical Fluorescence	Insite IG	1000	10 Probe	The sensor is an optical type sensor that measures the fluorescence and quenching reactions of a ruthenium complex that is immobilized in a sol-gel matrix.	In-situ	0.00 to 25.0 ppm and 0 to 50 degrees C	Repeatability 0.01 ppm; Sensitivity or Resolution: 0.01 ppm; Stability (per 24 hr period): 0.01 ppm; Non-Linearity: 1.1%	1% of reading or 0.02 ppm, whichever is greater. Sensor Drift: Less than 1% per year		90% in less than 60 seconds	Not required nor recommend during initial startup. Provisions for one-point in water calibration provided.

Dissolved Oxygen Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure ment Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
mg/L or ppm	Optical Fluorescence	Insite IG	1000	10 Probe	The sensor is an optical type sensor that measures the fluorescence and quenching reactions of a ruthenium complex that is immobilized in a sol-gel matrix.	In-situ	0.00 to 25.0 ppm and 0 to 50 degrees C	Repeatability 0.01 ppm; Sensitivity or Resolution: 0.01 ppm; Stability (per 24 hr period): 0.01 ppm; Non-Linearity: 1.1%	1% of reading or 0.02 ppm, whichever is greater. Sensor Drift: Less than 1% per year		90% in less than 60 seconds	Not required nor recommend during initial startup. Provisions for one-point in water calibration provided.
mg/L	Galvanic	Royce Technologies	9210/9220	96	Galvanic Oxygen Measurement Sensor	In-Situ	0 to 99.9 mg/L or 0 to 99% Saturation		+/- 0.1 mg/L or 1% Saturation		99% of actual from Air Calibration = less than 60 Seconds with 1 mil membrane	Twice per year when using electro-chemical cleaning
mg/L	Galvanic	Royce Technologies	900	95/99	Galvanic Oxygen Measurement Sensor	Portable	0 to 99.9 mg/L or 0 to 99.9% Saturation		+/- 0.1 mg/L or 1 % Saturation		99% of actual from Air Calibration = less than 30 Seconds with 1 mil membrane	Once per week (Air Calibration)

Dissolved Oxygen Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure ment Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
mg/L	Galvanic	Royce Technologies	9100	95/99	Galvanic Oxygen Measurement Sensor	In-Situ	0 to 99.9 mg/L or 0 to 99.9% Saturation		+/- 0.1 mg/L or 1% Saturation		99% of actual from Air Calibration = less than 60 Seconds with 1 mil membrane	Once per year when using jet cleaning system.
mg/L	Galvanic	Royce Technologies	9200	96	Galvanic Oxygen Measurement Sensor	In-Situ	0 to 99.9 mg/L or 0 to 99.9% Saturation		+/- 0.1 mg/L or 1% Saturation		99% of actual from Air Calibration = less than 60 Seconds with 1 mil membrane	Twice per year when using electro-chemical cleaning.
mg/L	Galvanic	Royce Technologies	9110/9120	95/99	Galvanic Oxygen Measurement Sensor	In-Situ	0 to 99.9 mg/L or 0 to 99.9% Saturation		+/- 0.1 mg/L or 1% Saturation		99% of actual from Air Calibration = less than 60 Seconds with 1 mil membrane	Once per year when using jet cleaning system.

Dissolved Oxygen Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measure ment Range	Measurement Uncertainty	Accuracy	Measure ment Interval	Response Time	Calibration Frequency
mg/L	Polarographic	WTW	184 Sensor Net Transmitter	TriOxmati c 700IQ DO Sensor	Polarographic with three electrodes	In-Situ	0.0 to 60.0 mg/L or 0% to 600% saturation, user selectable	Repeatability: 1% plus one digit (analyzer plus sensor); Sensitivity or Resolution: 0.1mg/L	1% of reading plus 1 digit (Transmitt er); Sensor Drift: 1% per month		180 sec t/90	Calibration every 6 months typically. Calibration Method: In-Air; Maintenance Requirements: Periodic (12 months) membrane changes.

