1. What is a sensor network?

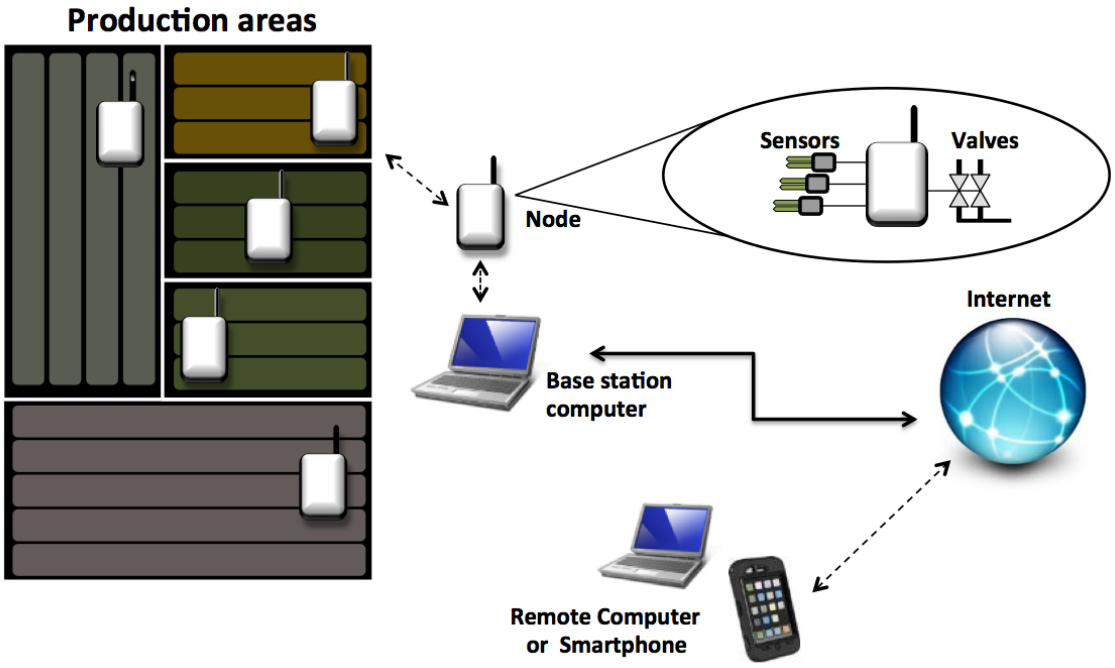

Figure 1. Overview of a wireless sensor network that depicts components and the flow of information (data) from the sensor to the node, then to the base station computer, then to the Internet and last to any web-enabled computers or mobile devices. Wireless transmissions are depicted by dashed lines and wired connections are depicted by solid lines.

2. Components

A wireless sensor network (WSN) is a hardware and software package that typically consists of four parts (see Figure 1):

a) 'Sensors' connected to each node by a wired connection. In our case, we use sensors that can measure soil moisture, electrical conductivity, soil temperature, water pressure, flow rate, or a range of weather variables (light, air temperature, wind, humidity, etc.).

Figure 2. One of many sensors that can be connected to a node, this EC-5 sensor (Decagon Devices, Inc. Pullman, WA) measures volumetric water content (soil moisture).

b) 'Nodes' collect the data from sensors and transmit that to a 'base station' computer using a one way (in the case of monitoring) or two-way (in the case of monitoring and control) radio. Nodes can simply monitor environmental and soil conditions or can be used to make control decisions. For example, some nodes have the capability to control an electric valve, such as an irrigation valve.

Relay switch, used to control irrigation valve(s), is located here.

Figure 3. This nR5 (Decagon Devices, Inc. Pullman, WA) node is powered off of 5-AA batteries and is connected to 5 soil moisture sensors via stereo ports. The nR5 node is also capable of controlling irrigation valve(s), based on user-defined settings.

c) 'Base Station' computer connects the system to the internet, so that data collected by the nodes, then transmitted to the base station computer, can be viewed anywhere an internet connection is available.

d) 'Graphical User Interface' is the web-based software package, that allows the data collected by sensors to be viewed. The software is also used to set irrigation parameters.

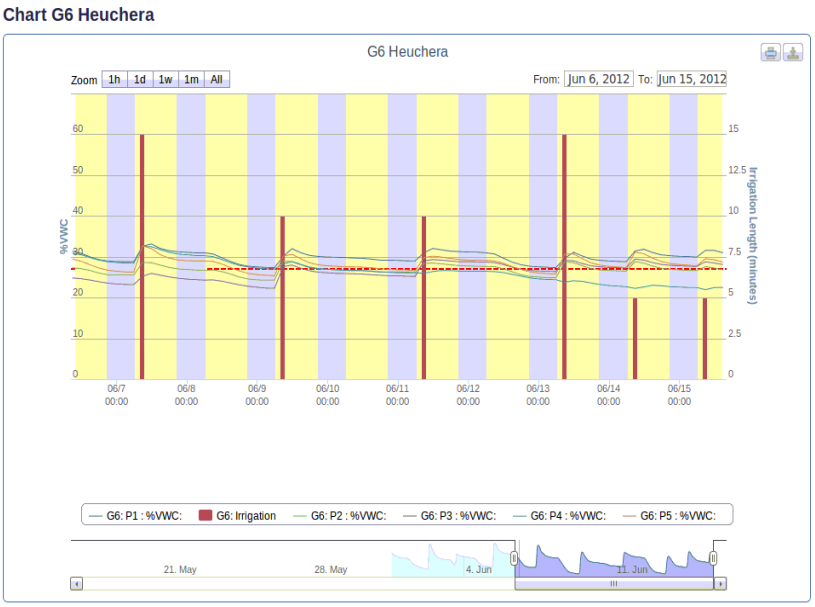

Figure 4. The graphical user interface above depicts the volumetric water content (soil moisture) as horizontal lines and irrigation events and amounts as bars. Notice the increase in soil moisture after each irrigation event.

