INSTRUCTION MANUAL

Wireless Sensor Network

Revision: 3/14



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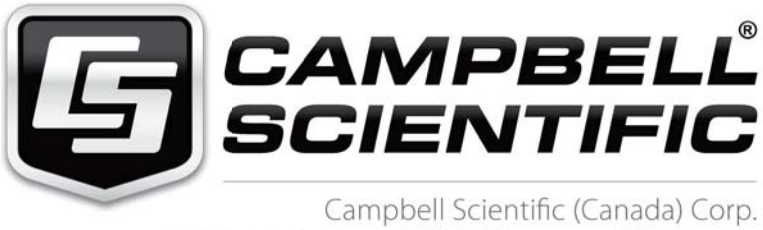
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PLEASE READ FIRST

About this manual

Please note that this manual was originally produced by Campbell Scientific Inc. (CSI) primarily for the US market. Some spellings, weights and measures may reflect this origin.

Some useful conversion factors:

Area:	1 in^2 (square inch) = 645 mm^2
Length:	1 in. (inch) = 25.4 mm
	1 ft (foot) = 304.8 mm
	1 yard = 0.914 m
	1 mile = 1.609 km
Mass:	1 oz. (ounce) = 28.35 g
	1 lb (pound weight) = 0.454 kg
Pressure:	1 psi (lb/in2) = 68.95 mb
Volume:	1 US gallon = 3.785 litres

In addition, part ordering numbers may vary. For example, the CABLE5CBL is a CSI part number and known as a FIN5COND at Campbell Scientific Canada (CSC). CSC Technical Support will be pleased to assist with any questions.

About sensor wiring

Please note that certain sensor configurations may require a user supplied jumper wire. It is recommended to review the sensor configuration requirements for your application and supply the jumper wire is necessary.

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Wireless Sensor Network

1. Understanding a Wireless Sensor Network

1.1 General Description

Why wireless?

There are situations when it is desirable to make measurements in locations where the use of cabled sensors is problematic. Protecting cables by running them through conduit or burying them in trenches is time consuming, labor intensive, and sometimes not even possible. Local fire codes may preclude the use of certain types of sensor cable inside buildings. In some applications measurements need to be made at distances where long cables decrease the quality of the measurement or are too expensive. There are also times when it is important to increase the number of measurements being made but the datalogger does not have enough available channels left for attaching additional sensor cables. Each of these instances can be resolved with a Campbell Scientific Wireless Sensor Network (WSN). A WSN provides a reliable, low maintenance, low power method for making measurements in applications where cabled sensors are impractical or otherwise undesirable.

What is it?

A Campbell WSN consists of a CWB100 Wireless Base Station and one or more Campbell Wireless Sensors (CWS). The base station communicates with a Campbell Scientific CR800-series, CR1000, or CR3000 datalogger, which serves as the gateway to the network. Although compatible dataloggers use the PakBus© communication protocol, PakBus© is not used for the datalogger to base station communication, nor for the base station to sensor communication. In other words, the CWB100 and wireless sensors are not PakBus© devices.

The base station communicates with all of the wireless sensors in the network. Any sensor can serve as an RF repeater to communicate with other wireless sensors. A sensor can route its transmissions through up to three other sensors on the way back to the base station.

Wireless sensors include the CWS220 Wireless Infrared Radiometer, the CWS655 Wireless Water Content Reflectometer, and the CWS900 Wireless Sensor Interface. Additional sensor types can be integrated into the network by connecting them to the CWS900 Wireless Sensor Interface.

How does it work?

The CWB100 Wireless Base Station and one or more wireless sensors are first configured using an A205 CWS to PC Interface and Campbell Scientific's Wireless Sensor Planner, Network Planner or Device Configuration Utility software.

The datalogger is programmed with the CRBasic editor to interface with the CWB100 and determine a polling interval. After the polling interval has been received, the base station uses that information to poll the sensors prior to being polled by the datalogger. Power is applied to the sensors and a Setup button pressed to cause them to establish a route to the base station. The base

station synchronizes wireless sensor measurements and polls all sensors, storing the collected measurements so that it can transfer them as soon as the datalogger requests them. This minimizes the amount of time the datalogger needs to wait for a response from the network through the CWB100 base station. At the start of each polling interval the datalogger polls the base station and sensor values are transferred to the datalogger for storage. This method of data transfer from the sensors to the datalogger provides the fastest and lowest power method available. An optional configuration string file may be downloaded to the datalogger to predefine sensor and field names along with the order in which values are returned to the destination array.

In order to conserve battery power, the sensors do not initiate any communication except during Network Discovery. Instead they transmit only when polled by the base station.

1.2 CWB100 Wireless Base Station

The CWB100 is the master radio in the wireless sensor network and serves as the interface between the datalogger and the wireless sensors. It holds information for the routes to all the sensors in the network and is responsible for polling the sensors. It synchronizes wireless sensors to make their measurements at the beginning of the datalogger's scan. The CWB100 communicates using serial protocol or USB.

The CWB100 is packaged in an extruded aluminum housing, and needs to be sheltered in an enclosure. It has a terminal block for connecting power and data lines from the CWB100 to the datalogger wiring panel. It also has a USB port for connection to a computer during configuration. The CWB100 is powered through either the USB connector or the terminal block.



FIGURE 1-1. CWB100 Wireless Base Station

For specifications of the CWB100, see Section 2.2, *CWB100 Specifications*.

1.3 CWS220 Wireless Infrared Radiometer

The CWS220 is a Wireless Infrared Radiometer that incorporates Apogee Instrument's SI-111 infrared sensor to provide a non-contact means of measuring the surface temperature of an object. It senses the infrared radiation being emitted by the target. The CWS220 is used to measure leaf, canopy, and average surface temperature. Contact sensors have difficulty making measurements without influencing the temperature, maintaining thermal contact, and providing a spatial average.

The CWS220 is mounted at an appropriate distance from the target where it can measure an individual leaf, a canopy, or any surface of interest. Because the CWS220 is wireless, it can be mounted in many locations that would be problematic for a cabled sensor.

The CSW220 includes a thermopile for measuring a millivolt output dependent on the target to sensor body temperature difference. A thermistor measures the temperature of the sensor body. The sensor body temperature is used to reference the target temperature.

The calibration coefficients used for determining the target temperature by means of the Stefan-Boltzman equation are stored in the CWS220 at the time of calibration.



FIGURE 1-2. CWS220 Wireless Infrared Radiometer

The CWS220 outputs 5 values: Target temperature, Sensor body temperature, Internal temperature, Battery Voltage, and Signal strength.

Additional detail regarding CWS220 output is available in Appendix B, *Measurements Names and Meanings*.

For specifications of the CWS220, see Section 2.3, *CWS220 Specifications*.

1.4 CWS655 Wireless Water Content Reflectometer

The CWS655 is based on Campbell Scientific's CS655 water content reflectometer. It measures volumetric soil water content, electrical conductivity (EC), dielectric permittivity, and ambient temperature of soils or other porous media.

The water content information is derived from the probe's sensitivity to the dielectric permittivity of the medium surrounding its stainless-steel rods. Dielectric permittivity increases with volumetric water content in a predictable fashion. During water content measurements, the CWS655 is configured as a water content reflectometer with the two parallel rods forming an open-ended transmission line. A differential oscillator circuit is connected to the rods. An oscillator state change is triggered by the return of a reflected signal from one of the rods. The two-way travel time of the oscillator-induced electromagnetic waves on the rod increases with increasing volumetric water content of the surrounding media, hence the name water content reflectometer.

The electrical conductivity of the surrounding medium is derived from signal attenuation information. This is accomplished by exciting the rods with a known non-polarizing waveform and determining the signal attenuation due to EC. The EC measurement is used to correct the oscillator period and is also available to the user.

Temperature is measured with a thermistor that is in contact with one of the rods. The thermistor makes a point measurement near the top of the sensor rods. In a typical application this will correspond to a soil temperature reading near the soil surface so care should be taken in interpreting soil temperature data.

Because the CWS655 is wireless, it can be mounted in many locations that would be problematic for a cabled sensor.

The CWS655 is generally not intended for burial below the soil surface in typical installations as this will attenuate the radio signal and make it difficult to change the batteries. Submersion in water or saturated soil may cause damage to sensor electronics.



FIGURE 1-3. CWS655 Wireless Water Content Reflectometer

The CWS655 outputs 8 values: Volumetric water content, Bulk electrical conductivity, Dielectric permittivity, Soil temperature, Period Average, Voltage ratio, Internal temperature, Battery voltage, and Signal strength.

Additional detail regarding CWS655 output is available in Appendix B, *Measurement Names and Meanings*.

For specifications of the CWS655, see Section 2.4, *CWS655 Specifications*.

1.5 CWS900 Wireless Sensor Interface

The CWS900 is a Wireless Sensor Interface. The CWS900 measures analog voltages, low level AC, pulse counts, and can supply an excitation voltage for powering some sensors or making bridge measurements. It has a sealed connector for use with a variety of sensors, such as temperature/humidity probes, rain gages, wind monitors, or other low power sensors. The type of measurement that the sensor performs is configured using Wireless Sensor Planner, Network Planner, or DevConfig software.



FIGURE 1-4. CWS900 Wireless Sensor Interface

The CWS900 outputs 4 - 12 values, depending on configuration. TABLE 1-1 and TABLE 1-2 show available configurations and outputs.

It is important to note the units of the measurement being made by the CWS900. In some cases additional processing of the measurement by the datalogger program or post processing in a spreadsheet or database will be necessary to convert the measurement to engineering units.

TABLE 1-1. CWS900 Configurations and Outputs

Configuration / Output	Single Ended Channel 1, V	Single Ended Channel 2, V	Single Ended Channel 3, V	Differential Channel, V	Total Count of Switch Closures	Interval Count of Switch Closures	Max Pulse Freq during polling interval, Hz	Avg Pulse Freq during polling interval, Hz	Probe Temperature, C	Probe Pressure, kPa	Relative Humidity	Leaf Wetness Sensor, V	Dissolved Oxygen, V	pH, V	Signal Strength	Battery Voltage, V	CWS900 Internal Temperature, C
Single Ended Channel 1 Measurement	*														*	*	*
Single Ended Channel 1 and 2 Measurement	*	*													*	*	*
Single Ended Channel 1, 2, and 3 Measurement	*	*	*												*	*	*
Differential Channel Measurement				*											*	*	*
Switch Closure					*	*									*	*	*
Pulse Count							*	*							*	*	*
Low Level AC							*	*							*	*	*
Rain Gage					*	*									*	*	*
Pyranometer (or Quantum Sensor)				*											*	*	*
109 Temperature Probe									*						*	*	*
HMP60 Temp/Humidity Probe									*		*				*	*	*
LWS Leaf Wetness Sensor												*			*	*	*
CS511 Dissolved Oxygen Sensor													*		*	*	*
CS525 ISFET pH Probe														*	*	*	*
CS450 Pressure Transducer									*	*					*	*	*

TABLE 1-2. CWS900 Wind Sensor Configurations and Outputs

Configuration / Output	Wind Speed Average, m/s	Wind Speed Maximum, m/s	Wind Speed Minimum, m/s	Wind Speed Std Dev, m/s	Wind Dir Avg Unit Vector Mean Wind Dir, deg	Wind Dir Std Dev, Yamartino Algorithm, deg	Resultant Mean Wind Speed, m/s	Resultant Wind Dir Avg, deg	Resultant Wind Dir Std Dev CSI algorithm, deg	Signal Strength	Battery Voltage, V	CWS900 Internal Temperature, C
05103, 05103-45, or 05106 RM Young Wind Monitor	*	*	*	*	*	*	*	*	*	*	*	*
05305 RM Young Wind Monitor	*	*	*	*	*	*	*	*	*	*	*	*
03002 RM Young Wind Sentry Set	*	*	*	*	*	*	*	*	*	*	*	*
034B Met One Windset	*	*	*	*	*	*	*	*	*	*	*	*
#40C or #200P NRG Wind Set	*	*	*	*	*	*	*	*	*	*	*	*

Additional detail regarding CWS900 configurations and outputs is available in Appendix B, *Measurement Names and Meanings*.

For specifications of the CWS900, see Section 2.5, *CWS900 Specifications*.

2. Specifications

2.1 Wireless Sensor Network Radio

The CWB100 and CWS sensors use a 25 mW FHSS radio. Three models are available depending on location of usage. TABLE 2-1 shows model numbers and locations used for all models.

2.1.1 Electrical

TABLE 2-1. CWS FHSS Radio Specifications

Model	Where Used	Frequency	FHSS Channels
CWSxxx, CWB100 CWSxxxA, CWB100A	U.S. Canada, Australia, and New Zealand	902-928 MHz	50
CWSxxxE, CWB100E	Europe	868 MHz	16

Transmitter Power Output: 25 mW (+14 dBm)

Receiver Sensitivity: -110 dBm (0.1% Frame Error rate)

Current Drain
- Standby: 3 µA
- Receiving: 18 mA typical (full run)
- Transmitting: 45 mA

Average operating current w/1 second access time: 15 µA

Operating Temperature Range: -25° to +50°C (-13° F to + 122°F)

Additional Features

GFSK modulation

Data interleaving

Forward Error Correction BCH (31,21)

Data scrambling

Quality of Service management RSSI

2.1.2 Typical RF Range

RF range is affected by antenna height and by obstacles between the two antennae. The following ranges represent typical distances of RF range as measured with a 0 dBd Omnidirectional 1/2 wave whip antenna connected to the CWB100 radio base station:

Location	Base Height	Sensor Height	RF Range
Dense Corn Field 2.1 m (7') tall	1.2 m (4')	0.9 m (3')	152 m (500')
	1.2 m (4')	0.0 m (0')	131 m (430')
Inside Industrial Building	1.2 m (4')	0.9 m (3')	> 76 m (250')
Mixed Juniper/Maple Forest	1.2 m (4')	0.9 m (3')	156 m (513')
	1.2 m (4')	0.0 m (0')	103 m (340')
Residential Street (Line of Sight)	1.2 m (4')	0.9 m (3')	392 m (1285')
	1.2 m (4')	0.0 m (0')	329 m (1080')

2.1.3 RSSI

Received Signal Strength Indicator (RSSI) is a measurement of the power present in a radio transmission received by a wireless sensor. RSSI is a unitless number between 0 (no signal) and 32 (full signal). RSSI is measured periodically when the CWB100RSSI instruction is executed in the datalogger program. The RSSI measurement may be used to determine whether a sensor in the WSN is well positioned for reliable data transmission. See Section 5.3, *CWS Sensor Search for Base Station*, for details on the CWB100RSSI instruction.