F.6 Nitrate-Nitrogen

Analytical instruments that measure nitrate-nitrogen include the traditional technologies of colorimetric and ion-selective electrodes. Non-traditional instrument technologies use advanced oxidation process using hydroxl radicals and ultraviolet (UV) absorbance to measure nitrate-nitrogen.

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	Colorimetric	Applikon	Alert Colorimeter	Alert Colorimeter	Differential Absorbance Colorimetry (DAC) Method	Ex-situ	0 to 10 ppm	Repeatability: +/- < 3% of full scale reading	Inaccuracy: +/- < 5% of full scale reading	Nitrate: 10 min.	Nitrate: 10 min.	Automatic, Programmable
mg/L	ISE	Applikon	Alert Ion	Alert Ion	Dynamic Standard Addition (DSA) Method	Ex-situ	0 to 10 ppm	Repeatability: +/- < 3% of full scale reading	Inaccuracy: +/- < 5% of full scale reading	5 min.	5 min.	Automatic, Programmable
mg/L	UV	AWA	NX 1000 (single parameter)		UV light differential absorption by chromophore N-O at 210-220 nm according to Beer-Lambert Law	Ex-Situ	0 – 100 mg/l NO3-or (0 – 3000 mg/l on request)	Repeatability +/- 0.1 mg/l NO3-		5 sec to 12 hours (configurable)	10 sec	Calibration check: every 6 months

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	Advanced Oxidation Process using Hydroxyl Radicals	BioTector	BioTector Series 4Plus	BioTector Series 4Plus	Patented 2 Stage Advanced Oxidation Process.	Ex-Situ	Automatic Range Selection (ARS) Valve which selects the correct range anywhere between 0-5mg/l and 0-25,000 mg/l	Repeatability: ± 3% of reading or ± 0.5mg/l	Signal Drift: < 5% per year	Batch Samples Minimum < 6 minutes		Automatic Calibration and Sample Line Cleaning. MAINTENANCE: Normal service frequency is 6 months. Separate service kits are available.
mg/L	ISE	Bran + Luebbe Lightnin	90 S Ionometer	90 S Ionometer	ISE (potentiometric)	Ex-situ	0—2.5 mg/L 0—200 mg/L	Precision: < 5% of full scale	Drift: < 3% of full range	3 minutes or longer (multi-channel models)	(T95) 6 min	Automatically, once a day programmable
mg/L	UV	Bran + Luebbe Lightnin	ISIS	ISIS II	UV-Vis Spectrometer (extended Near InfraRed range available soon)	In-situ	0—25 mg/L	Precision: < 5% of full scale	Drift: < 3% of full range	1 minute or longer (multi-channel models)	(t95)1 min	Precalibrated Onsite adjustment to local sample conditions.

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	UV	ChemScan	UV-3150	3150	UV Multiple wavelength absorbance	Ex-situ	Nitrate (0.1 to 25 mg/L as N) Nitrite (0.1 to 10 mg/L as N)	accuracy 2 to 5% of range		1–9999 min.	Immediate after sample flush	Calibrated to plant lab or reference at startup, thereafter automatically zeroed against deionized water standard at operator set intervals.
mg/L	UV	Endress + Hauser	Stamo-Sens CNM750 CNS70		UV light absorption	In-situ	Clean water: 0.2–60 mg/L NO₃-N, 0–260 mg/L NO₃ Activated Sludge: 0.2–30 mg/L NO₃-N, 0–130 mg/L NO₃	Repeatability 0.5 % (with homogenous media)+/- 2% maximum measured error of measuring range end		40 s	60 s	Automatic in-situ

