Making a water-secure world – the three I’s

**INFRASTRUCTURE**
to store, transport &
... treat water

**INSTITUTIONS**
Stronger & more-
adaptable

**INFORMATION**
Better & more-accessible

Ecosystem services

**Water security**: the reliable availability of an acceptable quantity & quality of water for health, livelihoods & production, coupled w/ an acceptable level of water-related risks
Myth:
We can, with a high degree of skill, estimate or predict the magnitude of these quantities.

Reservoirs:
- Snowpack storage
- Soil-water storage
Basin-wide deployment of hydrologic sensor groups—American R. basin

Strategically place low-cost sensors to get spatial estimates of snowcover, soil moisture & other water-balance components.

Network & integrate these sensors into a single spatial instrument for water-balance measurements.
Goals of American River Hydrologic Observatory

Provide information of unprecedented accuracy & scope for forecasting & decision support

Enhance hydropower operations
Reduce uncertainty in water-supply forecasts
Enable more-flexible operation of Folsom Dam
Demonstrate basin-scale, real-time intelligent water-resources information system
Provide first core element of broader information system for California

Document & forecast impacts of forest management on water
Duncan Peak sensor nodes
Components of American River basin water-information system

Satellite, aircraft & other spatial data

Ground-based sensor data

Analysis & QA/QC

Data integration & information management

Decision support tools

Modeling toolbox

Demand data

Planning
Scheduling
Informing

user interface

user interface

Analysis & QA/QC
Project collaborations
American River Hydrologic Observatory

- Integrate with satellite imaging to map out entire basin

American River Basin Hydrological Observatory
- 4,500 km²
- 15 networks
- 10 Wireless Sensor nodes per network
- Sensor node - snow depth, temperature, humidity, solar radiation, soil moisture
- 1000’s sensors

Real time data acquired by wireless sensor networks provides better predictive capabilities for reservoir mass-balance and system dynamics
Technology and Status

- A 15-site Wireless Sensor Network is operational in the American River basin
- We are actively collecting real-time data

Outline:

1. ARHO network status
2. System design & hardware
Wireless Sensor Networks - network architecture

- Design composed of multiple WSNs
- Each network covers 1-2 km² physiographic zone
- Each WSN connects to off-site servers
- Hierarchically, the network is composed of:
  ① Sensor Nodes
  ② Repeater Nodes
  ③ Network Managers (embedded Linux computer)
  ④ External connection to the Internet
  ⑤ Central off-site data servers
Example network mesh
Super Katie after an 8 km hike carrying 20 kg of equipment!
Sensor node design

External 4 dBi antenna

Solar energy sensor

Snow depth sensor

Solar radiation shield for: temp/rH Sensor

Solar Panel

NEMA Electrical Enclosure with Metronome Systems NeoMote, Li battery, Metronome Systems charge controller

(Buried below ground are 4 soil moisture, temperature, and matric potential sensors)

The wireless data logger housing is built from robust industrial materials to withstand the harsh winters experienced in the Sierra Nevada.
Our WSNs are relatively low cost to acquire, install, and maintain

• No need to dig trench for conduits and wires, less human cost and environmental impact

• Network elements are modular, down elements can be replaced in toto, allowing quick repairs
Sensor and relay nodes, Duncan Peak

SITE NAME: DUNCAN PEAK
MEAN ELEVATION: 2095 m
SENSOR NODES: 10
SIGNAL REPEATERS: 19
SITE COVERAGE: 1 SQ. km
MODEM TYPE: CELL
IP: ***.***.**.144
INSTRUMENTED: OCT 2013
SENSOR INSTALLED:
SNOW DEPTH
TEMP/RH

Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

NET ELEM.
PATH RSSI(dB)
SENSE NODE
SIGN. REPEATER
BASE STATION
> -70
-71 -- -80
< -81
WSN system for environmental monitoring should be Smart and Reliable

- One system to integrate sensor interfacing, data logging, data transmission and networking

