Introduction

This handbook is a reference for the elearning program *Making Sense of Water With Sensors.* It covers use of water sensors for monitoring water quality characteristics such as: pH, conductivity, oxidation reduction potential (ORP), biological oxygen demand (BOD), and flow.

It also covers information for constructing a mobile water sensor kit.

This handbook focuses on food and beverage (F&B) industry water monitoring but also applies to deploying sensors in a variety of settings and other industries. F&B facilities use water to produce products and clean equipment. Waste streams are produced from the associated production and cleaning processes. Monitoring water quality and quantity via water sensors can aid F&B facilities in reducing water use and waste streams they produce.

Why Use Mobile Sensor Kits?

Sensor deployment at facilities allows for real-time monitoring of conductivity to support better decision-making about water quality and efficient operations. For example, with real-time conductivity data, facility personnel can mitigate equipment fouling by quickly determining proper water treatment strategy for lower conductivity water. Understanding process water can reduce equipment malfunction and replacement.

Mobile sensor kits can be deployed practically anywhere water requires analysis and can be tapped. The kits are small and contained in a rugged hard-shelled suitcase style box with a touchscreen on the outside. Deployments can be 1 hour, 1 day, 1 week or longer. Therefore, kits can be deployed to pick up trends for a variety of lengths of time.

Benefits to deploying sensor kits is their temporary nature. Sensor kits are an effective, non-invasive option for a facility because there is no construction down-time or non-facility personnel onsite for extended periods of time. Multiple sensor kits can be deployed at one time. Therefore, trends between locations can be established, or simply analyzing multiple locations at once so visits can be limited.

Mobile sensor kits succeed in locations that are typically far removed from power outlets, lack the ability for a permanent sensor to be installed due to cost, location, or if impractical. Operations or production lines that require attention but do not have a big budget for professional consultation could also see benefits from sensor kit deployment. Also, smaller facilities that do not know how or where to start for water quality monitoring, or what to monitor, can also find value in the real-time data provided by sensor kits.

Water Quality Characteristics Sensors Can Analyze

- **Conductivity:** Many municipal water supplies (i.e., tap water) have higher total dissolved solids (TDS) than desired in F&B products so TDS must be removed by reverse osmosis (RO). Reducing TDS also reduces corrosion potential for pipes and equipment. If tap water quality varies seasonally, then it is possible that RO could be bypassed during part of the year and conductivity monitoring would be key to managing seasonality. A conductivity sensor on the membrane concentrate line can monitor RO process efficiency, and with the conductivity sensor for tap water, be used to calculate the recovery of the RO process.

- **pH:** Cleaning solutions typically acidic (low pH) or basic (high pH) to facilitate cleaning, and product waste streams can have low or high pH. Either low or high pH can be problematic for discharge permits, so using a monitoring pH can assist with waste stream disposal such as determining the amount of dilution necessary for discharge or disposal.

- **Oxidation reduction potential (ORP):** The ORP of water is correlated with oxidant and disinfectant chemicals like chlorine. Chlorine sensors are expensive (>$1000) while ORP sensors are lower cost (~$100). So ORP is a low-cost way to monitor cleaning solution or other water/waste streams where disinfectant or oxidant is present.

- **Biological oxygen demand (BOD)**: BOD is a measure of the biodegradable content of water/waste and is of concern for waste streams that are discharged to a sewer or disposed of other ways. High BOD waste streams are particularly relevant for bottling facilities and snack foods. Although sensors for BOD are an active research area, it is possible to use existing sensors like turbidity or ultraviolet (UV) light absorbance to monitor BOD in waste streams to enable dilution and proper discharge.