2.1.4 Service Discovery Protocol

The CWS radio incorporates a service discovery protocol (SDP) which allows the network of wireless sensors to auto-discover their connection to the base, and the route used for that connection. The end result of this auto-discovery is a list of sensor node addresses, and the route through other wireless sensors, if any, used to reach these sensor nodes. The base station then uses these routes to poll the sensors for data. The CRBasic instruction CWB100Routes may be used to retrieve the routing information from the CWB100 radio. See Section 4.5, *CWB100Routes() Instruction*, for details on the CWB100Routes instruction.

The sensors periodically check the synchronization status and, if the connection to the base station is lost, it is automatically re-established, through routers if necessary. It may take up to a day for a sensor to rediscover the base station if early attempts fail, but the process may be manually triggered by pressing the Setup button on the back of the sensor and holding it in for 8-10 seconds (see Section 5, *CWS Button and LED Behavior*).

The only parameter needed by the service discovery protocol is the base station radio address. This parameter is used to prevent overlapping sensor networks from "joining" each other. All sensors that are part of one network are configured with the same base station address and that is the only base station to which they will establish a communication link.

2.1.5 Antenna Options

All CWS wireless sensors contain a built-in 0 dBd 1/4 wave antenna. No other antenna options are available for the wireless sensors.

The CWB100 Wireless Base Station has a RPSMA connector for use with one of several models of antenna. The base station does not automatically ship with an antenna, so one must be ordered as a separate item. Antenna options available for the CWB100 and CWB100A include the following:

Model	Description
15730	900MHz 0dBd Omni 1/4 Wave Whip Antenna w/Right Angle
15731	900MHz 0dBd Omni 1/4 Wave Whip Antenna, Straight 2 inches Tall
14204	900MHz 0dBd Omni 1/2 Wave Whip Antenna
15970	900MHz 1dBd Dipole Antenna w/Adhesive Mount
14221	900MHz 3dBd Omni Antenna
14201	900MHz 9dBd Yagi Antenna

Larger outdoor antenna models require a cable to connect to the CWB100. Available options include COAXRPSMA-L LMR195 cable and COAXNTN-L RG8 cable. A surge suppressor kit, part number 14462, is required for connecting the COAXNTN-L cable to the CWB100.

For antenna options for the CWB100E 868 MHz Wireless Base Station, contact Campbell Scientific.

2.2 CWB100 Specifications

2.2.1 CWB100 Physical Specifications

Dimensions (including mounting bracket):	10.8 cm x 4.4 cm x 4.4 cm (4.25” x 1.75” x 1.75”)
Weight:	140 g (5 oz)

2.2.2 CWB100 Electrical Specifications

Power:	4.5 - 22 VDC
Current Drain (@12V)	
Standby:	< 1 mA
Receiving:	10 mA
Transmitting:	20 mA
Radio:	Internal 25 mW FHSS Radio
Communication:	Serial Protocol or USB

Terminal Block Connector:	Bi-Directional Serial datalogger connection
USB Port:	Computer connection for configuration
Antenna:	RPSMA antenna connection
Memory:	Can store data table for up to 50 wireless sensors.
Operating Temperature Range:	-25° to +50°C (-13° F to + 122°F)

Terminal Block Pin-Out:

I/O	Name	Description
In	+12V	12V Supply
n/a	GND	Supply Ground
i/o	DATA/A	CPI "A"
i/o	B	CPI "B"
n/a	ISO_GND	CPI Signal Reference

2.2.3 CWB100 Environmental Specifications

Temperature Range:	-25° to +50°C (-13° F to + 122°F)
Humidity Range:	Store and use in non-condensing (desiccated) environment.

2.2.4 Datalogger Compatibility

The CWB100 is compatible with Campbell Scientific datalogger models CR800-series, CR1000, and CR3000. These dataloggers use the CRBasic instruction CWB100() to communicate with the CWB100. See Section 4, *Programming the Datalogger*, for programming details.

Datalogger operating systems that support the CWB100 and CWS sensors are:

CR800-Series	CR800.Std.21 and higher
CR1000	CR1000.Std.21 and higher
CR3000	CR3000.Std.21 and higher

2.3 CWS220 Specifications

2.3.1 CWS220 Physical Specifications

Dimensions:	15 cm x 6 cm x 4.5 cm (6" x 2.4" x 1.8")
Weight:	270 g (9.6 oz)

2.3.2 CWS220 Electrical Specifications

Power:	2 AA Batteries
Average Current Drain:	300 μA with 15 minute polling
Radio:	Internal 25 mW FHSS Radio
Absolute Accuracy:	±0.2°C @ -10° to +65°C; ±0.5°C @ -40° to +70°C
Repeatability:	±0.05°C @ -10° to +65°C; ±0.1°C @ -40° to +70°C
Response Time:	<1 s to changes in target temperature
Wavelength Range:	8 to 14 μm (corresponds to atmospheric window)
Field of View (FOV):	22° half angle

2.3.3 CWS220 Environmental Specifications

Temperature Range:	-25° to +50°C (-13° F to + 122°F)
Humidity Range:	0 to 100%
Weather Resistance:	IP67 rating for sensor and battery pack (battery pack must be properly installed; each sensor is leak tested)

2.4 CWS655 Specifications

2.4.1 CWS655 Physical Specifications

Dimensions

Body:	14.5 cm x 6 cm x 4.5 cm (5.7” x 2.4” x 1.8”)
Rods:	12 cm (4.7”)

Weight: 216 g (7.6 oz)

2.4.2 CWS655 Electrical Specifications

Power:	2 AA Batteries
Average Current Drain:	300 μA with 15 minute polling
Radio:	Internal 25 mW FHSS Radio
Soil Water Content Accuracy:	± 2% when using Topps equation
EC Accuracy:	±(5% of reading + 0.05 dS/m)
Temperature Accuracy:	± 0.2°C

2.4.3 WS655 Environmental Specifications

Temperature Range:	-25° to +50°C (-13° F to + 122°F)
Humidity Range:	0 to 100%
Weather Resistance:	IP67 rating for sensor and battery pack (battery pack must be properly installed; each sensor is leak tested)

2.5 CWS900 Specifications

2.5.1 CWS900 Physical Specifications

Dimensions:	15 cm x 6 cm x 4.5 cm (6” x 2.4” x 1.8”)
Weight:	184 g (6.5 oz)

2.5.2 CWS900 Electrical Specifications

Power:	2 AA Batteries
Average Current Drain:	300 µA with 15 minute polling (depending on attached sensor)
Radio:	Internal 25 mW FHSS Radio
Single-Ended Analog Channels:	SE1, SE2, SE3
Differential Analog Channels:	DF1
Analog Input Range:	-1 to + 2.5 VDC
Accuracy:	±(0.02% of reading + 2 µV) @ 0° to +50°C; ±(0.05% of reading + 2 µV) @ -35° to +70°C
Resolution:	0.3 µV
Excitation Voltage:	2.5V, 3.3 V, 5.0 V 20 mA maximum
Excitation Voltage Accuracy:	±2% @ -35° to +70°C
Bridge Measurement Accuracy (+2.5 excitation only):	±(0.03% of reading + 3 µV) @ 0° to + 50°C; ±(0.07% of reading + 3 µV) @ -35° to + 70°C
Low Level AC Input:	20 mV minimum 10 kHz maximum frequency
Switch Closure	
Maximum Count Rate:	100 Hz
Minimum Open Time:	5 ms
Minimum Closed Time:	5 ms
Maximum Bounce Time:	4 ms
Temperature Accuracy:	± 0.2ºC

2.5.3 CWS900 Environmental Specifications

Temperature Range:	-25° to +50°C (-13°F to + 122°F)
Humidity Range:	0 to 100%
Weather Resistance:	IP67 rating for sensor and battery back (battery pack must be properly installed; each sensor is leak tested)

3. Getting Started: Creating a Wireless Sensor Network

The steps to quickly creating a wireless sensor network are:

1. Obtain the required hardware and software
2. Create a model of the network using default names
3. Configure all the devices in the network
4. Send configuration string file to the datalogger (optional)
5. Program the datalogger to communicate with the CWB100
6. Connect the CWB100 to the datalogger
7. Apply power to the wireless sensors and initiate auto-discovery
8. Verify that data is being transmitted

NOTE When building the network it is always best to start at the base and work outwards.

3.1 Hardware and Software Required for a WSN

3.1.1 A205 CWS to PC Interface

The A205 CWS to PC Interface is used to communicate between wireless sensors and a computer via a USB cable. One end of the A205 has a type B female USB port while the other end has a four-pin female connector that connects to the four-pin male connector located behind the battery pack of a CWS sensor.

The A205 is necessary for configuring wireless sensors prior to deployment and is also useful for testing and troubleshooting them. When connected to a USB port on the computer, the A205 provides power to the wireless sensor.

CAUTION When connecting the A205 CWS to PC Interface to a wireless sensor, be sure the sensor has been powered down (battery pack disconnected) for at least 15 seconds.



FIGURE 3-1. A205 CWS to PC Interface



FIGURE 3-2. Connection of A205

3.1.2 Required Cables

A data cable, CSI part number 17648, ships with the A205. The cable has a USB type A male connector on one end and a type B male connector on the other end. The type B connector is connected directly to the CWB100 without the A205 during configuration and is connected to the A205 when configuring wireless sensors.

A serial cable is used for communication between the computer and the datalogger.

3.1.3 Configuration CD

A Configuration CD ships with each CWB100 Wireless Base Station. The CD has software and files needed to configure and use wireless sensors including:

- Wireless Sensor Planner
- Device Configuration Utility
- Device drivers for CWB100 radio
- Operating Systems for CR800-Series, CR1000, and CR3000 dataloggers
- CRBasic Help files for CRBasic instruction related to wireless sensors
- Wireless Sensor Network Manual

The contents of the Configuration CD are also available at www.campbellsci.com/downloads.

3.1.4 Configuration Software

Wireless Sensor Planner is typically used to configure a wireless sensor network. Wireless Sensor Planner is similar to Network Planner, a component of LoggerNet 4.1 and higher. Either Wireless Sensor Planner or Network Planner can be used with wireless sensor networks. Device Configuration Utility version 1.17 and higher may also be used to set up the network.

Network Planner and DevConfig are bundled with LoggerNet software. LoggerNet version 4.1 and higher is required for support of the wireless sensor devices. Wireless Sensor Planner and DevConfig are on the Configuration CD that ships with the CWB100 Wireless Base Station. DevConfig and Wireless Sensor Planner are also available as standalone products at www.campbellsci.com/downloads.

After setting up the network with Wireless Sensor Planner, configuration settings are written to the components of the network.

3.1.5 Driver Installation

If no CWB100 or A205 have been previously plugged into your computer, it will be necessary to install device drivers to enable communication with this device. The drivers are available on the Configuration CD that ships with the CWB100. The drivers can also be downloaded at www.campbellsci.com/downloads.

3.2 Creating a Model of the WSN

3.2.1 Wireless Sensor Planner and Network Planner

The Wireless Sensor Planner is a graphical application that assists in the design of wireless sensor networks. The Wireless Sensor Planner is essentially a subset of the Network Planner. It is identical in functionality and use, but contains only the components for a wireless sensor network. The CWB100 and wireless sensors are placed on a drawing canvas and communication links

are specified. As the network is being designed, Wireless Sensor Planner automatically determines many individual device settings. After the model is completed, device settings can be written to the devices using Wireless Sensor Planner.

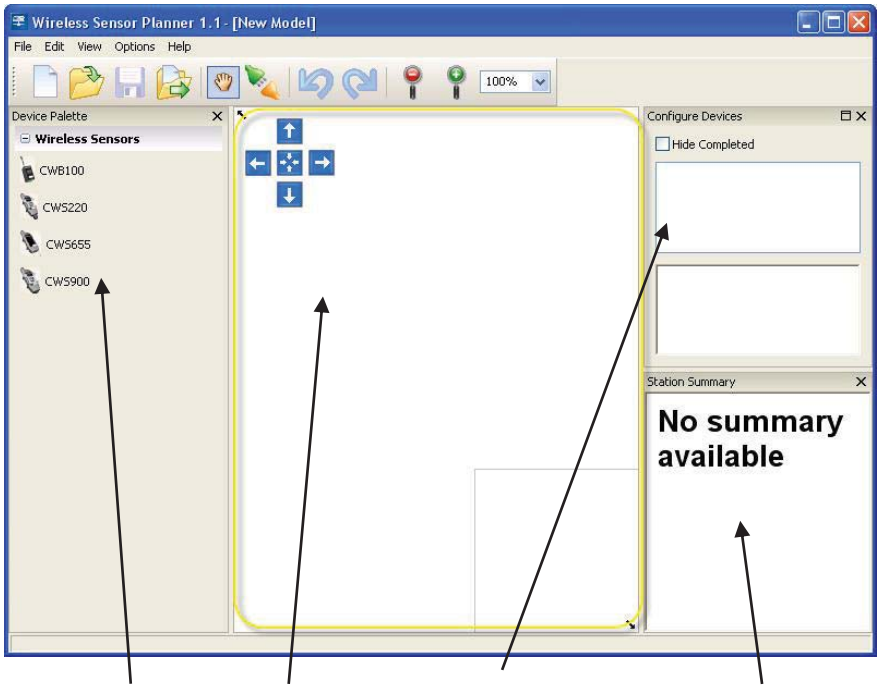
Network Planner version 1.1 or higher, available in LoggerNet 4.1 and higher, can also be used to set up a wireless sensor network. See Section 4 "Setting up Datalogger Networks" in the LoggerNet manual for more information on using Network Planner. This manual will show only the use of Wireless Sensor Planner to set up the wireless sensor network, but the steps shown will be almost identical to those used with Network Planner.

3.2.2 Installing Wireless Sensor Planner

Run Setup from the CWB100 Configuration CD.

3.2.3 Using Wireless Sensor Planner

Launch Wireless Sensor Planner by double-clicking the Wireless Sensor Planner shortcut on the Windows desktop. This will open a window that includes a Device Palette, Drawing Canvas, Configure Devices list, and Station Summary. These will be used to develop a model that includes a wireless base station and one or more wireless sensors. After specifying the communication links between the base station and the sensors, configuration settings will be sent to components of the system.