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	UV	Hach	NITRATAX plus sc	plus sc	UV absorption	In-situ or Ex-situ	1 mm sample measuring gap: 0.1–100 mg/L NO2+3-N; 2 mm sample measuring gap: 0.1–50 mg/L NO2+3-N; 5 mm sample measuring gap: 0.1–25 mg/L NO2+3-N		Accuracy: +/- 3% of measurement or +/- 0.5 mg/L, whichever is greater	> 1 min.	1 min. (t100)	Each probe is factory calibrated
mg/L	UV	Hach	NITRATAX eco sc	eco sc	UV absorption	In-situ and Ex-situ	1 mm sample measuring gap: 1.0–20 mg/L NO<sub>2+3</s ub>-N		Accuracy: +/- 5% of measurement or +/- 1.0 mg/L, whichever is greater	> 5 min.	15 min. (t100)	Each probe is factory calibrated
mg/L	UV	Hach	NITRATAX clear sc	clear sc	In-situ UV absorption or ex-situ UV absorption				Accuracy: +/- 5% of measure-ment or +/- 0.5 mg/L, whichever is greater	> 1 min.	1 min. (t100)	Each probe is factory calibrated

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE	Murtac	OMT20-SX / DXN-NO3	DXN-NO3	Ion-Selective Electrode (ISE)	Ex-situ	1– 20mg/L NO3-N	+/- 5% scale end		10 min	7 min	Every measurement (3point standard addition)
mg/L	ISE	Myratek	ND-2000	ND-2000	Ion-Selective Electrode (ISE)	In-Situ	0.1– 99.9 ppm	Resolution: 0.1 ppm Reproducibility : within 5%	Accuracy: +/- 5 % of measurement or +/- 0.5 ppm (larger)	10 min or greater	5 min	Automatic: Default is every 6 hours – Adjustable to 1 hour or greater
mg/L	UV	S::can Messtechnik GmbH	8580 Constat	82N Nitrolyser	UV-VIS spectro-photometrical analysis	In-Situ	0.1 – 10 mg/l	+/-0.1 mg/l		2 minutes	30 seconds	Global calibration for intended application preloaded at factory.
mg/L	ISE	Severn Trent	Aztec N1000	N1000	Ion-Selective Electrode (ISE)	Ex-situ	Auto Ranging 0.05–1000 mg/L as NO3		Accuracy: 3% of reading (or ± 0.5 mg/L NO3 whichever is greater)		5 min	Automatic 1 /day

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	UV	Tytronics	Tytronics FPA 1100	Tytronics FPA 1100	UV Spectrophotometer	Ex-situ	0–100 ppm	+/- 2% of reading or +/- 2% of full scale (whichever is greater)		Continuous possible	Continuous	Auto or manual
mg/L	ISE	Tytronics	Tytronics Sentinel Nitrate	Tytronics Sentinel Nitrate	ISE Direct or using single known addition method	Ex-situ	0–10 ppm to 0-100 ppm	+/- 5% of reading or +/- 5% of full scale (whichever is greater)		5 min	5 min	Weekly / User programmable
mg/L	UV	Wedgewood Analytical	STIP-scan	STIP-scan	UV / Visible Spectroscopy (Vis.)	In-situ	0.1 to 23.0 mg/L NO3-N	5%		1 to 5 min.	5 min.	
mg/L	UV	WTW	TresCond Modules ON 210/OS 210	TresCond Modules ON 210/OS 210	UV absorption	Ex-situ	0.1 to 100 mg/L	Coefficient of variation for method +/- 2% Resolution 0.1 mg/L		Continuous or Adjustable	30 s	Automatic every 6, 12 and 24 hours
mg/L	UV	WTW	IQ Sensor Net	IQ Sensor Net	UV/VIS spectrometric	In-Situ	0.1 to 100 mg/L	+/- 3% of measured value +/- 0.5 mg/L with check algorithm		Continuous	< 3 Minutes	Not required

Nitrate-Nitrogen												
Units	Tech-nology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	ISE	WTW	IQ Sensor Net NitraLyt 700 IQ	IQ Sensor Net NitraLyt 700 IQ	Ion-selective	In-situ	0.1 to 100 mg/l	+/- 10 % of Measured Value Resolution 0.1 mg/L		Continuous	< 3 Minutes	Manual

F.7 pH, ORP, Conductivity and Alkalinity

pH, ORP, conductivity and alkalinity are often measured concurrently. Manufacturers of pH, ORP and conductivity online analyzers use separate sensors to measure each parameter, however manufacturers sometimes use the same transmitter electronics for pH, ORP and conductivity measurements.

