EXPERIENCE WITH ONLINE WATER QUALITY MONITORING IN A DISTRIBUTION SYSTEM

Michigan Water Utility Security Summit

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Project Goals

- Develop an on-line water quality program for the distribution system to:
  - Provide for security enhancements to the system to maximize public health protection from contamination events.
  - Monitor natural water quality changes in the distribution system.

Review of Phase 1

- Reviewed relevant data, literature, experiences at other utilities
- Conducted site visits
- Evaluated monitoring locations using USEPA TEVA SPOT and EPANET programs
- Selected monitoring parameters
- Pilot tested multiple manufacturers of selected parameters
- Performed preliminary response planning

Phase 2 Tasks

- Perform long term (6 month) test of two monitoring stations
- Evaluate CANARY EDS (Event Detection System)
- Complete a response plan for contamination incidents
- Develop recommendations for future deployment

Monitoring Panel

Parameter	Phase 1 Recommendations	Phase 2 Deployment
UVAS (UV254)	Hach	Hach
pH	Not evaluated	Hach
ORP	Not tested	Hach
DO	In Situ or YSI	Hach
Conductivity	In Situ	Hach
Total Chlorine	Siemens (US Filter)	ProMinent

- pH was not originally evaluated as the water is well buffered
- ORP was not originally identified as parameter of interest
- Hach was selected to provide single manufacturer for the monitoring panel

Installed Monitoring Panel

Sensors

Local Display and Control Panel

Monitoring Locations

- WTP
- Liberty Pump Station (LPS)