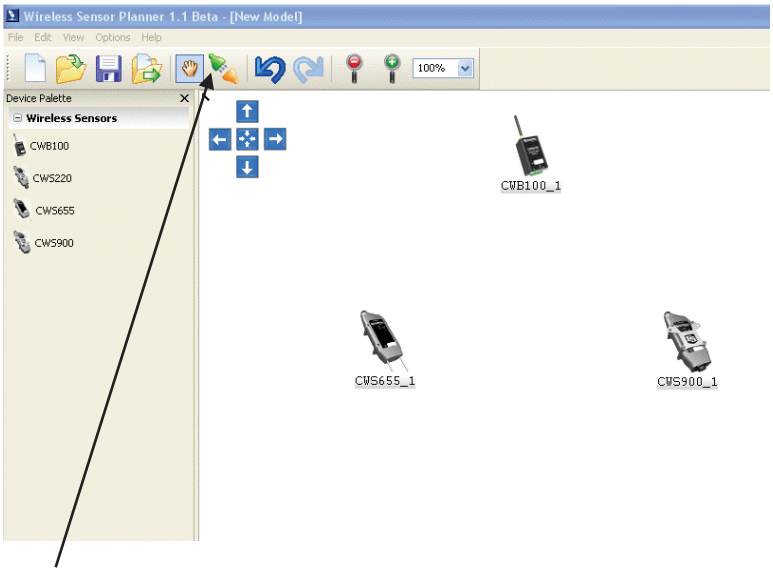
3.2.3.1 Simple WSN Example

In this example, a CWB100 base station communicates with a CWS655 and a CWS900 with a 109-L-CWS temperature sensor attached. Both sensors are within radio range of the base so no repeaters are necessary.

Although station names and measurement names may be customized in Wireless Sensor Planner, the fastest way to configure the network is to use the default names provided. When using default names, the network is configured simply by entering the base station address and choosing a measurement configuration for each CWS900 in the network. In this Quick Start example, default names will be used.

Placing Devices on the Drawing Canvas

Begin by placing a CWB100, a CWS655 and a CWS900 on the Drawing Canvas. Select **CWB100** from the Device Palette then click anywhere on the Drawing Canvas to place it there. Next select **CWS655** from the Device Palette and select the Drawing Canvas. Finally, select **CWS900** from the Device Palette and select the Drawing Canvas. The icons on the Drawing Canvas may be repositioned by selecting the icon and dragging it to a different part of the canvas.

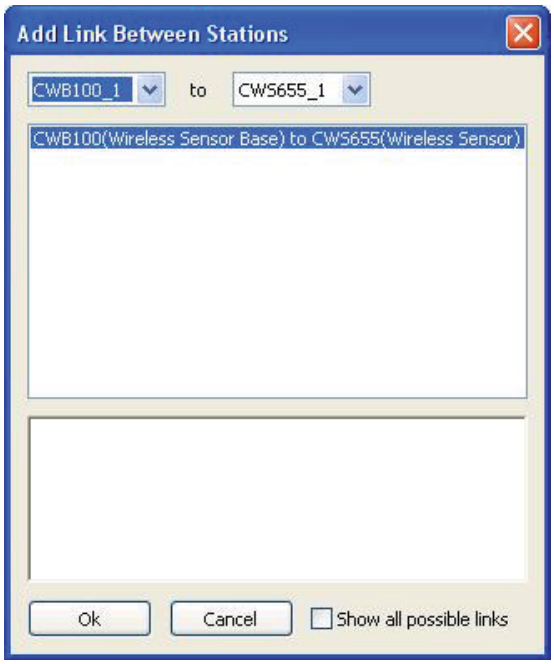


Link Tool

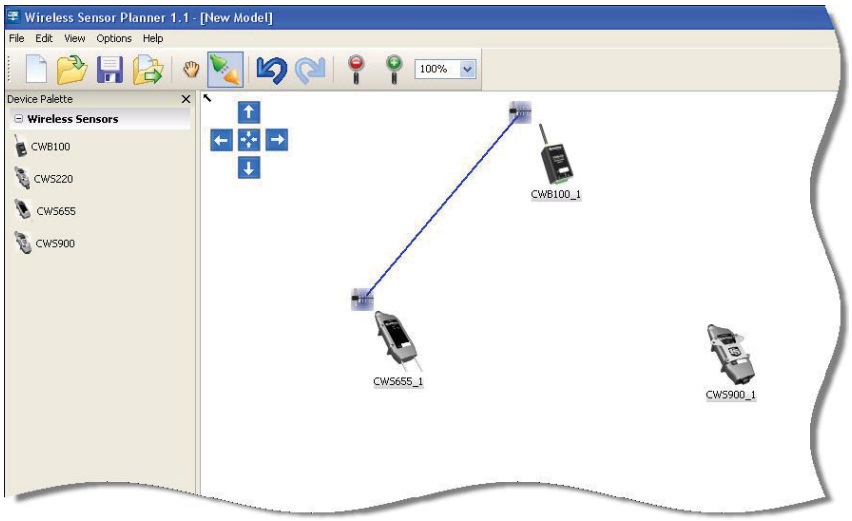
Adding Communication Links to Devices

The next step is to add links between the base station and the other two devices. This represents the radio communication link between the devices. To create links, click the Link Tool icon on the toolbar. The mouse cursor changes from a hand to a jagged line indicating the Link Tool is currently active. Select CWB100 to indicate that it is the first device in the link. Next drag the resulting line to the CWS655 to complete the link.

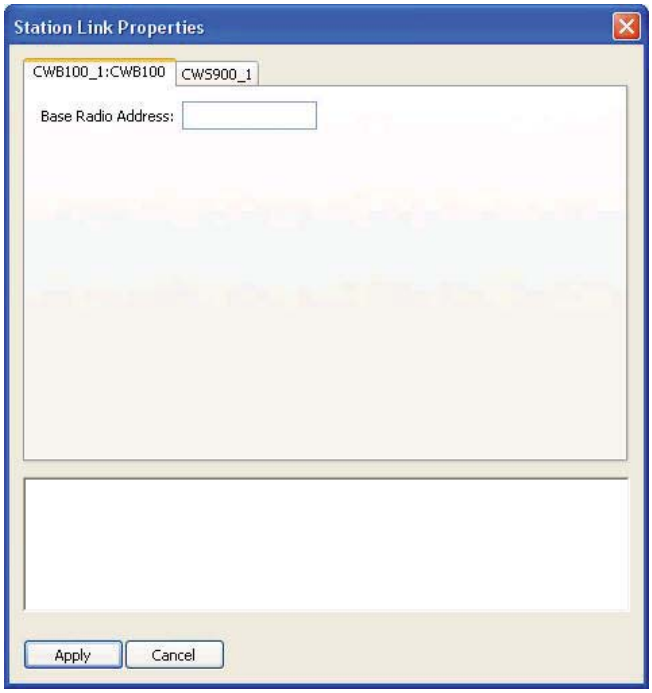
A dialog box will appear highlighting the link. Click the OK button to accept the link.



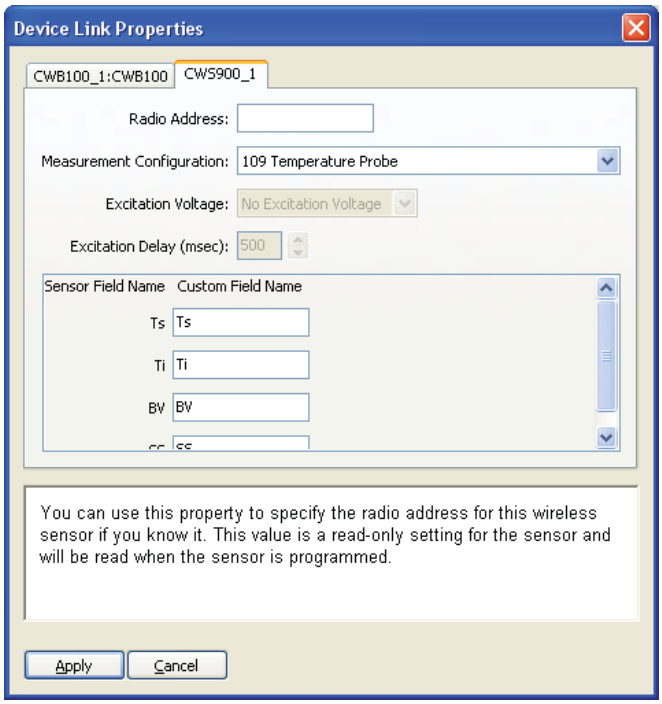
The link is now represented on the Drawing Canvas by a line between the base station and the CWS655.



To add the link from the CWB100 to the CWS900, select the CWB100 and drag the resulting line to the CWS900. Another Add Link Between Stations dialog box will appear showing the new link. Click the OK button to accept the link. A new dialog box called Station Link Properties will appear.



The CWS900 Wireless Sensor Interface connects to a variety of sensors. This dialog box provides options for selecting the measurement type, excitation voltage, and excitation delay needed for your sensor. Select the CWS900_1 tab at the top of the dialog box.



The Radio ID may be left blank and will be filled in automatically when the device is programmed. Use the Measurement Configuration drop-down list to choose the 109 Temperature Probe. The dialog box also shows the default sensor field names that will be used when a measurement is taken. You can accept the default field names or type in custom field names.

After making the selections, press the Apply button to close the dialog box and complete the link.

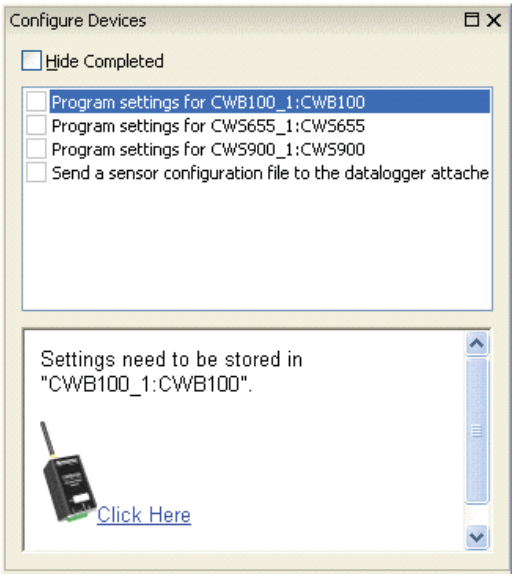
3.3 Configuring the Devices in the WSN

The next step in setting up the network is to send configuration settings to the devices in the wireless sensor network model. The devices that need to be configured are listed in the Configure Devices panel. If the Configure Devices list is not visible to the right of the Drawing Canvas, enable it by navigating to View | Show Device Configuration List. The Configure Device list shows each task that needs to be completed to set up the network successfully.

The settings that need to be configured for the sensors include the address of the CWB100 base station, sensor name, field names, and measurement settings. These settings are stored in non-volatile flash memory and are not erased, even when a new operating system is sent to the wireless sensor.

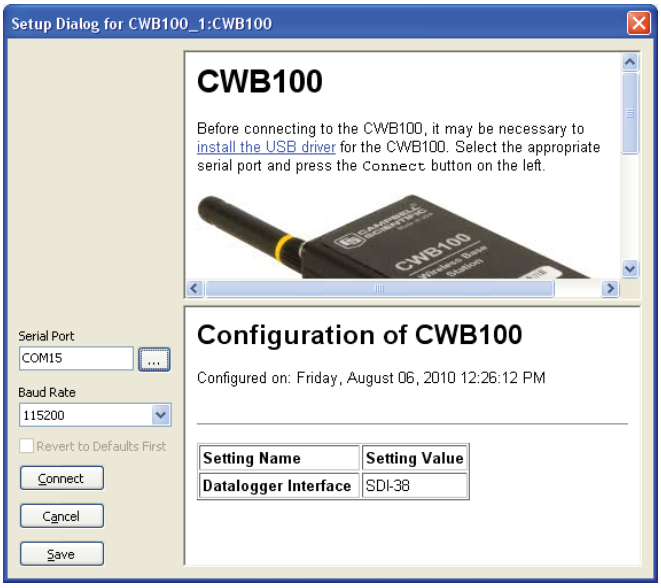
3.3.1 Configuring the CWB100

Configure the CWB100 by connecting it directly to a USB port on your computer using the 17648 cable. The cable will provide power to the CWB100. Select the **Program settings for CWB100_1:CWB100** item in the list, then select Click Here.

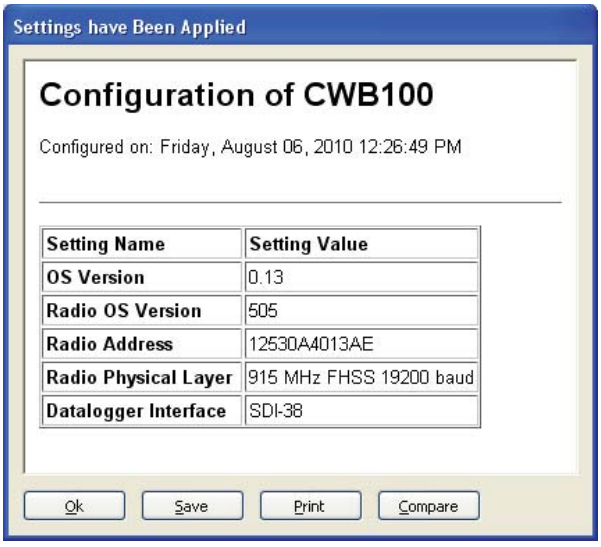


When the Setup Dialog window opens, make sure that the computer is connected to the device as described in the dialog and that the correct Serial Port is specified (it will show up as CWB100 (COMxx). A table showing settings that Wireless Sensor Planner has determined for the CWB100 will be

shown. To save these settings in a XML file for future reference, click Save and choose a filename. To send these settings to the CWB100, click Connect. After settings have been sent to the CWB100, a new window will show which settings have been applied. This window will provide the option to save the XML file, print it, and compare it to another saved configuration file.



After the new settings have been sent to the device, the "Settings have Been Applied" window will appear. Options are available for saving the settings to a XML file, printing the settings, and comparing the settings to another XML file. When finished with these actions, click OK.