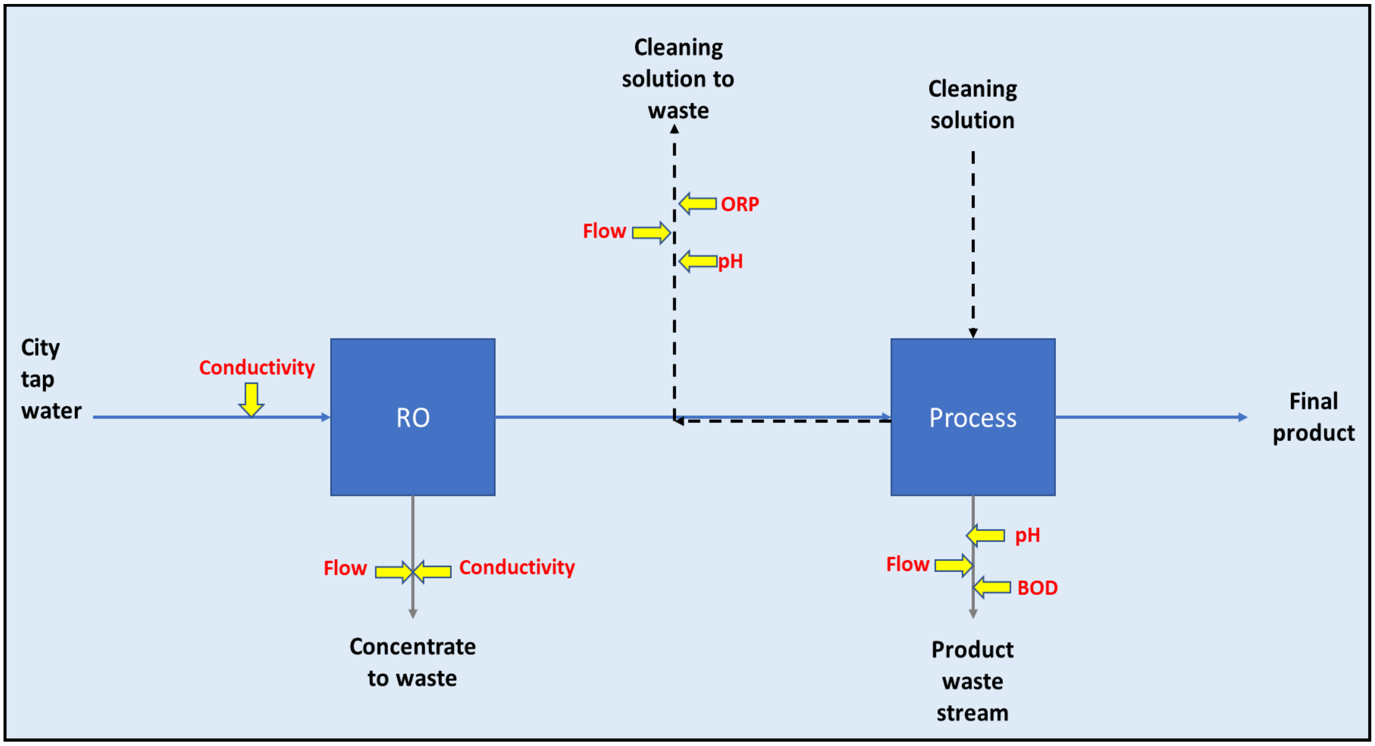
- **Water flow**: Ultrasonic flow sensors are noninvasive way to monitor flow, which can be especially useful on waste streams involving discharge permits or on processes like RO to monitor water recovery and efficiency.

Collecting and Using Data for Improving Water Use and Processes

Mobile sensor kits provide data to help facilities understand the changes in water quality after the water leaves the treatment plant, plus provide information about usage trends.

For example, a municipality may report their observed total dissolved solids samples ranged from 384 – 816 mg/L for the entire year. However, this does not indicate the same quality of water is reaching the facility.

Example of a Simplified Process Flow Schematic for an F&B Facility Using Reverse Osmosis



Municipal tap water enters the facility where it is used to produce product and clean equipment. To meet product specifications, the municipal tap water is treated by reverse osmosis (RO) to reduce the total dissolved solids (TDS) content of the municipal tap water. The RO process creates two liquid streams: RO permeate, which is low TDS water used to produce the product, RO concentrate, which is waste stream high in TDS and other constituents present in the municipal tap water. The RO permeate is used to produce the F&B product, and during the F&B process (e.g., bottling), one of more waste streams are produced. Finally, periodic cleaning occurs during product or flavor change overs and to maintain hygienic conditions, which in turn create waste streams.