F.7.1 pH

The primary traditional instrument technology for measuring pH utilizes the electrometric method. Non-traditional pH measurement would include ion-selective field effect transistor technology.

pH												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
pH	electrochemical potential	Krohne	MAC 080	PAS 2000	pH	in-situ	-2 to 16 pH					
pH	ISE	Hach	si792x P				-2.00 to +16.00		-2.00 to +16.00			
pH		Yokogawa	PH450G 4-wire				-2 to 16 pH				<4 sec for 90 % (pH 7 - pH 4)	Semi-automatic 1 or 2 point calibration using pre-configured NIST, US, DIN buffer tables 4, 7 & 9
pH	electrochemical potential	Endress+Hauser	Liquiline M CM42	CPS91	pH	in-situ	–2 to 16 (glass electrodes)					

pH												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
pH	electromechanical	Hach GLI	GLI P53 pH/ORP Controller				-2.0 to 14.0 pH or -2.00 to 14.00 pH	Stability: 0.05% of span per 24 hrs., non-cumulative	0.1% of span			Calibration Methods: 2-point Buffer Method (pH only):buffer from a sele
pH	electrometric	Honeywell	APT4000 pH/ORP analyzer		electrometric	in-situ	0.00 pH to +14.00 pH; ORP value: –1500 mV to +1500 mV		pH: < 0.02; mV: < 1 mV			
pH	electrometric	JUMO Plus	AQUIS 500 pH/ORP PID controller	tecLine PRO Industrial High Performance pH Electrode		in-situ	pH Range: -1.00 to 14.00; ORP Range: -1999 to +1999 mV		> 0.25% of measurement range			
pH		Royce Technologies	5300	55A	pH	in-situ	0-14 pH		Measurement: +/- .2% of full scale.			
pH	electrometric	Polymetron, Hahc Ultra	Polymetron 9135 pH Transmitter			in-situ	0 to 14 pH; redox - 1500 to 1500 mV		± 1% of reading			Auto calibration in std buffers

F.7.2 ORP – Oxidation Reduction Potential (ORP)

The primary traditional instrument technology for measuring ORP utilizes the electrometric method.

ORP – Oxidation Reduction Potential												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Fre-quency
mV	Electrometric	Siemens Stranco	Strantrol 880	Strantrol	Electrometric-High Resolution Redox	In-situ	pH 0.00 – 14.0; ORP HRR -1000 mV to +1000 mV	Resolution: pH 0.1; ORP HRR 1mV	Monitoring accuracy is ± 0.05% per year			
mV	Electrometric	ATI	Q45P/R	Q22	Electrometric with a differential sytel	In-situ	-1000 to +2000 mV; Sensor voltage: ±500 mV; Loop current: 4.00 to 20.00 mA	Repeatability: 0.1% of span or better;	Sensitivity: 0.05% of span		6 seconds to 90% of step input at lowest setting	
mV	Electrometric	Endress + Hauser	Mycom S CPM 153	Orbisint CPS12	Electrometric	In-situ	-1500 to +1500,ORP signal output max. 0.75% of measuring range	Resolution 1 mV / 0.1%				
mV	Electrometric	Hach	sc 100	RC2K5N	Electrometric	In-situ	-2000 to +2000 millivolts					
mV	Electrometric	Royce Technologies	5000	55A	Electrometric	In-situ	+/- 1999mV ORP		+/- .2% of full scale			

F.7.3 Conductivity

Conductivity analyzers measure the ion concentration of a solution. Conductivity analyzers utilize electrode technologies.