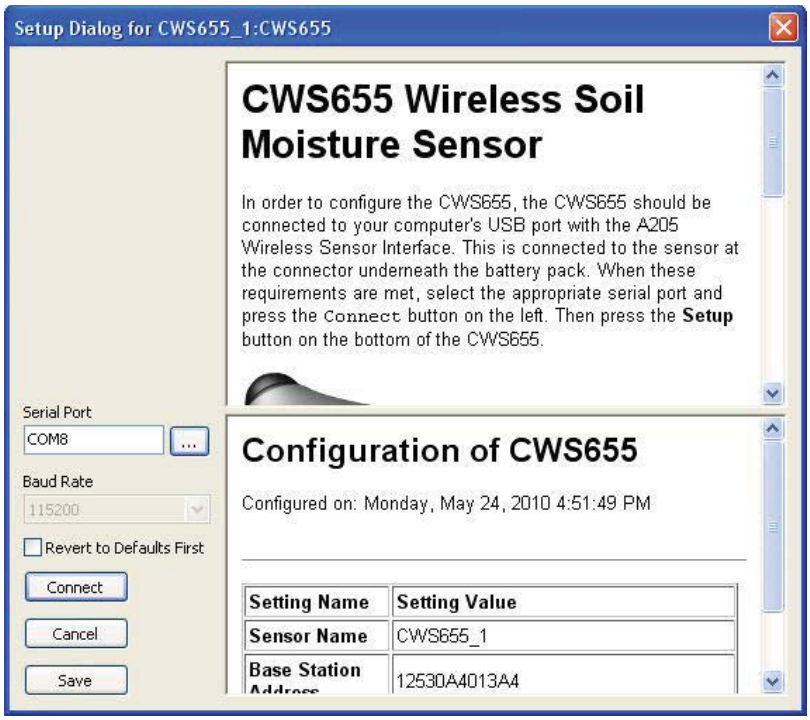
3.3.2 Configuring the CWS655

To configure the CWS655 Water Content Reflectometer, first connect the A205 to the type B USB connector on the 17648 cable. Remove the battery door on the CWS655 and locate the four-pin connector near the top of the sensor. Connect the A205 to the sensor at the four-pin connector. The A205 label should be facing toward the CWS655 antenna.

Select the **Program settings for CWS655_1:CWS655** item in the Configure Devices list, then select Click Here.

When the Setup Dialog window for configuring the CWS655 opens, verify that the Serial Port matches the port number where the A205 is connected and click Connect. Press the Setup button on the back of the CWS655. Settings will be transferred and applied to the CWS655. In the Settings have Been Applied window, options are available for saving the settings to a XML file, printing the settings, and comparing the settings to another XML file. When finished with these actions, click OK.

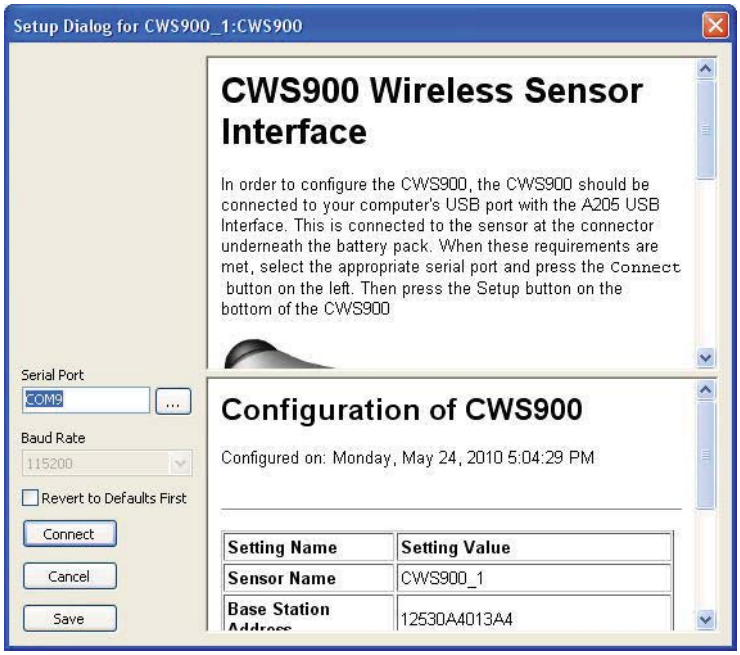
NOTE The Setup button must be pressed to enable communications between the wireless sensor and computer.



3.3.3 Configuring the CWS900

To configure the CWS900 Wireless Sensor Interface, first connect the A205 to the type B USB connector on the 17648 cable. Remove the battery door on the CWS900 and locate the four-pin connector near the top of the sensor. Connect the A205 to the sensor at the four-pin connector. The A205 label should be facing toward the CWS900 antenna.

Select the **Program settings for CWS900_1:CWS900** item in the Configure Devices list, then select Click Here.



When the Setup Dialog window for configuring the CWS900 opens, verify that the Serial Port matches the port number where the A205 is connected and click Connect. Press the Setup button on the back of the CWS900. Settings will be transferred and applied to the CWS900. In the Settings have Been Applied window, options are available for saving the settings to a XML file, printing the settings, and comparing the settings to another XML file. When finished with these actions, click OK.

NOTE The Setup button must be pressed to enable communications between the wireless sensor and computer.

3.4 Sending the Sensor Configuration File to the Datalogger

The sensor configuration file is a text file with a single line of text that provides the datalogger with information related to the data that will be transmitted by wireless sensors in the network. It is useful for predefining sensor field names so that the datalogger table definitions do not change each time a new wireless sensor is discovered. Wireless Sensor Planner creates the file based on the radio address, sensor name, and sensor field names or custom field names specified for each sensor in the network.

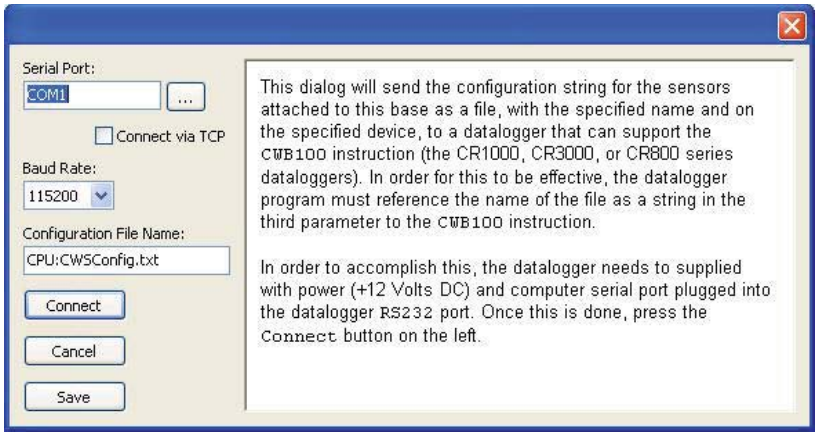
The CRBasic instruction CWB100 reads the sensor configuration file into a constant string that is used by the datalogger to apply names to the values

transmitted by wireless sensors. See Section 4.2.1, *Configuration String*, for more information on the format and use of the configuration string.

After the configuration settings have been sent to the base station and wireless sensors, the sensor configuration file may be sent to the datalogger. The datalogger must then be programmed to access that file using the third parameter of the CWB100 instruction. See Section 4, *Programming the Datalogger*, for programming details.

To send the sensor configuration file to the datalogger, connect a serial cable or USB-to-serial cable to the RS-232 port between the computer and the datalogger.

Select the **Send a sensor configuration file to the datalogger attached** item in the Configure Devices list, then select Click Here. Enter the correct COM port number for the cable that attaches to the datalogger. Ensure that the datalogger is powered as described in the dialog box. The datalogger's PakBus address does not need to be specified for this transaction but if a security code is present in the datalogger, that code needs to be entered in the Datalogger Security Code field. Click Connect to send the configuration file to the datalogger.



3.5 Programming the Datalogger

The datalogger program must include a destination array large enough to store all the values returned by the wireless sensors and a scan that includes a CWB100() instruction. The scan interval must be large enough to allow the sensors time to transmit.

In this example, the program will simply collect data from the two wireless sensors once per minute and store a sample of each value collected. For additional details and advanced programming examples, see Section 4, *Programming the Datalogger*.

Begin by opening the CRBasic editor in LoggerNet, PC400 or RTDAQ software. Select New CR1000 Program File to begin editing the datalogger program. For information on writing datalogger programs or using the CRBasic editor, see the CR1000 and LoggerNet manuals. Additionally, the CRBasic editor help file has an example program for the wireless sensor instructions.

Determining Size of the Array

In this example the WSN includes a CWS655 and a CWS900 configured to measure a 109 temperature probe. Section 1.4, *CWS655 Wireless Water Content Reflectomer*, shows that the CWS655 transmits 8 values and Section 1.5, *CWS900 Wireless Sensor Interface*, shows that the CWS900 transmits 4 values when configured to measure a 109 probe. Thus the array needs to be sized to accept at least 12 values:

```
Public WSN(12)
```

Note that since the array is sized to fit the number of incoming values exactly, no additional wireless sensors may be added to this network without first modifying the datalogger program.

Determining the Scan Rate

The scan in which the CWB100() instruction resides must be long enough to allow for 60 seconds per sensor per hop. If the CWB100RSSI() instruction is used also, an additional 60 seconds/sensor/hop must be included. In this example, each sensor needs only one hop to transmit data to the base station. At 60 seconds per hop, the minimum scan rate is 120 seconds:

```
Scan (120,Sec,0,0)
.
.
.
NextScan
```

NOTE The 120 second scan rate in this example provides a relatively fast check of system components, but will drain the sensor's batteries within a few months. In practice, a more typical scan rate is in the range of 5 to 15 minutes. See Appendix C, *Battery Life*, for details on battery life.

Inserting the CWB100() Instruction

For the CWB100() instruction, specify the odd numbered control port where the CWB100 radio will attach to the datalogger (C1), the destination array where CWS measurements will be stored, and the name of the configuration string (in quotes " "):

```
CWB100(1, WSN(),"CPU:CWSConfig.txt")
```

Finishing the Program

Add a one minute data table and CallTable instruction to complete the program

```
Public WSN(12)

DataTable (WSNData,True,-1)
  DataInterval (0,2,Min,0)
  Sample (12,WSN(),FP2)
EndTable

BeginProg
  Scan (2,Min,0,0)
    CWB100(1, WSN(),"CPU:CWSConfig.txt")
    CallTable WSNData
  NextScan
EndProg
```

Save the program and send it to the datalogger.

NOTE If the CRBasic editor does not compile the program and indicates the error message "Undeclared variable CWB100" this indicates that the compiler is too old and does not support the wireless sensor CRBasic instructions. It is still possible to send the program and run it in the datalogger as long as the datalogger has operating system version 21 or higher.

3.6 Connecting the CWB100 to the Datalogger

The DATA/A terminal on the CWB100 radio connects to the odd numbered control port specified in the CWB100() instruction. In this example, DATA/A connects to C1.

1. Power down the datalogger.
2. Connect CWB100 G terminal to G terminal on the datalogger.

CAUTION Connect to power ground (G), not analog ground (⏚).

3. Connect CWB100 +12V terminal to 12V terminal on the datalogger.
4. Connect CWB100 DATA/A terminal to C1 on the datalogger.
5. Apply power to the datalogger.

The LED activity indicator on the CWB100 will flash red and green rapidly as it goes through the power-up sequence. Then the red LED will flash every 5 seconds.

3.7 Powering CWS Sensors and Initiating Auto-discovery

Connect the 109-L-CWS sensor to the CWS900 female connector at the bottom of the CWS900. Press the connector firmly into the sockets and rotate the locking nut to hold it in position.

Power the CWS sensors by attaching the battery pack to the 4-pin connector. The red LED light will hold steady for about 4 seconds and then turn off.

Press and hold the Setup button on the back of the sensor. The blue LED light will flash up to four times indicating the battery voltage then stop flashing. When the Setup button is continually pressed, about four seconds later the blue LED will start flashing again about once per second as the sensor searches for the base station. This process is known as auto-discovery. Once auto-discovery begins, release the Setup button and wait for the sensor to establish communication with the CWB100 radio.

Establishing the radio link may take five minutes or more. **Patience is important at this stage of the network setup.**

Once the radio link is established, the sensor will flash its red LED light and transmit its table definitions to the CWB100. During this process the red LED on the CWB100 stays on longer than usual indicating that it is receiving a transmission. Afterward the sensor will flash the blue LED when it makes a measurement followed by a flash of the red LED indicating that it has transmitted the measurement to the CWB100.

If the Setup button is not pressed to initiate auto-discovery, the wireless sensor will automatically begin auto-discovery 12 hours after being powered.

For additional information about CWS sensor diagnostics, see Section 5, *CWS Button and LED Behavior*.

3.8 Verify that Data is being Transmitted

After the sensors have established links to the CWB100 radio, verify that data is being received. This may be done with the Connect screen in LoggerNet, the Monitor Values tab in PC400, or the Monitor Data tab in PC200W.

3.9 Physical Connections

3.9.1 Connecting the Base Station to the Datalogger

Connect the CWB100 to the datalogger as shown in FIGURE 3-3.

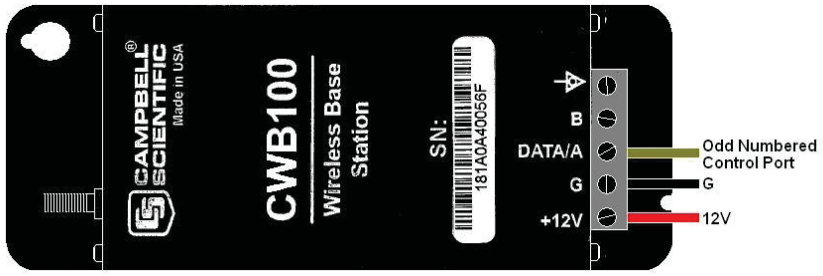


FIGURE 3-3. CWB100 Wiring Connections

3.9.2 Connecting Sensors to the CWS900

For sensors that are compatible with the CWS900 but do not have the –LWS connector option available, or for compatible sensors not sold by Campbell Scientific, a connector will need to be added to the sensor in order to interface it with the CWS900. Two options are available.

A CWS900 Mating Connector may be purchased from Campbell Scientific and connected to the sensor pigtail. This will require soldering the sensor wires to pins on the connector and ensuring the connections are waterproof.

A DES2 Junction Box with a special –LWS cable may be purchased from Campbell Scientific and the sensor connected to the –LWS cable through a terminal block.