Given the process flow for an F&B facility described, water quality and water flow sensors can be strategically placed in the facility to provide new insights on the process. The water quality sensors explored here are conductivity, pH, oxidation-reduction potential (ORP), and biochemical oxygen demand (BOD), and water flow by noninvasive ultrasonic flow sensor.

Monitoring Options – In-line or Drop-in

In-line water quality monitoring

- This is the primary mode of measurement. The flow-through cell is designed to connect in-line with existing water flow.
- To connect a water stream to the flow cell, all that is needed is flexible tubing.
- If suitable, the sensor kit can be installed in-line with the water stream being measured. The connection on either end of the flow cell are push-to-connect fittings and it does not matter which side is the entrance and which is the exit.
- It will most likely be more convenient to branch off the measured water stream with a tee and connect that smaller stream to the flow cell and discard the effluent to a drain or storage tank with an appropriate length tube segment.

Drop-in water quality monitoring

- The secondary mode of measurement involves connecting the sensors to the external BNC connectors.
- This mode is useful when it is easier to drop the sensors into the water stream or volume being measured instead of using the flow cell.
- To do this, the sensors are removed from the internal flow cell by loosening the compression fittings and pulling them out and disconnecting their corresponding BNC cables from the Tentacle board on the Raspberry Pi.
- 3” BNC female to female extension cables are needed to connect from the Tentacle board to the inside of the BNC bulkhead connectors.
- After the sensors are removed from the flow cell, the sensors can be connected to the external BNC connectors and will be recognized immediately by the program. A third sensor can be used in this mode and requires the appropriate EZO circuit installed on the third slot of the Tentacle board.

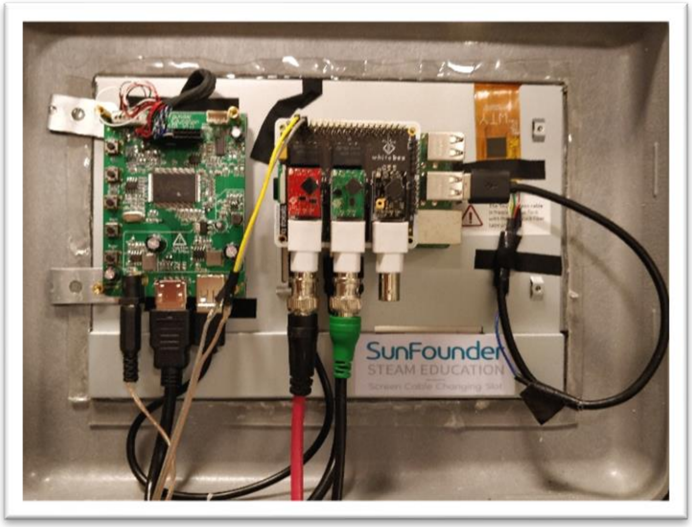
Mobile Sensor Kit Construction

Housing and Flow cell

The water sensor kit consists of a PVC flow cell contained within a briefcase style enclosure. Bulkheads are attached at both ends of the flow cell for easy and quick in-line flow connections. Within the enclosure the flow cell has two sensor slots available. A thermocouple used for temperature compensation of the paired sensor and the other is swappable between pH, conductivity, dissolved oxygen, or oxidation reduction potential. If an in-line flow cell configuration is not desirable, the unit has three external BNC sensor connections installed to allow for temperature and any of the other two sensors to be used. In this mode sensors can measure grab samples, placed into running streams or installed into existing piping.