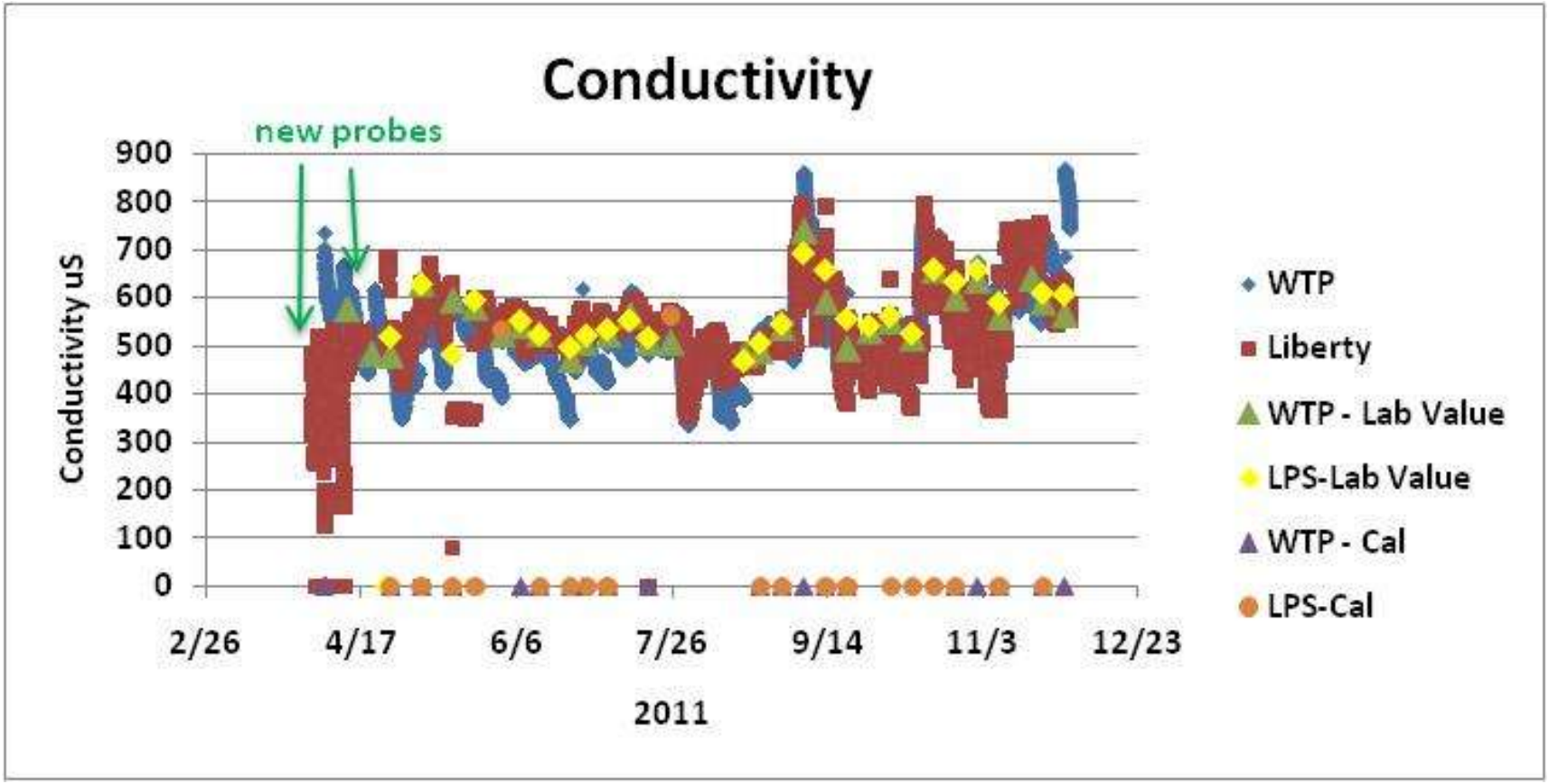
Calibration Approach

1. Primary calibration:
   - Performed using one or two standards
   - Difficult and requires significant time when temperatures are low or high
2. Bench comparison:
   - Collect sample, analyze immediately, adjust sensors
   - Can require extra trip to Liberty
   - Needed to acquire portable analyzers
3. Level of effort for bench comp:
   1. 2 Hr/wk + travel time per panel

Calibration Criteria

Parameter	Acceptable Difference between grab sample and on-line data	Frequency of site visit and grab sample collection
pH	0.1	Monthly
ORP	40 mV	Every 2 weeks
Conductivity	40 uS	Every 2 weeks
DO	0.5 mg/L	Every 2 weeks
Chlorine	0.3 mg/L	Every 2 weeks
Temperature	0.1 ^{o}C	Monthly
Flow	500 to 900 mls/min acceptable range	Monthly