The connector pin-out for the CWS900 is shown in FIGURE 3-4.

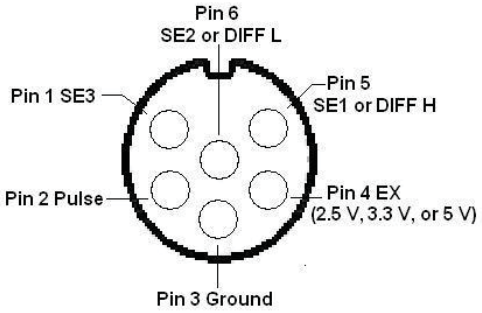


FIGURE 3-4. CWS900 Connector Pin-Out

After connecting the non-standard sensor to the CWS900, test the connections and sensor performance with DevConfig software. See Appendix A, *Using DevConfig for CWS Setup*, for details.

4. Programming the Datalogger

Section 3, *Getting Started: Creating a Wireless Sensor Network*, uses a simple datalogger program to set up a network of two wireless sensors. More advanced programming concepts are described below.

4.1 Array Declaration

All wireless sensors in a network will have their values written to the same variable array. It is important that the array be sized large enough to store all of the values from all of the sensors. If a sensor is discovered but the array is not large enough to hold all of the values reported by the sensor, then none of the values reported by that sensor will be received and it will appear that the sensor has not been discovered. Each sensor in the network will transmit 4 – 10 values, depending on its configuration.

TABLE 4-1. Values Transmitted by CWS Sensors

shows the number of values transmitted by different sensors in a wireless network.

TABLE 4-1. Values Transmitted by CWS Sensors	
Sensor	**Values Transmitted**
CWS220 Wireless Infrared Radiometer	5
CWS655 Wireless Water Content Reflectometer	8
CWS900 Wireless Sensor Interface*	4 – 10
*See Section 1.5, *CWS900 Wireless Sensor Interface*, for more information on number of values transmitted by the CWS900	

In the network example shown in Section 3, *Getting Started: Creating a Wireless Sensor Network*, a CWS655 and a CWS900 configured for a 109-L probe are used. The CWS655 transmits 8 values and the CWS900 transmits 4 values. The array needs to be dimensioned for at least 12 variables, for example:

Public WSN(12)

The array can be sized larger than necessary to allow additional sensors to be added to the network later without reprogramming the datalogger. Oversizing the array will use extra datalogger memory and should be implemented with caution.

4.2 CWB100() Instruction

The CRBasic instruction CWB100 is used to set up the polling of the base station by the datalogger. The instruction has the following format:

CWB100(Port, Destination Array, Configuration)

Port: The Port parameter is a constant indicating the odd numbered control port (C1, C3, C5, or C7) to which the CWB100 DATA line will be connected.

Destination Array: The Destination Array is the array variable that will hold the values from the network. Its size determines the maximum number of values expected from the sensor network.

One of the following error codes may be written to the first element of the destination array if there is a problem with communication between the datalogger and the CWB100 (see Section 8, *Troubleshooting*, for more information):

Error Code	Meaning of Error Code
-1	The datalogger has failed after three consecutive attempts to collect data from the base station.
-2	The signature verifying communication is wrong.
-3	The signature of the names held by the datalogger is different from the signature of names held by the CWB100.

Configuration: The Configuration parameter is an optional constant string parameter that specifies a list of sensor descriptions. This configuration string is supplied by the user to predefine sensor and field names along with the order in which values are returned to the destination array. It overrides the names provided by the sensor and predefines field names.

This parameter can specify a file, as in *"CPU:CWSConfig.txt"*, in which case a file called CWSConfig.txt that contains the configuration string is copied to the datalogger's CPU. The file can be created by the Wireless Sensor Planner or Network Planner software and downloaded into the datalogger as part of the process of configuring a network of sensors.

Use of the configuration string is optional.

4.2.1 Configuration String

The configuration string consists of a list of comma separated sensor descriptions where each sensor description is a space separated list of the following items:

Sensor ID	Radio ID of the sensor	Required
Sensor Name	Station name of the sensor	Required
Number of Fields	Number of values to be transmitted by the sensor	Optional. Defaults to 1 if not specified.
1st Field Name	Name of first value transmitted.	Optional. Treated as unknown if not specified
2nd Field Name	Name of second value transmitted.	Optional. Treated as unknown if not specified
Nth Field Name	Name of last value transmitted.	Optional. Treated as unknown if not specified

It is good practice to keep the custom field names short in order to minimize radio transmission time from a wireless sensor.

Unknown field names are serialized with an uncommon root name, "_F", with the serial number starting at one greater than the number of field names specified for that sensor.

Example of a configuration string:

12530A4013BA N40 9 WC_Corn EC_Corn Ts_Corn Ka PA VR Ti BV SS,
12530A4013B7 Barn 4 Tair Ti BV SS

The configuration string predefines field names in the destination array. The advantage of this is that the datalogger table definitions do not change as wireless sensors are discovered.

If no configuration string is specified, the elements of the destination array will be renamed with field names from the sensors in the order that the sensors are

discovered. This can make it difficult to use specific values in the datalogger program because of uncertainty as to which position in the array the value of interest will be assigned. The CRBasic instruction ArrayIndex may be used to reference values returned by wireless sensors regardless of where those values are in the destination array. See Section 4.3, *ArrayIndex() Instruction*, for details on ArrayIndex.

4.2.2 Field Names

Field names are generated or learned by the base and are provided to the datalogger for the purpose of generating table definitions. The configuration string is used as a starting point for field name generation. If the configuration string does not fully specify field names, default names with a serialize root name " _Fn" are generated by the base. Later, as new sensors are discovered, the generated names are modified by field names learned from the sensor with the "_Fn" portion of the name replaced by the field name learned from the sensor.

For example, before discovery, a generated field name might be: "CWS650__F3", then after discovery, this may change to "CWS650_BatV" where "BatV" was the field name provided for the third field by the sensor.

If a sensor name is not provided by the configuration string, then the sensor name learned from sensor discovery will be used to name the sensor. These auto-discovered sensor field names are added to the end of the list of field names until all available space in the Destination Array is consumed.

These default sensor field names are shown in Wireless Sensor Planner, Network Planner, and DevConfig software. Descriptions of the default sensor names are found in Appendix B, *Measurement Names and Meanings*.

4.2.3 Status Monitoring

All CWS sensors generate both measurement and status values. The status fields (usually battery voltage, module temperature, and RSSI) are always included as the last three fields returned by the sensor. Including status information along with measurement data from each sensor is the easiest way to manage status information. It is recommended that status data be recorded by the datalogger to assist in data analysis and troubleshooting.

If status data is not desired, then specify only the measurement fields in the configuration string. If the configuration string specifies fewer values than are returned by the sensor, only as many values as are specified will be saved in the Destination Array.

For example, CWS650_1 returns 7 values, including 3 status values. To ignore the status values use a configuration string similar to:

AF6345bd3404 CWS650 4.

Limiting the number of fields to 4 means the first 4 measured values will be stored in the destination array and the last 3 status values will not.

4.3 ArrayIndex() Instruction

The ArrayIndex function is used to return the index of a named element in an array which would otherwise be unknown. The value can then be further processed in the program because of its known position in the array. If the named element is not found, the function returns 0 (this will result in a Variable Out of Bounds error).

In a wireless sensor network where auto-discovery is being used, the sensor measurements are returned in the destination array in the order in which the sensors are discovered by the base. It is not known until the sensors are discovered where in the array each sensor's measurement values will be stored. The names of the values returned by the sensors are known, however. Thus, the ArrayIndex function can be used to return the correct index value so that further processing such as output processing or unit conversion can be performed.

The instruction has the following format:

ArrayIndex (Name)

Name: A string that contains the name of the value for which an index is desired. All CWS sensors have a default sensor name, and a fieldname for each returned value. For instance, a CWS900 with a sensor name of CWS900_3AF has a 109 probe attached and returns four default values: Ts (109 temperature), Ti (internal temperature), BV (battery voltage), and SS (signal strength). Thus, the default name for the sensor's temperature measurement might be CWS900_3AF_Ts. This would be entered as a string in the ArrayIndex function:

```
Const NumValues = 12
Public CWSArray(NumValues)
Public Tair_F

DataTable (WSN5min,True,1000)
  DataInterval (0,2,Min,0)
  Sample (1,CWSArray(ArrayIndex("CWS900_TS")),FP2)
  FieldNames (CWS900_Temp)
  Sample (1,CWSArray(ArrayIndex("CWS655_VWC")),FP2)
  FieldNames (CWS655_VWC)
EndTable

BeginProg
  Scan (2,Min,0,0)
    CWB100 (3,CWSArray())
    Tair_F = CWSArray(ArrayIndex("CWS900_TS")) * 1.8 + 32
    CallTable (WSN5min)
  NextScan
EndProg
```

In this example wireless sensor data is written to a destination array called CWSArray. Because the default measurement name is known, it is entered in quote marks in the Name field of the ArrayIndex instruction. The datalogger can then search for that name in the destination array and reference its position

in the array for program use regardless of the order in which the sensor was discovered.

CRBasic instruction Fieldnames is used after each output instruction to provide a unique output name to the values. If more than one output instruction is in the DataTable and Fieldnames is omitted, a compiler error will be returned indicating duplicate output names. If the compiler error is ignored and the program sent to the datalogger, the datalogger may generate additional compiler errors or it may accept the program but size the DataTable with fewer fields than specified in the program. It is therefore good practice to put a FieldNames instruction after each output instruction that utilizes ArrayIndex.

4.4 CWB100RSSI() Instruction

The CRBasic instruction CWB100RSSI is used to trigger a round of RSSI (signal strength) polling of each sensor in the network. The RSSI values will be returned along with other data in the next measurement cycle. If RSSI polling is never triggered, the RSSI field associated with each sensor will always return NAN. The instruction has the following format:

CWB100RSSI (Port)

Port: The Port parameter is a constant indicating the control port (C1, C3, C5, or C7) to which the CWB100 Data line is connected.

The CWB100RSSI() instruction should not be executed as often as the CWB100() instruction polls the sensors. This is because it requires an additional RF polling cycle to measure the RSSI from the sensors, which decreases battery life and scan rate (see Section 3.5, *Programming the Datalogger*).

4.5 CWB100Routes() Instruction

The CRBasic instruction CWB100Routes is used to view the routes used by various wireless sensors to transmit their data to the CWB100 base station. The instruction returns the sensor serial number, the sensor name and any hops to the base for each wireless sensor in the network. A hop is a sensor's link through a routing sensor back to the wireless base. The hop is also specified as sensor serial number sensor name. The format of the returned string is:

RadioID SensorName Hop1 Hop2 Hop3

The path specified by Hop1 Hop2 Hop3 is the path from the sensor back to the base (the base would be after Hop3). If a sensor transmits directly to the base with no hops, only the RadioID and SensorName will be returned. The information for each sensor is terminated by a carriage return/line feed.

This instruction does not trigger any additional communication to the sensors in the wireless sensor network, and thus, does not affect power consumption of the sensors.

The instruction has the following format:

CWB100Routes (Port, Routes)

Port: The Port parameter is a constant indicating the control port (C1, C3, C5, or C7) to which the CWB100 Data line is connected.

Routes: A destination variable of type String where the routing information will be stored. It is important to size the variable large enough to hold all of the routing information.

Example

```
Public WSNRoutes as String *100
.
.
.
Scan()
  CWB100Routes(C7, WSNRoutes)
NextScan
```

For example, in a network with sensors named W900_006, W900_Red, W900_39D, and W220_38F, the CWB100Routes() instruction returns the following string:

125309400006 W900_006

12530A401388 W900_Red

12530A40139D W900_39D: 12530A401388 W900_Red

12530A40138F W220_38F

This reports that sensor W900_006 hops directly to the base station. W900_Red also hops directly to the base station. W900_39D hops to W900_Red and from there hops to the base station. Finally, W220_38F hops directly to the base station.

4.6 Program Example

In example program 4.6-1, CWB100 is used to poll the CWB100 base station every 10 minutes and CWB100RSSI is used to trigger a radio strength signal measurement every 60 minutes. A flag called GetRSSI is available to manually force the RSSI measurement. Sensor routes are also updated hourly. The wireless sensor measured in this example is a CWS900 interfaced to a 109-LW temperature probe.

ArrayIndex is use in the DataTable and the disable variable is used to exclude NAN values from influencing the average and minimum calculations.

Wiring for Example Program 4.6-1:

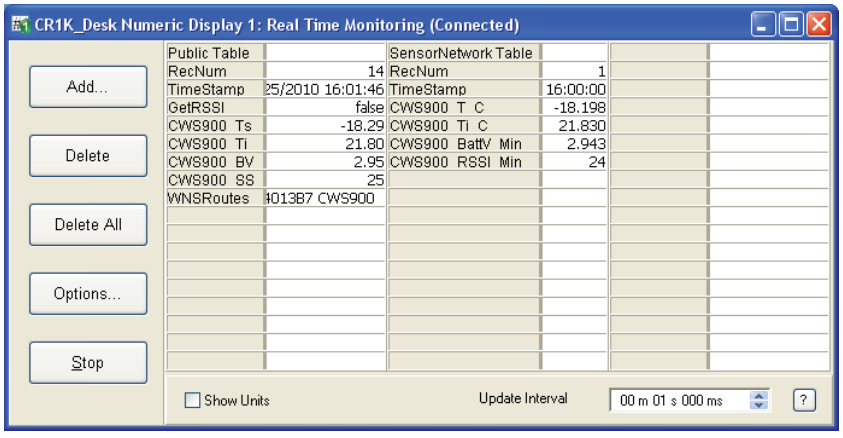
CWB100 Channel	Wire Color	CR1000 Channel
+12V	Red	12V
G	Black	G
DATA/A	Green	C3

Example 4.6-1. Program for Wireless Sensor Network

```
Const NumVals = 4 'Values returned by CWS900
Public GetRSSI As Boolean
Public WSN(NumVals)
Public WNSRoutes As String *100

DataTable(SensorNetwork,True, -1 )
  DataInterval( 0,10,Min,0)
  Average (1,WSN(ArrayIndex("CWS900_Ts")),IEEE4,WSN(ArrayIndex("CWS900_Ts"))= NAN)
  FieldNames (CWS900_T_C)
  Average (1,WSN(ArrayIndex("CWS900_Ti")),IEEE4,WSN(ArrayIndex("CWS900_Ti"))= NAN)
  FieldNames (CWS900_Ti_C)
  Minimum (1,WSN(ArrayIndex("CWS900_BV")),IEEE4,WSN(ArrayIndex("CWS900_BV"))= NAN,False)
  FieldNames (CWS900_BattV_Min)
  Minimum (1,WSN(ArrayIndex("CWS900_SS")),IEEE4,WSN(ArrayIndex("CWS900_SS"))= NAN,False)
  FieldNames (CWS900_RSSI_Min)
EndTable

BeginProg
  Scan (600,Sec,0,0)
    CWB100(3,WSN, )'Poll CWB100 for sensor data:
    If IfTime (0,60,Min) Then GetRSSI = True
    If GetRSSI = True Then
      CWB100RSSI( 3 ) 'Trigger a radio signal strength measurement
      CWB100Routes (3,WNSRoutes)'Verify routes
      GetRSSI = False
    EndIf
    CallTable SensorNetwork
  NextScan
EndProg
```



This numeric screen from LoggerNet shows both Public and final storage data generated by program example 4.6-1. CWS900_SS will display NAN except during the scan immediately following the CWB100RSSI() instruction. The disable variable in the Minimum() instruction excludes NAN values from the minimum calculation. Note that in the SensorNetwork data table, the labels for the measurements match those assigned by FieldNames in the datalogger program.