Conductivity Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
µS	Torodial conductivity	ATI	Q45CT	Toroidal	Toroidal electrode conductivity	In-situ	0 to 2,000 µS; Sensor Minimum Conductivity: 500 microSiemens	Repeatability: 0.3% of span, or 0.1 ìS, whichever is greater; Non-linearity: 0.3% of span, or 0.1 ìS, whichever is greater; Temperature Drift: Span or zero, 0.03% of span/ºC	Sensitivity: 0.05% of span or 0.1 ìS, whichever is greater; Stability: 0.1% of span per 24 hours	Warm-up Time: 7 seconds to rated performance	6 seconds to 90% of step input at lowest setting. Sensor Response Time: 2 seconds to 90% of full scale	Flexible Calibration: Two-point and sample calibration options include stability monitors to check temperature and main parameter stability before accepting data.
µS	Electrode Conductivity	ATI	A45C4 4-Electrode Conductivity Monitor	4	Electrode Conductivity 4-electrode sensor.	In-situ	0.0 µS to 2000 mS; 4-Electrode Style Sensor: Allows the sensor to be used over 0 to 2,000,000 µS range.	Repeatability: 0.3% of span, or 0.1 ìS, whichever is greater; Non-linearity: 0.3% of span, or 0.1 ìS	Sensitivity: 0.05% of span or 0.1 ìS, whichever is greater		6 seconds to 90% of step input at lowest setting	Flexible Calibration: Two-point and sample calibration options.

Conductivity Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
µS	Electrode	Hach	CDC401 IntelliCAL Standard Conductivity Probe			In-situ	0.01 µS/cm to 200 mS/cm	Resolution: 0.01 µS/cm (5 digits, maximum)				
µS/cm	Electrode	Endress + Hauser	Condumax W CLS21		Two electrode method using Ohm's law.	In-situ	10 µS/cm to 20 mS/cm.					

F.7.4 Alkalinity

Alkalinity analyzers measure total alkalinity using wet chemistry methods. Alkalinity analyzers utilize colorimetric, titrimetric and ion-selective electrode technologies.

Alkalinity Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L as CaCO3	titrimetric and colorimetric	Hach	APA 6000		titrimetric and colorimetric methods of detection to determine the concentration and continuously monitor total and phenolphthalein alkalinity	Ex-situ	1 to 1000 mg/L as CaCO3 total alkalinity; 5 to 1000 mg/L as CaCO3 phenolphthalein alkalinity	Repeatability: Better than 3 % of reading or ± 0.6 mg/L, whichever is greater	Better than ± 5 % of reading or ± 1.0 mg/L, whichever is greater	8 minutes	Less than 5 minutes for 90% response to setup change at instrument sample fitting	self priming and self-calibrating; auto-calibrates with set and forget operation

F.8 Phosphate

Phosphate analyzers use the traditional technology of photometric and the non-traditional technology of advanced oxidation process using hydroxyl radicals.

Phosphate Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measuremnt Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/L	Advanced Oxidation Process using Hydroxyl Radicals	BioTector	BioTector Series 4Plus On-Line Organic Analyser	BioTector Series 4Plus	Patented 2 Stage Advanced Oxidation Process.	Ex-Situ	Automatic Range Selection (ARS) Valve which selects the correct range between 0-5mg/l and 0-25,000 mg/l	Repeatability: ± 3% of reading or ± 0.5mg/l	Signal Drift: < 5% per year	Batch Samples Minimum < 6 minutes		Automatic Calibration and Sample Line Cleaning. MAINTENANCE: Normal service frequency is 6 months. Separate service kits are available.
mg/l orthophosphate (PO₄ ³⁻)	photometric	Endress + Hauser	Stamolys CA71PH	CA71PH	photometric	ex-situ	0.05 to 2.5 mg/l (ppm) PO		2% of measuring range end			

Phosphate Analyzers												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measuremnt Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
mg/l	Photometric	Endress + Hauser	SPECTRON TP - Total Phosphate	TP	Photometric quasi continuous	ex-situ	up to 100 mg/l P				12 minutes (excluding transit time for sample preparation system)	
mg/l	Colorimetric	Hach	5000		colorimetric	ex-situ	0 to 50 mg/l P		± 0.5 mg/L or ± 5%, whichever is greater		11 minutes	
mg/l	Colorimetric	Hach	Phosphax sc		colorimetric	ex-situ	Low range: 0.05 to 15 mg/l; High Rage: 1 to 50 mg/l P		Low Range: 2% ± 0.05 mg/L; High Range: 2% ± 1.0 mg/L	5 to 120 minutes, adjustable	(T90): Less than 5 minutes, including sample preparation	

F.9 Respirometry (oxygen uptake rate)

Respirometry measures the respiration rate of raw samples of wastewater by providing a continuous record of changes in oxygen use.