### The embedded platform

- 2-chip solution
- *Ultra-low power* – 30 μA
- *Up to 40 sensors*
- Any analog/digital
- 3.3V To 12V excitation sourced on single board

- **Variable power supply** (3-12V)
- **Real time clock**
- **RTC backup battery**
- **Dust M600x**
- **PSoC-5**
- **Reference Voltage (.05%)**
- **LEDs**
- **JTAG/USB Comm.**
- **SD Card**
- **USB**
- **Pinout bank** (64 GPIOs)
System Design

- Ultra-low power consumption
  - 30 μA average (60 μA with high-precision analog enabled)
- Ultra-low noise (0.5%) 1.25V voltage reference
- Real-time clock with backup battery source
- Variable power input (3V-25V)
- Multiple power regulator output for a suite of applications
  - 3.3-5V low-power switching supply (750mA)
  - 3.3-5V low-noise linear supply (500mA)
- Real-time operating system (RTOS) support
- Full-speed USB interface and mini-USB port
- Over The Air (OTA) updating
- SD-card interface for local storage
- Easy to use API to enable rapid prototyping

Programmable System on Chip

- Cypress PSoC®5: CY8C55 family
- 256 KB flash memory, 64KB SRAM
- CAN 2.0b compliant
- Programming through JTAG debug interface
- Programmable counter, timer, PWM, comparator blocks
  - 46 to 70 digital I/Os (60 GPIOs, 8 SIOs, 2 USBIOs)
- 67 MHz, 24-bit fixed point digital filter block (DFB) to implement finite impulse response (FIR) and infinite impulse response (IIR) filters
- Configurable delta-sigma ADC with 8- to 20-bit resolution (18.5 ENOB when analog regulator enabled)
- Two SAR ADCs, each 12-bit at 700 ksp
- Four configurable multifunction analog blocks. Example configurations are programmable gain amplifier (PGA) analog filtering, trans-impedance amplifier (TIA)
- Four 8-bit IDACs or VDACs
- Four uncommitted opamps with 25-mA drive capability

Wireless Sensor Networks

- Dust Networks’ Eterna™ SoC WSN technology
- 2.4 GHz network operations
- Automatic network formation
- Full-mesh networking that can easily scale to tens of thousands of nodes per square kilometer
- Time-synchronized communication across 15 frequency channels eliminates in-network collisions and multipath fading effects

Greater than 99.99% network reliability even in the most challenging environments

- Fully engineered RF transceiver, with power amplifier (at +8dBm)
- Unprecedented low power consumption with an RX current of less than 5 mA and a TX current of less than 10 mA at +8dBm (< 6 mA at 0 dBm)
- AES-128 bit encryption
- Compliant with IETF 6LoWPAN and IEEE 802.15.4e
- IPv6 Internet of Things compliant, enabling each node with a unique Internet-ready IP address
We Make Campbell Wireless!!

Seamless 2-way integration!

Metronome Systems NeoMote
Network Manager, which commands the network and interfaces with the data server

Linux OS, robust and secured

- Ultra low power 396MHz ARM9 CPU
- **Ultra-low power consumption (< 50 mA @ 5 V)**
- Support for connection of 100 NeoMotes (large mesh networks)
- 128MB DDR-RAM
- 256MB SLC XNAND Drive
- 1 MicroSD Card Slot
- 3 UARTs, 1 SPI, 1 I2C, 1 I2S, 4 ADC
- 2 USB Hosts, 10/100 Ethernet Port, Com port
- Watchdog Timer, Real Time Clock and Temp. Sensor
- Power input 5 - 36 V
- 5V and 12 V output for peripherals
- Fanless Operation from -40°C to +85°C
Challenge -- difficult terrain:

- > 30 deg. Slopes between elements
- 4 dB antenna gives better performance than 9 dB!
- vegetation and natural barriers (line of site not possible)
Look at that data!

http://glaser.berkeley.edu/wsn/
Determining representative network locations: feature space extraction