5. CWS Button and LED Behavior

The Setup button on the back of a CWS sensor and the RED and BLUE LED lights provide diagnostic information regarding the sensor and its communication with the CWB100 base station radio.

5.1 Sensor Link to Base Station

Press the Setup button momentarily to see how the CWS sensor is linked to the CWB100 base station. The RED LED flashes to indicate the number of hops to the base radio as follows:

No RED LED flashes:	no link to base
1 RED LED flash:	direct (1 hop) link to base
2 RED LED flashes:	link through 1 repeater to base (2 hops)
3 RED LED flashes:	link through 2 repeaters to base (3 hops)
4 RED LED flashes:	link through 3 repeaters to base (4 hops)

These flashes do not provide any information regarding the strength of the radio communication. They simply tell how many hops are required for the sensor to reach the CWB100 base station. Signal strength is measured when the datalogger executes a CWB100RSSI( ) instruction (see Section 4.4, *CWB100RSSI() Instruction*).

5.2 Sensor Battery Voltage

After pressing the Setup button momentarily the RED LED flashes if connected to the base as described above, while the BLUE LED flashes simultaneously to indicate battery voltage as follows:

1 flash:	Battery voltage < 2.25V; batteries should be replaced or recharged
2 flashes:	2.25V < Battery voltage < 2.50V
3 flashes:	2.50V < Battery voltage < 2.75V
4 flashes:	Battery voltage > 2.75V

5.3 CWS Sensor Search for Base Station

If the Setup button is held for about four more seconds after the link/battery status flashes have stopped, the BLUE LED will begin flashing about once per second, and the radio will attempt to find a link to the base station. This process is called auto-discovery. It will do this even if it already has a link to the base.

The sequence for the search is:

1. Attempt to link to base. The search attempt takes from 30 seconds to 5 minutes. During this time the BLUE LED blinks about once per second.

2. If the initial attempt fails to link to the base station, the CWS sensor will delay 5 minutes before attempting to link again. The BLUE LED will be off during this time. The sensor will try to link to the base at a five minute interval a total of three times.

3. If the 5-minute interval attempt fails to link to the base station, the CWS sensor will delay one hour before attempting to link again. The BLUE LED will be off during this time. The sensor will try to link to the base at a one hour interval a total of four times.

4. If the hourly attempts fail, the CWS sensor will try to connect to the base station every 12 hours. At the beginning of each 12 hour interval it will make three attempts spaced 5 minutes apart. This sequence will be repeated indefinitely.

If the Setup button is not pressed to initiate auto-discovery, the wireless sensor will automatically begin a search for the base station 12 hours after being powered.

If discovery has been successful and the base station later loses power, the wireless sensor keeps making measurements at the same polling interval. It does not transmit the measured values because it only transmits data when polled by the CWB100 base station. After 4-12 hours of no communication with the base station, the sensor will start the autodiscovery mode and follow the schedule shown above.

6. Testing the Network

NOTE Whenever possible it is best to bench test the network before field installation.

Test the network by powering the sensors and verifying their RF connectivity. This is done with the following steps:

1. Configure the wireless sensors (see Section 3, *Getting Started: Creating a Wireless Sensor Network*, for details).

2. Write the datalogger program (see Section 4, *Programming the Datalogger*, for details).

3. Connect the CWB100 radio base station to the datalogger with the DATA/A channel wired to the control port specified in the Port parameter of the CWB100 () instruction.

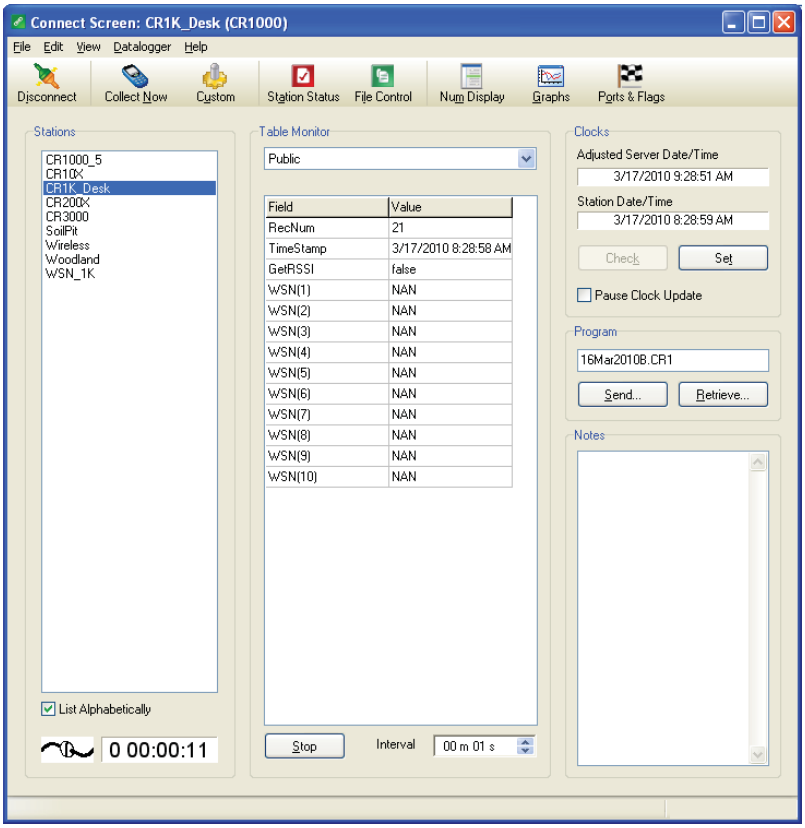
4. Send the program to the datalogger.

5. Connect the battery pack to the first wireless sensor. When first powered the red LED light will hold steady for 5 seconds and then turn off. Press the Setup button on the back of the sensor and hold it in for 8-10 seconds to force the sensor to start searching for the base station. When the button is first pressed, the blue LED light will flash 1 to 4 times to indicate the sensor battery voltage (see Section 5, *CWS Button and LED Behavior*). After several more seconds the blue LED will flash about once per second as the sensor searches for the base station. It may take several minutes for

the wireless sensor to link with the base station. Once the linking has taken place, the blue LED will stop flashing. From that point on, the blue LED will light up whenever a measurement is taken and the red LED will light up whenever the measurements are transmitted to the base station.

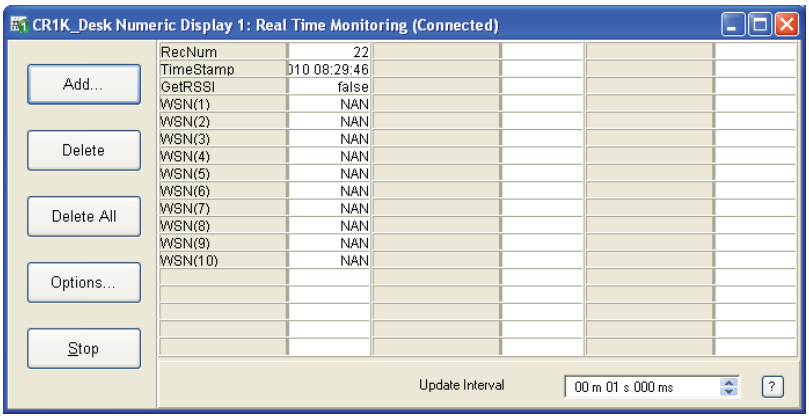
6. Connect the battery pack to the next wireless sensor, press in the Setup button for 8-10 seconds, and wait for that sensor to pair with the base station radio. It is also possible to power all the sensors at the same time, press the button to start the linking, and wait for them to autodiscover the base station.

7. To verify that all sensors have been discovered, you can view real-time data from the sensors from LoggerNet's Connect screen. There are two ways to do this. First, from the Table Monitor area of the Connect screen, choose Public from the drop down menu. Then click the Start button at the center bottom of the Connect screen. Prior to sensor discovery, the numeric monitor will display the name of the public variable specified in the CWB100 instruction with NAN as the output (if no configuration string is specified). Once any sensor has been discovered, the Public table will disappear and must be selected again from the drop down menu. At that time the newly discovered sensor names will appear in the Public table. On the next datalogger scan, the sensor values will also appear.

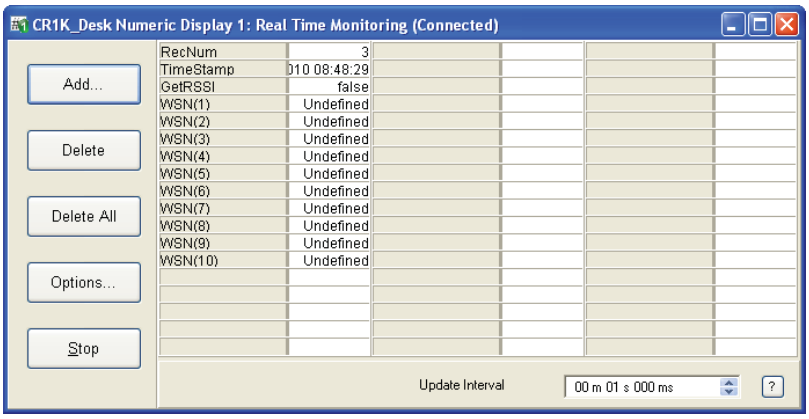


8. The second way to view real-time data from the sensors is to select the Num Display button at the top of LoggerNet's Connect screen and choose Display 1, Display 2, or Display 3. When the Numeric Display window opens, click the Add button. When the Add Selection window appears, select Public to highlight it and then drag it to a gray space in the Numeric

Display window. This will populate the window with names of variables in the Public Table. Click the Start button to begin monitoring.



Prior to sensor discovery, the numeric monitor will display the name of the public variable specified in the CWB100 instruction with NAN as the output. Once the sensor has been discovered, NAN will change to Undefined.



To view the user-specified Field Names in the numeric monitor, delete the original Public variables from the display with the Delete All button and add the Public table again with the Add button. Now the correct Field Names will be displayed for each sensor with their real-time values.

7. Maintenance

Minimal maintenance is required for the CWS900, CWS220, and CWS655 wireless sensors. If batteries are solar charged, the solar cell battery lid needs to be periodically cleaned with water to remove dust and debris. Alkaline batteries need to be replaced periodically as needed. It is good practice to store the battery voltage of individual sensors in the datalogger to determine when the sensor power supply needs attention.

It is important to keep the lens and view of the CWS200 clean. Otherwise the sensor will be measuring the temperature of the obstruction instead of the surface of interest. Clean the lens gently with a moistened cotton swab.

Distilled water or alcohol works well for most dust/dirt. Salt deposits dissolve better in a weak acid solution (~0.1 molar).

Sensors connected to the CWS900 may require regular maintenance and recalibration. See the documentation for the sensor of interest for recommended maintenance and recalibration details.

7.1 Replacing a Sensor in the Network

If a sensor in the network needs to be replaced, the CWB100 treats the replacement sensor as a new sensor because it has a different radio address than the original sensor. The data transmitted by the replacement sensor will have the same field names as the original sensor, but with a ~ appended to each name by the datalogger support software to make it unique. The original sensor will still appear in the final storage data file with NAN's instead of values because the sensor is no longer working. Data from the replacement sensor will be saved to a different position in the final storage data file with field names that include the ~ character.

If a sensor has not responded to six polls by the CWB100 and it has been more than two hours since the last communication, the CWB100 will stop polling that sensor.

The only way to fully remove a sensor from the network and replace it with another is to force the datalogger to read the sensor names from the CWB100 after the replacement sensor is configured and installed. Changing the size of the array or the scan interval in the datalogger program, for example, will force that reading when the program is compiled. In that case the ~ character will not be appended to the new sensor's field names.

If a configuration file or string is used in the CWB100( ) instruction, then the replacement sensor is accommodated by using a new file or string that has the old radio address replaced with the new radio address. The configuration file is only read by the datalogger one time at compile, so a change to the configuration file must be accompanied by a restart of the datalogger program for the new file to be used.

7.2 Stopping or Loading a New Datalogger Program

If the datalogger program is stopped or a new program loaded, the CWB100 base station will still retain its information for the discovered sensors in the network. The sensors will not have to initiate auto-discovery.

If the sensors are not polled by the base at least once in 13 hours, the sensors will initiate the auto-discovery process just as if the Setup button had been pressed to start auto-discovery.

8. Troubleshooting

Symptom	Possible Cause	Solution
Cannot connect to CWB100 with USB cable	Wrong serial port number specified	Choose correct serial port number from drop down menu. If correct port number does not display, wait 15 seconds for list to refresh and try again.
	Device drivers not installed	Install device drivers from Configuration CD
Cannot connect to CWS sensor with A205	Wrong serial port number specified	Choose correct serial port number from drop down menu. If correct port number does not display, wait 15 seconds for list to refresh and try again.
Datalogger program that includes CWB100 instruction has compile errors	CRBasic compiler too old	Update compiler using Configuration CD
	Datalogger operating system too old	Send latest OS to datalogger. This is available on the Configuration CD or from www.campbellsci.com
Compile results indicates configuration file does not exist	Configuration file has not been sent to datalogger	Send configuration file via Wireless Sensor Planner, Network Planner, or File Control
	CWSConfig parameter in CWB100 instruction does not match file on datalogge	Check spelling, pathway, and filename specified in program and correct if needed
Sensor LED does not respond when Setup button is pressed	Low Battery	Replace or recharge batteries
	Sensor is damaged	Connect sensor directly to computer using A205 and DevConfig software to verify performance. See Appendix A, *Using DevConfig for CWS Setup*, for details.