Respirometry													
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
	Respirometry	Challenge Technology	OLR-300		oxygen uptake	ex-situ	Minimum Oxygen Uptake Detection: ~ 1.0 mg/hr Maximum Oxygen Input Rate :> 1,000 mg/hr	Sensitivity: ~ 0.1 mg			hydraulic retention times of 15 minutes to 12 hours	
	Respirometry	Respirometry Plus, LLC	026-202		sensitive gas volume transducer	ex-situ	Range of total oxygen demand not limited	Precision +/- 2% as measured with sodium sulfite			Test results in minutes	

F.10 Turbidity

Turbidity measurement is a regulatory reporting requirement in the United States. The traditional technology for turbidity measurement is optical using nephelometric, per the U.S. EPA Method 180.1. The nephelometric measurement can vary by light source (either white light or infrared) and/or by type of scatter (side-scatter at 90 degrees or transmissive light and receiver at 180 degrees apart).

Turbidity												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
NTU, FNU, mg/l, ppm	Nephelometric	Endress + Hauser	Liquisys M CUM 223/ CUM 253	TurbiMax W CUS 31/ 31-W	nephelometric 90° NIR scattered light according to EN 27027	in-situ	0.00 ... 9999 FNU, 0.00 ... 9999 ppm, 0.0 ... 300 g/l (0.0...18.72 lb/ft3), 0.0 ... 200.0%					
Turbidity: User selectable - NTU, FNU, or TE/F; Suspended Solids: User selectable - g/L, mg/L, ppm, or % solids	Infrared	Hach	SOLITAX sc Turbidity Analyzer Includes a sc100 Controller	PVC t-line sc Turbidity Sensor (0.001 to 4000 NTU) with wiper	dual-beam infrared scattered light photometer and receptors	In-Situ	Model t-line sc sensor Turbidity only: 0.001 to 4000 NTU	Turbidity Less than 1% of reading; Suspended Solids: Less than 3% of reading	Turbidity Less than 1% of reading or ±0.001 NTU, whichever is greater. Suspended Solids: Less than 5% of reading	Signal Average Time User selectable ranging from 10 to 300 seconds	Initial response in 1 second	Calibration: Turbidity Formazin or StablCal Standard; Suspended Solids;Based on gravimetric TSS analysis
NTU	surface scatter	Hach	1720E		Optical	Ex-situ	0 to 100	Repeatability: (Defined According to ISO 15389): Better than ± 1.0% of reading or ±	± 2% of reading or ± 0.015 NTU (whichever is greater)		Initial response in 1 minute, 15 seconds for a full scale step change	

Turbidity												
Units	Technology	Manufacturer Name	Instrument Model	Sensor Model	Measurement Method	Sensor Location	Measurement Range	Measurement Uncertainty	Accuracy	Measurement Interval	Response Time	Calibration Frequency
								0.002 NTU, whichever is greater				
NTU	surface scatter	Hach	7 sc		Optical	Ex-situ	0 to 1000	Repeatability: ± 1.0% or 0.04 NTU, whichever is greater	± 5.0% of reading or ±0.1 NTU (whichever is greater) from 0 to 2000 NTU; ± 10.0% from 2000 to 9999 NTU		Initial response in 30 seconds with a flow rate of 2 L/minute	
NTU	infrared	Hach/GLI	T53	820	Infrared	Ex-situ	0 to 100	Repeatability: 0.1% of span or better	2% of reading, all ranges		Residence Time: 9.5 seconds at 1 GPM (3.8 LPM	

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