**Raw data**

LIDAR Flights
- 1 meter DEM
- 1 meter canopy product

If LIDAR unavailable:
- Google Earth Data
- 30m DEM SRTM
- Estimate Canopy with Aerial Photographs

**Calculate feature space from DEM**

- **Slope**
  \[ \text{Slope} = \text{arctan} \left( \frac{\sqrt{\text{Grad}_x^2 + \text{Grad}_y^2}}{\text{Grad}_z} \right) \]

- **Aspect**
  \[ \text{Aspect} = \text{arctan} \left( \frac{\text{Grad}_x}{\text{Grad}_y} \right) \]

- **Curvature**
  \[ \text{Curvature}_{\text{plan}} = \frac{2(DH^2 + EG^2 - FGH)}{G^2 + H^2} \]
  \[ \text{Curvature}_{\text{profile}} = \frac{-2(DH^2 + EG^2 + FGH)}{G^2 + H^2} \]

- **Concavity**
  \[ D = \frac{(Z_4 + Z_6)/2 - Z_5)^2}{C^2} \]
  \[ E = \frac{(Z_2 + Z_7)/2 - Z_6)^2}{C^2} \]
  \[ F = \frac{(Z_3 - Z_4 + Z_6 - Z_5)^2}{4C^2} \]
  \[ G = \frac{(Z_5 - Z_3)^2}{2C} \]
  \[ H = \frac{(Z_2 - Z_7)^2}{2C} \]

**Estimate Canopy Coverage (Support Vector Machine)**

**5 x 1 million feature space**

- **Slope**
- **Aspect**
- **Vegetation**
- **Concavity**
- **Elevation**
Maintenance and durability

At this point issues revolve around mechanical pieces

• hopper batteries every 2 years
• satellite modem has some issues maintaining connectivity
• tree falls
• lightning
• bears
• tighten bolts, etc.

Electronics and software

• stable
• long lived
• easily upgradable
Energy balance modeling scheme

Keep it simple – but not too simple!
ARHO 2014 data

- a. air temperature
- b. R.H.
- c. snow depth

Node 1: 6, 7, 8, 9, 10
202, 204, 206, 208, 210, 212, 214, 216
ARHO 2014 data – snow depth
Satellite & aircraft remote sensing offer opportunities for monitoring water resources over large areas.

While some satellite and aircraft products are now routinely available, they require further processing before they can be used for watershed-scale hydrologic applications.
Automated tools are required to acquire, correct and integrate satellite and LIDAR imaging data to better determine snow presence and distribution, snowpack water content, and more accurately predict runoff.
Information needs for hydrologic forecasting

Distributed snow sensors → Snowpack storage map → QA/QC & interpolation

Satellite snowcover → Weather forecast → Snowmelt model → Daily snowmelt map

Met stations → Distributed soil, RH, T sensors → Basin water-balance model → Reservoir inflow forecasts

Weather & climate outlooks → Other water-balance products

Forest management, drought planning
Seasonal runoff forecasts are based on historical observations & have some skill in a stationary climate. Precipitation forecasts use a few point measurements as indices of snow accumulation. Ground data and empirical & regression methods are used to make volume forecasts. Decision making is based on these forecasts.
Percent bias of April 1 forecast of annual streamflow

Wet years tend to be under-forecast, dry years over-forecast

Weekly to daily forecasts based on historical data are even more biased

Bias = \frac{\text{Forecast} - \text{Observed}}{\text{Observed}}
Some additional points re forecasting

1. We cannot model our way out of this uncertainty
2. Improvements in forecast skill require new observations
3. The technology to support new observations is available
4. This technology has matured over the past 5-10 years
Technology is sufficiently mature to invest in systems for operational use – harden WSN, blend w/ satellite data.

Forecasting water supply using spatial data & appropriate modeling could reduce uncertainty due to land-surface fluxes & stores by ~50%.

Even a few % improvement in high-elevation hydropower would provide significant gains.

American River basin is both research platform & core element of new water-information system.

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