Symptom	Possible Cause	Solution
Pressing Setup button for 8-10 seconds does not initiate auto-discovery (Blue LED does not blink every second indicating search for base station)	Sensor does not have radio base station address programmed into it	Reconfigure sensor to include base station radio address
First element in destination array specified in CWB100 instruction is -1 and all other elements in the array are zeroes	CWB100 is not connected to control port specified in CWB100 Port parameter. CWB100 is not powered. CWB100 G connected to datalogger analog ground.	Check program and verify that the CWB100 radio DATA/A terminal is well connected to the control port specified in the CWB100 instruction. Verify that +12V and G channel on CWB100 radio are well connected to 12V and G terminals on the datalogger. Verify that the datalogger is powered on. If connected to SW12 channel on datalogger, verify that datalogger program turns 12V channel on and leaves it on. Connect CWB100 G to datalogger power ground, G.
First element in destination array specified in CWB100 instruction is -2 and all other elements in the array are zeroes.	A device other than the CWB100 is connected to the control port specified in the CWB100 instruction Port parameter.	Change program or move wire connected to DATA/A terminal so that the program and physical connections match.

Symptom	Possible Cause	Solution
First element in destination array specified in CWB100 instruction is -3 and all other elements in the array are zeroes.	The measurement names in the datalogger do not match the names stored in the CWB100 base station.	This is a rare error message that should disappear after the datalogger has made its second attempt to communicate with the CWB100 base station. On the second attempt, the datalogger will send the CWB100 base its version of the names and then the name signatures from both devices will match.
Values in CWB100 destination array are NAN. This indicates that the CWB100 base is unable to get data from wireless sensor	CWB100 base station is polling sensor too quickly.	Minimum poll rate is 60 seconds per sensor per hop. Verify that the scan rate in the datalogger program for the scan that includes the CWB100 instruction is longer than the minimum poll rate.
	Sensor not powered.	Press Setup button on back of sensor to check battery voltage. Replace batteries if needed.
	Sensor not within radio range of CWB100 base station.	Move sensor closer to CWB100 radio or add another wireless sensor in between to serve as a router.
	Another radio is interfering with wireless sensor transmissions.	Try to identify and limit transmissions from other radio
Incorrect radio address/extra characters returned by CWB100Routes instruction	The CWSRoutes variable is not declared large enough	Increase the size of the string variable referenced by the CWSRoutes parameter
Variable Out of bounds error reported in Station Status after a sensor is discovered and no values are returned for that sensor	The sensor name does not match the name parameter specified in the ArrayIndex Instruction	Change the program or reconfigure the sensor so that the names match

Appendix A. Using DevConfig for CWS Setup

CWS Sensors can be configured using Device Configuration Utility, DevConfig, which can be downloaded from www.campbellsci.com/downloads. DevConfig does not allow custom field names and will not generate a configuration string, but it can be used to specify the base station radio address, sensor name, and the measurement configuration for the wireless sensor. It can also configure a CWS sensor to connect directly to the base station or use repeaters (see Appendix C.3, *RF Connection Type Setting*).

Because DevConfig triggers a measurement of the wireless sensor every 5 seconds, it can be used to verify that the sensor is operating as expected. This is useful when troubleshooting as it provides a quick method for determining whether an issue with data from a sensor is a measurement problem or a communication problem.

Steps for configuring sensors with DevConfig:

1. Launch DevConfig. Specify the serial port number for the A205 interface.

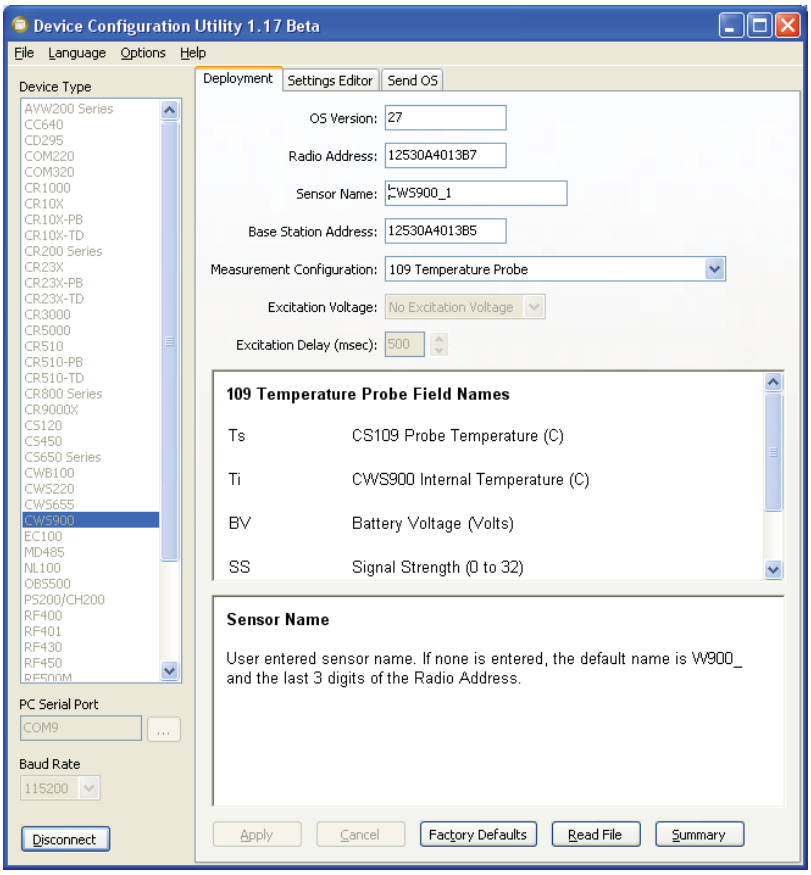
2. Connect the A205 interface to the 4-pin socket behind the sensor battery door as described in Section 3.3, *Configuring the Devices in the WSN*.

3. From the list of devices on the left side of the window choose the wireless sensor to be configured (In the example below, the CWS900 is selected).

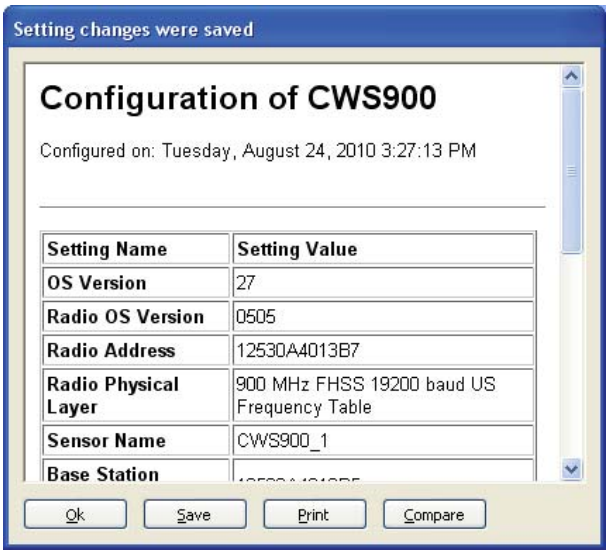
4. Click the Connect button and press the Setup button on the back of the sensor.



5. Once DevConfig connects to the sensor, enter the address of the CWB100 in the field called Base Station Address. If configuring a CWS900, choose the type of measurement the sensor will make from the drop-down menu called Measurement Configuration. If desired, change the Sensor Name from its default value.

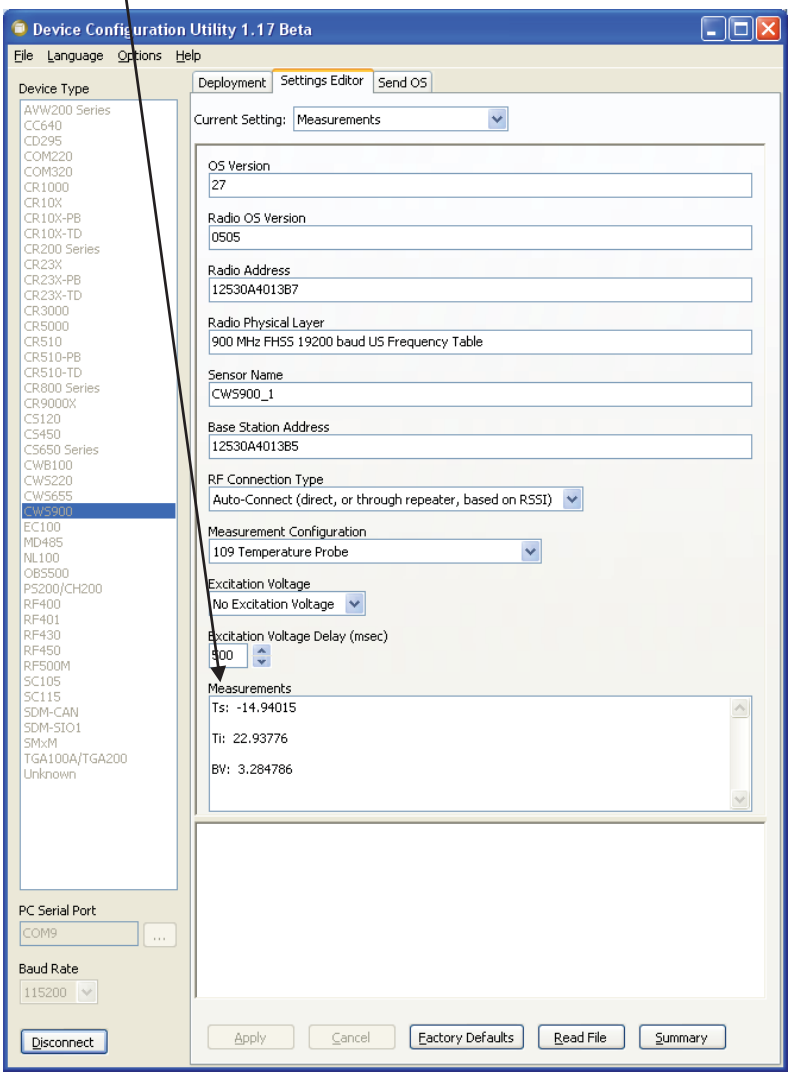


6. Click Apply to apply the changes. A configuration summary will be displayed. Save the configuration information if desired. Click OK.



7. If configuring a CWS900 sensor module, you can use DevConfig to ensure that the sensor is correctly configured and connected to the CWS900. To test the sensor, connect the sensor to be measured to the CWS900 and follow the instructions above for establishing communication with

DevConfig. When the sensor settings are displayed in the Deployment tab, click on the Settings Editor tab. The field called Measurement will display the most current measurements from the sensor with updates every 5 seconds.



8. When finished, click on Disconnect and repeat the process for the next sensor or close DevConfig.

Appendix B. Measurement Names and Meanings

Default measurement names are shown in Wireless Sensor Planner, Network Planner, and DevConfig software. Custom names may be assigned to the measurements with Wireless Sensor Planner or Network planner. It is good practice to keep the measurement names short. The default names, meanings and measurement units are listed below.

B.1 CWS220 Default Names

Default Name	**Meaning**	**Units**
Tt	Target Temperature	°C
Tb	Sensor Body Temperature	°C
Ti	Internal temperature of wireless sensor	°C
BV	Battery voltage of wireless sensor	Volts
SS	Signal strength of last received radio transmission	Unitless, ranging from 0 (no signal) to 32 (full signal)

B.2 CWS655 Default Names

Default Name	**Meaning**	**Units**
VW	Volumetric Water Content	m^3 water/m^3 soil
EC	Bulk Electrical Conductivity	dS/m
Ka	Dielectric Permittivity	unitless
Ts	Soil Temperature	°C
Pe	Period Average	μsec
AR	Voltage Ratio	unitless
Ti	Internal temperature of wireless sensor	°C
BV	Battery voltage of wireless sensor	Volts
SS	Signal strength of last received radio transmission	Unitless, ranging from 0 (no signal) to 32 (full signal)

B.3 CWS900 Default Names

Default Name	Meaning	Units
SE1	Single-ended DC voltage measured on pin 5 with respect to pin 3	Volts, may need additional processing to convert to engineering units
SE2	Single-ended DC voltage measured on pin 6 with respect to pin 3	Volts, may need additional processing to convert to engineering units
SE3	Single-ended DC voltage measured on pin 1 with respect to pin 3	Volts, may need additional processing to convert to engineering units
DF1	Differential DC voltage measured between pin 5 (high) and pin 6 (low)	Volts, may need additional processing to convert to engineering units
TC	Total count of switch closures measured since sensor configuration	Integer, requires additional processing to convert to engineering units
IC	Number of switch closures detected during polling interval	Integer, requires additional processing to convert to engineering units
MF	Maximum frequency of pulses detected during polling interval	Hz, may need additional processing to convert to engineering units
AF	Average frequency of pulses detected during polling interval	Hz, may need additional processing to convert to engineering units
Ts	Temperature of sensor connected to CWS900	°C
RH	Relative humidity	%
LWS	Leaf wetness sensor voltage	Volts
DO	Voltage returned from CS511 Dissolved Oxygen Sensor	Volts, requires additional processing to convert to DO
pH	Voltage returned from CS525 ISFET pH probe	Volts, requires additional processing to convert to pH
SS	Signal strength of last received radio transmission	Unitless, ranging from 0 (no signal) to 32 (full signal)

Default Name	Meaning	Units
BV	Battery voltage of wireless sensor	Volts
Ti	Internal temperature of wireless sensor	°C
WSA	Wind speed average during last polling interval	meters per second
WSMX	Wind speed maximum during last polling interval. Calculated from a running average of three successive, one-second wind speed measurements	meters per second
WSMN	Wind speed minimum during last polling interval. Calculated from a running average of three successive, one-second wind speed measurements	meters per second
WSSD	Wind speed standard deviation during last polling interval.	meters per second
WDA	Wind direction average. Calculated over the polling interval using the average of one-second wind direction measurements, excluding zero wind speed measurements.	Degrees from north, ranging from 0° to 355°
WDSD	Wind direction standard deviation. Calculated over the polling interval using the average of one-second wind direction measurements and the Yamartino algorithm (See B3.1 for details).	Degrees
RWS	Resultant wind speed. Vector mean horizontal wind speed calculated over the polling interval using one-second measurements including measurements of zero wind speed.	meters per second
RWDA	Resultant wind direction average. Calculated over the polling interval using one second wind direction measurements, excluding zero wind speed measurements.	Degrees from north, ranging from 0° to 355°

Default Name	Meaning	Units
RWDSD	Resultant wind direction standard deviation. Vector mean wind direction standard deviation calculated over the polling interval with the CSI wind speed weighted algorithm (See B3.1 for details).	Degrees

B.3.1 Wind Vector Calculations

When a wind speed sample is 0, the CWS900 uses 0 to process scalar or resultant vector wind speed and standard deviation, but the sample is not used in the computation of wind direction.