Processing Unit

The sensors connect to the kits' processing unit, a Raspberry Pi 3 Model B+, via a Whitebox Labs Tentacle T3 board. The T3 board stacks on top of the Raspberry Pi 3 GPIO pin header and has 3 BNC type connectors for receiving sensors. Each sensor in turn needs its own respective analog-to-digital (ADC) conversion circuit, which installs behind its BNC connector and is swappable. This circuit takes the analog sensor readings and converts then to a digital value the processing unit can accept. Once converted, the digital sensor values are transmitted to the Raspberry Pi 3 via its I2C (inter-integrated circuit) communication bus. There is a Python program running that collects, logs and displays the values. Values are logged every 5 minutes and stored locally in a csv file.



Display

- A 12VDC 10-inch screen is installed on the front of the case to display current values readings. The display screen's power supply is used to power the entire kit when a wall outlet is available or else it is powered off the 12V internal battery.
- The display has a 5 VDC output used to power the Raspberry Pi microcomputer and sensors.

Power Sources

A toggle switch is installed on the outside of the case to switch between AC or DC power sources. A wall adapter can be plugged into the outside of the case and to a wall outlet to run the unit indefinitely off AC power. Otherwise, if AC power is not available at the sensing location, the unit can be powered by an internal DC battery supply for 24 ~ 48 hours.

Also, the kit can be retrofit to connect to solar cells in order to operate for an extended period of time in remote areas where outlets are not available or measurements need to be taken for a longer period of time than the battery pack can support.

Additionally, the kit has built-in WiFi capabilities and can be used to transmit collected data directly to a cloud database given access to a local wireless network.

Data Storage

Data is logged locally to a CSV file on the Raspberry Pi's SD card. The data is logged at a given fixed time interval that can be changed based on user's need.

Container/Enclosure for Sensor Hardware

- Recommended case: Apache watertight protective hardcase can withstand use in any wet/dry indoor/outdoor environment.
- Case dimensions: 8.39 inches x 5-11/16 inches x 3-1/4 inches
- Alterations to the case for the sensor kit:
    - A ½" hole is drilled on the bottom of each 3-1/4" side for flow-cell installation.
    - For power, on the top left-hand side of the box drill a ½" hole for the toggle switch and ¼" below it for power adapter plug-in.
    - For external sensor connections (non-flow-cell measurements), three ½" holes are drilled on the top portion of the box for installation of male BNC bulkhead connectors.

Flow-through Cell

- The flow-thru cell is made of ½" PVC fittings, two ¼" push-to-connect to ½" threaded male fittings are used as bulkhead fittings through the two previously drilled holes.
- The internal portion of the flow cell consists of two ½" threaded-to-slip straight fittings to thread with the bulkhead fittings and glue to the two internal ½" PVC tees that will hold the sensors. These fittings are glued together using ½" PVC pipe.
- For the temperature sensor a ½" threaded thermowell is used to house the thermocouple and for the other sensor, a ½" threaded compression fitting is used.

Raspberry Pi Microcomputer

- The Raspberry Pi 3 Model B+ was used as the controller for the sensors and data logging. It is an affordable microcomputer running a Linux based operating system that can be used for scientific or electronic projects.

- The display screen's power supply is used to power the entire kit when a wall outlet is available or else it is powered off the 12 V internal battery.
- The display has a 5 VDC output used to power the Raspberry Pi and sensors.

Sensor Installation and Connections

- The temperature sensor will sit in its thermowell and its BNC cable connects to BNC connector 1 on the Tentacle board.
- The conductivity sensor or sensor 2 will sit in flow cell's second position and its BNC cable will connect to BNC connector 2 on the Tentacle board.

Outlet Adapter

- To use an AC power wall adapter flip the power toggle switch in the downward direction when the AC power adapter is connected to a power outlet and the power jack is connected to the receiver besides the toggle switch.
- In this configuration the sensor kit can run indefinitely and is only susceptible to power outages.