<u>Not every WSN will have all four components, but to get optimal functionality the systems developed as part of this project do.</u>

A very simple WSN example that many can relate to is that of the wireless environmental monitoring system used by the National Weather Service (NWS). You have probably seen these at a local airport or school. In this case, sensors measure environmental conditions and send this data to a node that wirelessly transmits the data using a cell signal or wireless signal to a base-station computer where NWS employees (and you) can view the current temperature (or rainfall/dew point, wind, etc.) via a website or application ('app').

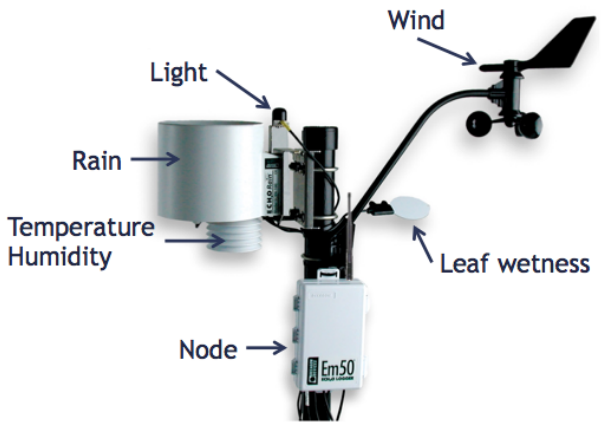

Figure 5. Typical environmental monitoring sensors that you would see at a National Weather Service (NWS) monitoring station. These same components can be used in a wireless sensor network by a specialty crop producer.

3. PlantPoint™ – A WSN for irrigation and environmental monitoring/control

Decagon Devices, Inc. (Pullman, WA), our commercial partner, will commercialize the PlantPoint™ system in 2015. This system consists of three different types of nodes, which look similar, but have distinctly different functions: monitoring nodes, control nodes, and gateway nodes. Since the nodes are powered by batteries, they can be placed in production areas where power is not available and data is transmitted via wireless signal (line of sight) or cellular connection.

Monitoring nodes can be used to connect up to five sensors, but can only monitor environmental and soil conditions (not control an electric irrigation valve). Control nodes accommodate only a few sensors, but can be used to control up to four separate irrigation zones. The gateway node relays information between the control nodes, monitoring nodes, and the base station computer, increasing the geographic range of WSNs.

Figure 6. Hardware components of the PlantPoint system include nodes (gateway, monitoring and control), a base station computer (foreground) and sensors (not pictured).

The base station computer generates a website that can be accessed on-line. The computer runs the software (or graphical user interface) that is used to control the setup of the entire network and to configure irrigation parameters. Growers can use the information from the sensors to decide how they want to manage the irrigation of different crops. These decisions can be programmed into the graphical user interface. The website can be customized with a map of a specific greenhouse, nursery, or farm and detailed information from each of the nodes can be seen in graphs that summarize the most important information from each node. The data is presented in a way that helps growers use that information to make better informed decisions about irrigation scheduling.

The website is also used to configure the irrigation control nodes. Growers can program whether they want to irrigate based on a set schedule, based on substrate water content, or based on another parameter (e.g. temperature for frost protection). The hardware and software are designed for maximum flexibility to accommodate the needs of different growing operations. One crucial feature is scalability: growers can start with a small system and gradually expand that system over time. This will hopefully encourage growers to adopt this new technology, starting with a small system to determine whether it is cost-effective and, if so, to scale up. The system is expected to be released in Fall 2015.

4. Benefits of wireless sensor networks for irrigation management

Provide growers with real-time information: Sensor networks provide growers soil moisture and environmental conditions for their own production areas. Since the data can be seen on-line, access to this information is easy. This provides growers with information they trust and can act upon. We have learned that most growers make much better irrigation/environmental management decisions once they have access to data collected in their own operation. Seeing the impact that your irrigation/environmental management decisions makes it easy to improve on standard practices.

Precision Control of Irrigation: We have shown through our research that we can achieve between a 40 and 70% reduction in irrigation water applications with soil moisture sensor-based irrigation control. Although reductions vary from operation to operation, because all growers manage irrigation differently, we have

consistently seen large reductions in irrigation water use. For one of our nursery growers, a 50% reduction in irrigation saved over 43 million gallons of water, and $6,500 in pumping costs in 2012. In the central valley of California, where water costs are typically $750 / acre foot, the net cost of this 43 million gallons of water would have been at least $100,000, without accounting for additional pumping, plant growth or other economic benefits. In this case, the return on investment for the $48,000 sensor network would have been achieved in less than 4 months.

Impact on Water Availability: For most growers, the cost of water is low compared to other variable costs, such as labor. However, some operations are limited by the capacity of their well or pump, or by the time it takes to irrigate all crops. Water availability and irrigation time can limit the amount of plants that can be grown. One nursery grower was able to install an additional 30-acre tree production area, simply based on the amount of water he saved elsewhere using sensor-based irrigation.

Increased Yields and Quality: Growers can use these sensors as a tool to refine their growing practices for increases in yield and quality. For example, a snapdragon cut flower grower was able to make more timely irrigation decisions through the use of sensor networks in his greenhouse production. Since these plants were grown in a recycling hydroponics system, water savings were not much of a concern. But better irrigation management increased the yield and quality of snapdragon cut-flowers by 30% depending on season and cultivar. This clearly shows that the benefits of precision irrigation go well beyond just water savings.