Measured raw data:

S_i = horizontal wind speed
Θ_i = horizontal wind direction
Ue_i = east-west component of wind
Un_i = north-south component of wind
N = number of samples

Calculations:

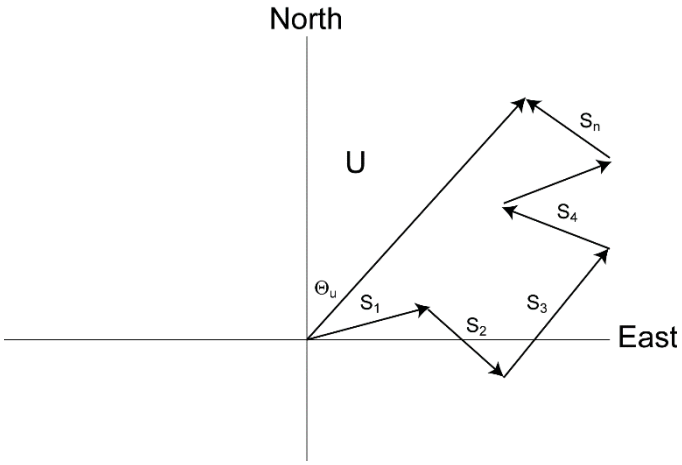


FIGURE B-1. Input Sample Vectors

In FIGURE B-1, the short, head-to-tail vectors are the input sample vectors described by S_i and Θ_i, the sample speed and direction, or by Ue_i and Un_i, the east and north components of the sample vector. At the end of output interval T, the sum of the sample vectors is described by a vector of magnitude U and direction Θu. If the input sample interval is t, the number of samples in output interval T is $N = T / t$. The mean vector magnitude is $\overline{U} = U / N$.

Scalar mean horizontal wind speed, S:

$$S=(\Sigma s_i)/N$$

where in the case of orthogonal sensors:

$$S_i=(Ue_i^2+Un_i^2)^{1/2}$$

Unit vector mean wind direction, Θ1:

$$\Theta 1=\text{Arctan } (Ux/Uy)$$

where

$$Ux=(\Sigma \sin \Theta_i)/N$$
$$Uy=(\Sigma \cos \Theta_i)/N$$

or, in the case of orthogonal sensors

$$Ux=(\Sigma(Ue_i/U_i))/N$$
$$Uy=(\Sigma(Un_i/U_i))/N$$

$$\text{where } U_i=(Ue_i^2+Un_i^2)^{1/2}$$

Standard deviation of wind direction, σ(Θ1), using Yamartino algorithm:

$$\sigma(\Theta 1)=\text{arc } \sin(\varepsilon)[1+0.1547\ \varepsilon^3]$$

where,

$$\varepsilon=[1-((Ux)^2+(Uy)^2)]^{1/2}$$

and Ux and Uy are as defined above.

Resultant mean horizontal wind speed, $\overline{U}$:

$$\overline{U}=(Ue^2+Un^2)^{1/2}$$

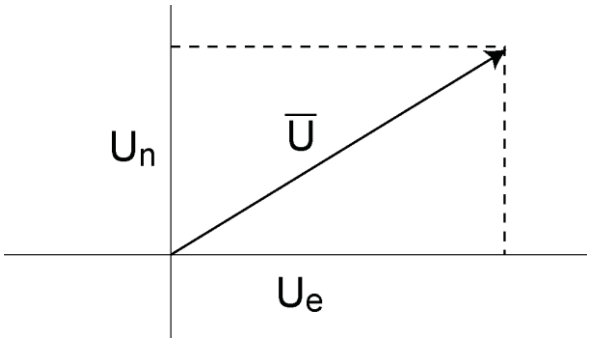


FIGURE B-2. Mean Wind Vector

where for polar sensors:

$$Ue=(\Sigma S_i \text{ Sin } \Theta_i)/N$$
$$Un=(\Sigma S_i \text{ Cos } \Theta_i)/N$$

or, in the case of orthogonal sensors:

$$Ue=(\Sigma Ue_i)/N$$
$$Un=(\Sigma Un_i)/N$$

Resultant mean wind direction, Θu:

$$\Theta u = \text{Arctan}\,(Ue/Un)$$

Standard deviation of wind direction, σ(Θu), using Campbell Scientific algorithm:

$$\sigma(\Theta u) = 81(1 - \overline{U}/S)^{1/2}$$

The algorithm for σ(θu) is developed by noting (FIGURE B-3) that

$$\text{Cos}\,(\Theta_i') = U_i / s_i;\ \text{where}\ \Theta_i' = \Theta_i - \Theta u$$

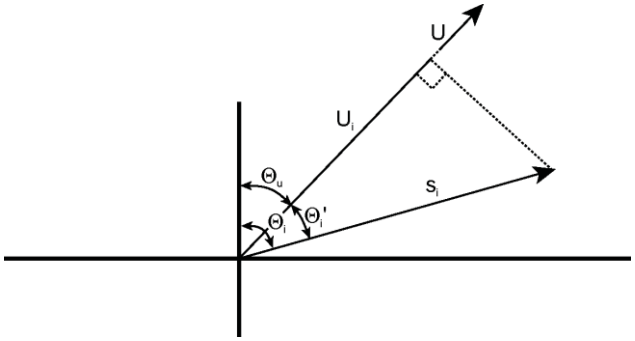


FIGURE B-3. Standard Deviation of Direction

The Taylor Series for the Cosine function, truncated after 2 terms is:

$$\text{Cos}\,(\Theta_i') \cong 1 - (\Theta_i')^2 / 2$$

For deviations less than 40 degrees, the error in this approximation is less than 1%. At deviations of 60 degrees, the error is 10%.

The speed sample may be expressed as the deviation about the mean speed,

$$s_i = s_i' + S$$

Equating the two expressions for Cos (θ‘) and using the previous equation for s_i ;

$$1 - (\Theta_i')^2 / 2 = U_i / (s_i' + S)$$

Solving for $(\Theta_i')^2$, one obtains;

$$(\Theta_i')^2 = 2 - 2U_i / S - (\Theta_i')^2 s_i'/S + 2s_i'/S$$

Summing $(\Theta_i')^2$ over N samples and dividing by N yields the variance of Θu. Note that the sum of the last term equals 0.

$$(\sigma(\Theta u))^2 = \sum_{i=1}^{N}(\Theta_i')^2 / N = 2(1-\overline{U}/S) - \sum_{i=1}^{N}((\Theta_i')^2 s_i') / NS$$

The term, $\sum((\Theta_i')^2 s_i') / NS$, is 0 if the deviations in speed are not correlated with the deviation in direction. This assumption has been verified in tests on wind data by CSI; the Air Resources Laboratory, NOAA, Idaho Falls, ID; and MERDI, Butte, MT. In these tests, the maximum differences in

$$\sigma(\Theta u) = (\sum(\Theta_i')^2 / N)^{1/2} \text{ and } \sigma(\Theta u) = (2(1-\overline{U}/S))^{1/2}$$

have never been greater than a few degrees.

The final form is arrived at by converting from radians to degrees (57.296 degrees/radian).

$$\sigma(\Theta u) = (2(1-\overline{U}/S))^{1/2} = 81(1-\overline{U}/S)^{1/2}$$

Appendix C. Battery Life

C.1 Battery Characteristics

The battery life of the CWS wireless sensors is a function of the polling interval, repeater usage, type of batteries, and temperature. The types of batteries that can be used in the sensors are AA sized alkaline, Lithium, NiMH, or NiCd; their capacities and characteristics are:

Battery Type	**Manufacturer**	**Capacity mWH)**	**Temperature Characteristics**
Alkaline	Duracell MX1500	3800	-20 °C to +54 °C
Alkaline	Energizer EN91	3800	-18 °C to +55 °C
Lithium	Energizer L91	4000	-40 °C to +60 °C
NiMH	Duracell DX1500	2500	-20 °C to +50 °C
NiMH	Rayovac LD715	2500	-10 °C to +45 °C

The capacities that are listed are for 21° C operation; for all the battery types (except Lithium), the capacity decreases as the temperature decreases. For example, the capacity of the Alkaline batteries decreases by 30% when the temperature is at 0° C. All these batteries can be used below the stated temperature range (the Duracell Alkaline and NiMH have both been tested to -30° C), but their capacity is reduced.

For the rechargeable batteries, while all types can be used, by far the best type to use is the "low self-discharge" NiMH batteries. Both of the NiMH batteries listed above are of this type. The normal NiMH and NiCd batteries have very high self-discharge, and would probably only last for a couple of months.

C.2 Effect of Polling Interval and Repeaters on Battery Life

The largest factor affecting battery life is polling interval, followed by repeater usage. This is because the radio RX/TX current is the dominant drain on the batteries. Any sensor that is used as a repeater by another sensor will also have its battery life decreased, as it has to send its own data as well as data from sensors repeating through it.

Using the Duracell MX1500 Alkaline batteries, derated by ~20%, gives the following expected sensor battery life:

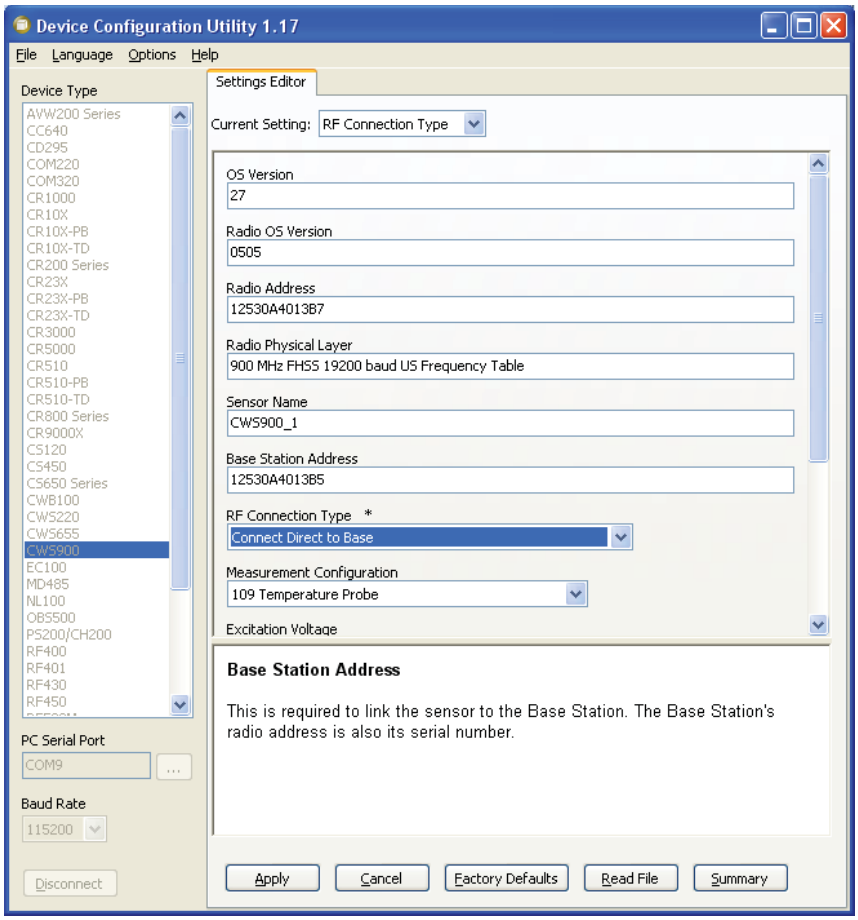
Sensor and Connection	5 Min Polling	10 Min Polling	15 Min Polling
CWS900 w/109 Probe or CWS655	15 months	21 months	24 months
Same as above, used as a repeater for 1 sensor	8 months	12 months	15 months
Same as above, used as a repeater for 2 sensors	6 months	8 months	12 months

C.3 RF Connection Type Setting

In the Device Configuration Utility Settings editor, there is a setting called RF Connection Type. This setting is used to control how the radio does its auto-discovery of a path to the base station. The default setting is **Auto Connect**, which is what should be used for most networks. With this setting, a sensor first tries to find a direct path (one hop) to the base; it does this three times over 15 minutes. It then tries to find a path to the base using a repeater. It also does this three times.

It can be useful to change this setting from its default in certain instances. For example, if the wireless sensor network is composed of a large number of sensors that are all within range of the base, changing it to **Connect Direct to Base** will force all the connections to the base. There will be no attempt to use repeaters. As long as every sensor is within range of the base, this saves battery power.

To access the RF Connection Type Setting, connect to the CWS sensor as described in Appendix A, *Using DevConfig for CWS Setup*, and select the Settings Editor tab. Find the drop-down menu for RF Connection Type and choose the option desired.



In another situation, there may be a sensor in a location that permits a direct connection to the base, but misses a significant number of data polls. Changing the sensor's RF Connection Type setting to **Connect Through Repeater** will force it to go through a repeater, and it will not attempt any direct connection to the base, which may result in fewer missed polls.

When changing the setting to Connect Through Repeater, battery life of the repeater should be taken into consideration (see Appendix C.2, *Effect of Polling Interval and Repeaters on Battery Life*, above).

C.4 Repair of a Lost Connection

A CWS sensor radio will detect if it has lost the connection to the base, and initiate a new path discovery automatically. The radio sends out a "beacon" every 90 minutes, and if two of these are missed in succession, the auto-discovery process will begin.

If a CWS sensor has not received any data polls from the datalogger for more than 13 hours, it will initiate the auto-discovery process

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