Battery

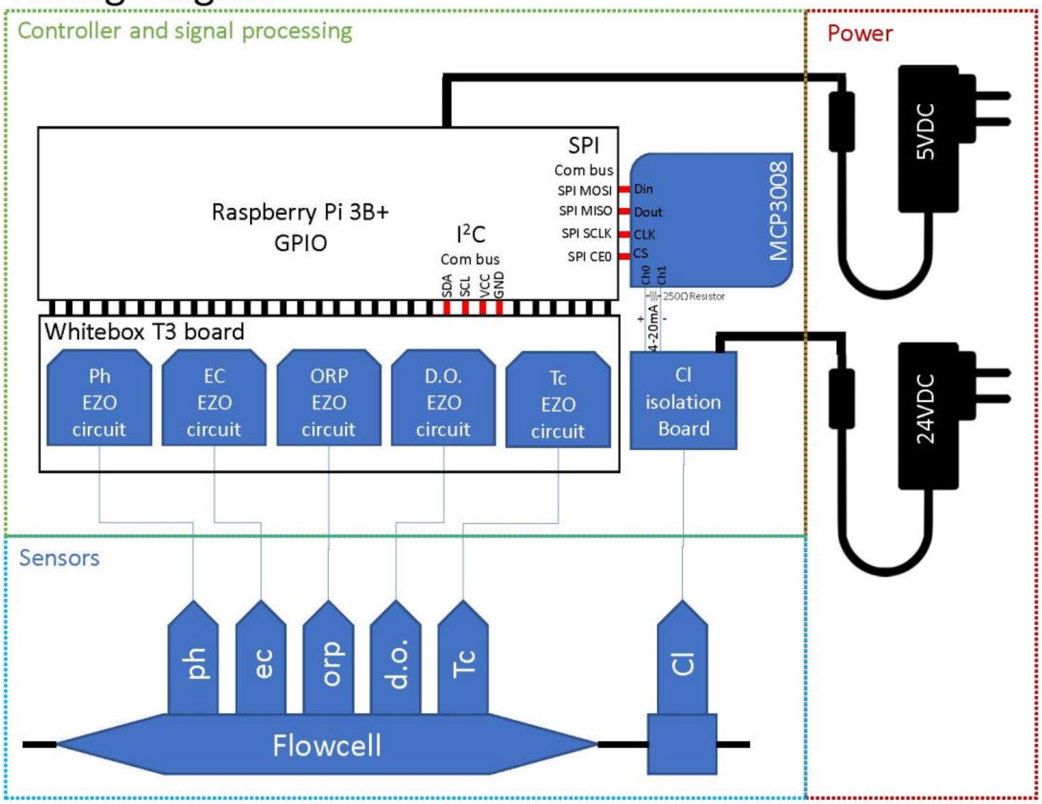
- To run off the internal battery, move the power toggle into the upward position and this will power on the unit.
- The internal 12V DC battery will last between 24 to 48 hours after which the battery needs recharging or replaced to continue use. A larger capacity battery can be used to extend the battery operation period.

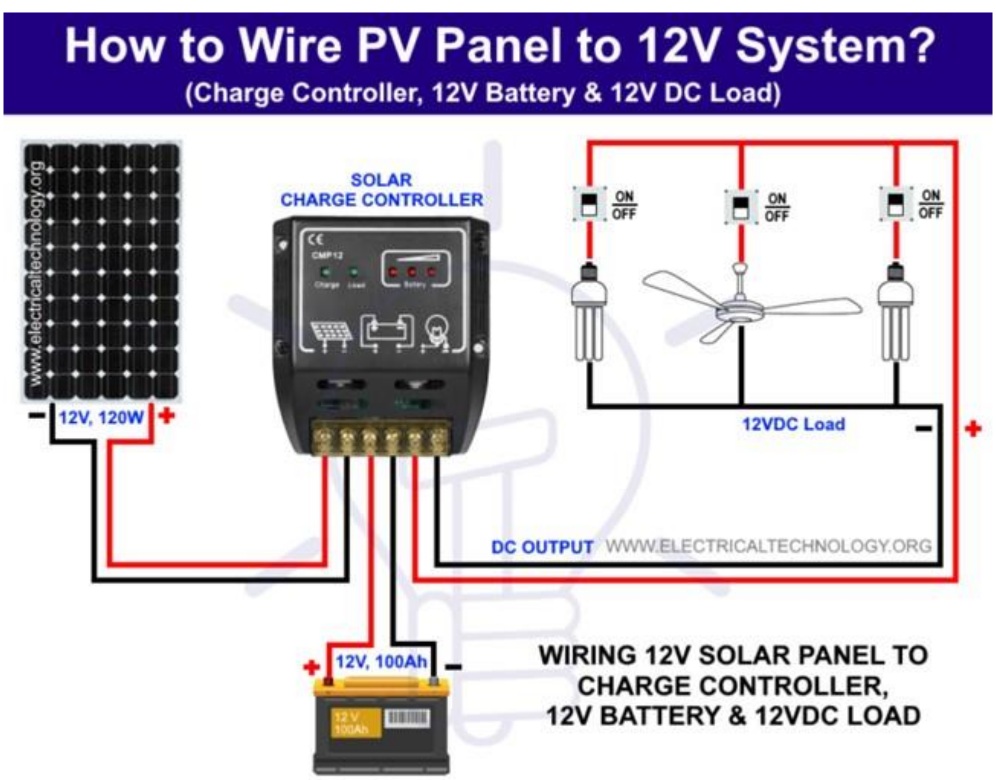
Estimated Kit Costs

[*Note: A parts list with links to sources is available on the Resources page]*

Item	Cost
Conductivity Sensor	$158
Temperature Sensor & thermal well	$40
Conductivity EZO circuit	$60
Temperature EZO circuit	$28
Raspberry Pi 3 Kit	$59
Screen	$130
Enclosure	$30
Battery Pack	$68
Power Switch	$15
Raspberry Pi Interface Board	$105
Flow Cell PVC and Fittings	$30
Total	$723

Wiring Diagram





Raspberry Pi OS downloads and installation instructions

- To get started Raspbian Operating System will need to be flashed onto an SD card.
- Many Raspberry Pi kits are sold with NOOBS installer already pre-loaded onto the SD card so that you can install directly from the card on first boot-up of the system.
- An official and detailed explanation on how to flash the Operating System and how to install the Raspbian OS can be found using following links:
  Raspberry Pi Operating System SD card flash
  Installing with NOOBS

Github repository with Python code and instructions for running the program

- Download sensorkit.py file from the github repository link.
- Place the file on the desktop of the of the Raspberry Pi or any folder you want to operate from.
- To run the program you can either open the file with any of the pre-installed Python programming environments (i.e. Idle, Thonny) and run the program, or you can open a command window for the folder where the Python program resides and on the command line type: python sensorkit.py

Retrieving data locally on Raspberry Pi or copying it to a computer

- After the program is running, sensor data is logged every 5 minutes.
- A ‘data.csv’ file is automatically generated and saved in the same folder as the Python program location.
- The sensor logs can be viewed on the sensor kit itself using LibreOffice to view as a spreadsheet and create charts similarly to Microsoft Excel.
- Or to remove the data file, copy it to a USB drive and open it with Excel or any other spreadsheet application to view and visualize.

Online storage options

- Raspberry Pi has ethernet and Wi-Fi capabilities for connecting to the internet. Sensors can be connected to any online database like Google Sheets.
- Raspberry Pi has been used to store sensor data in Google Sheets and the data can be used to host an online dashboard. *Note:* Creating the dashboard can be complicated. A Python programmer is needed to edit the program to add a communication channel with an online data storage option of your choice.

Resources

As mentioned in the elearning course found at https://iac.engineering.asu.edu/, in the EPA Connections section, links for downloads resources are available for resources such as:

- The DIY Sensor Kit Parts List
- The two wiring diagrams

Raspberry Pi 3 Model B+ link

https://www.raspberrypi.com/products/raspberry-pi-3-model-b-plus/

Raspberry Pi OS installation information

https://www.raspberrypi.com/software/

Installation using NOOBS