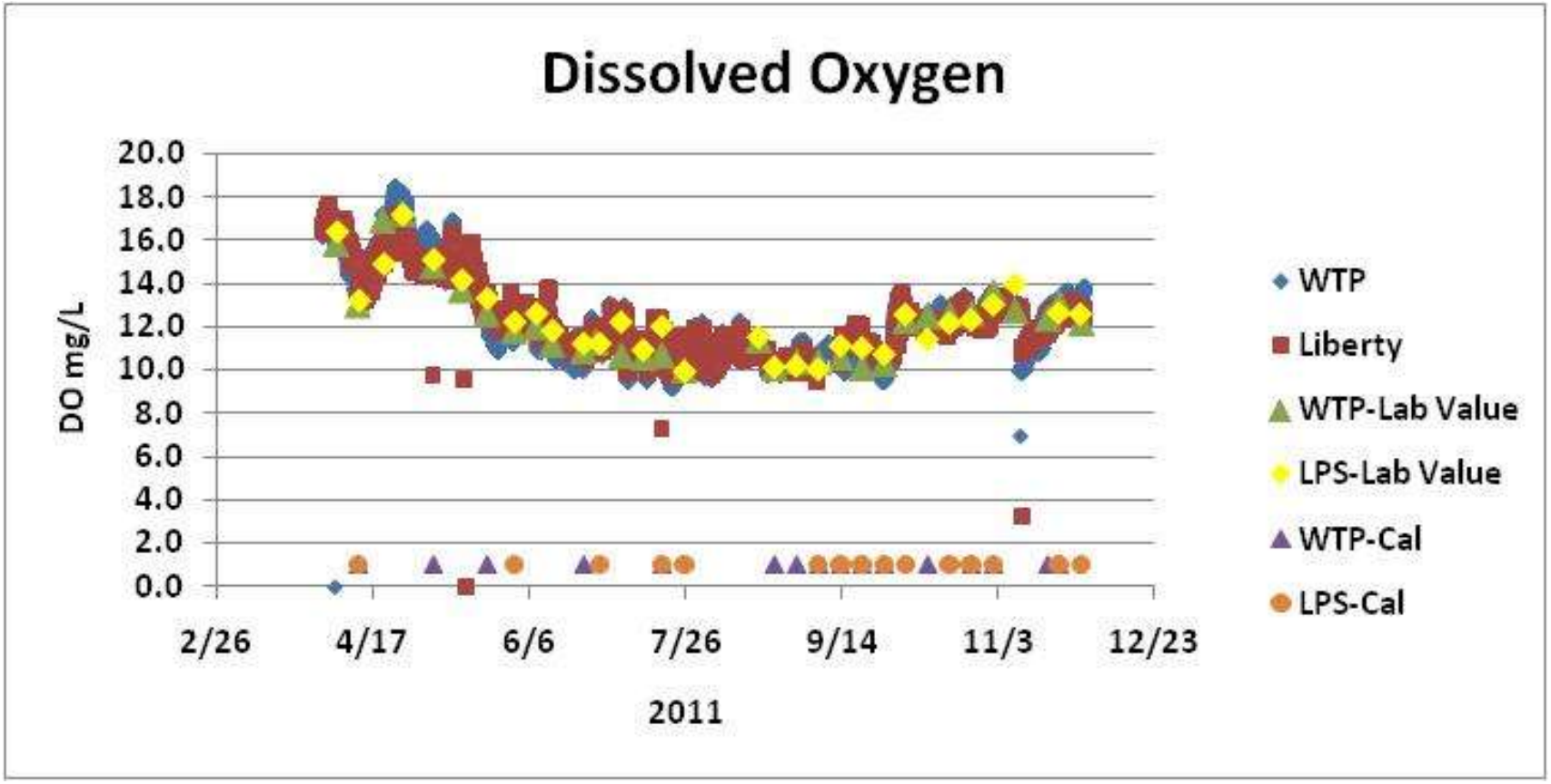
Data Results - Conductivity



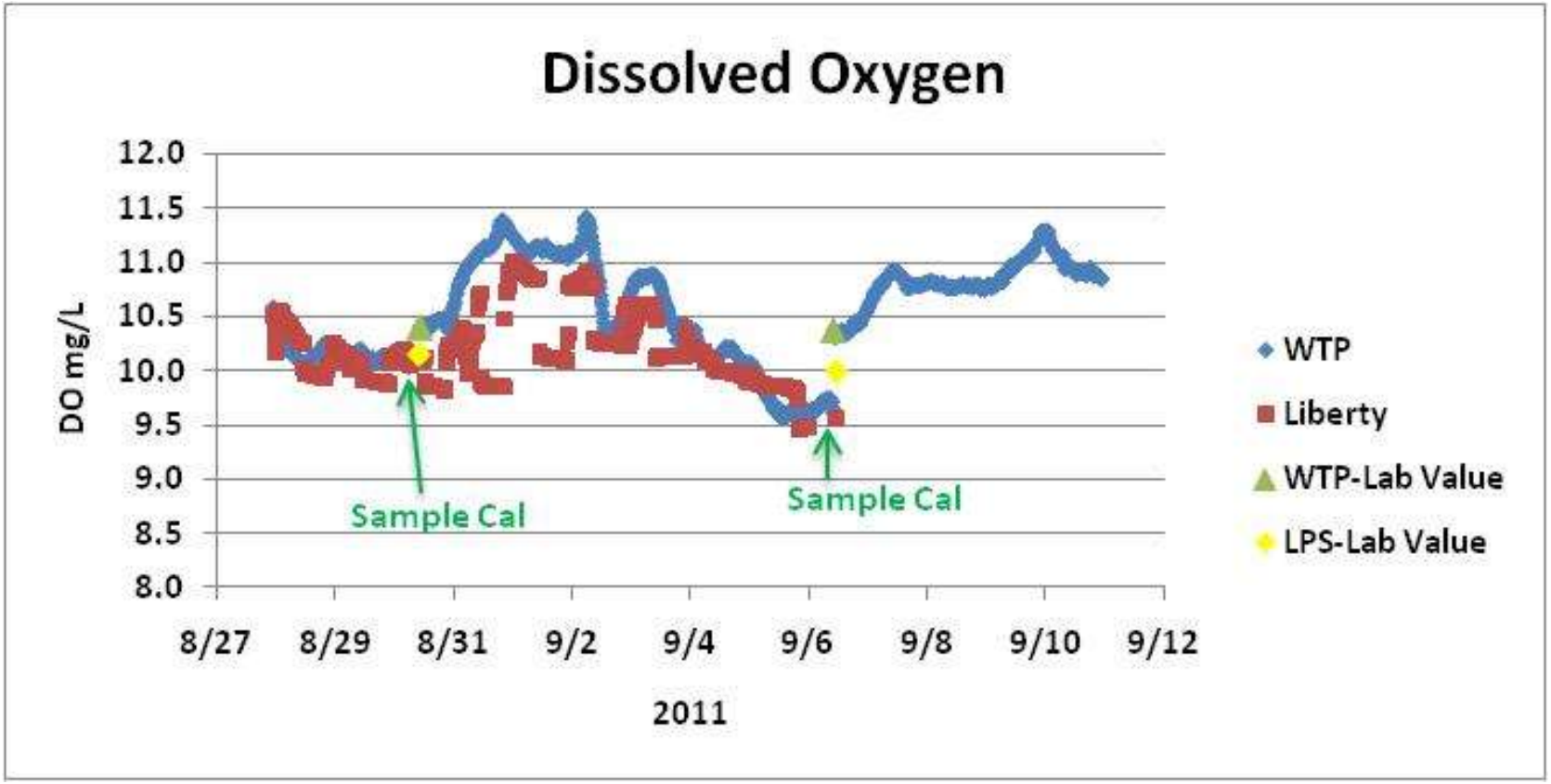
Observations – Conductivity

- Conductivity higher and more variable in the fall
- Variability does not relate to rainfall
- Conductivity at WTP and remote sites correlated

Data Results- LDO



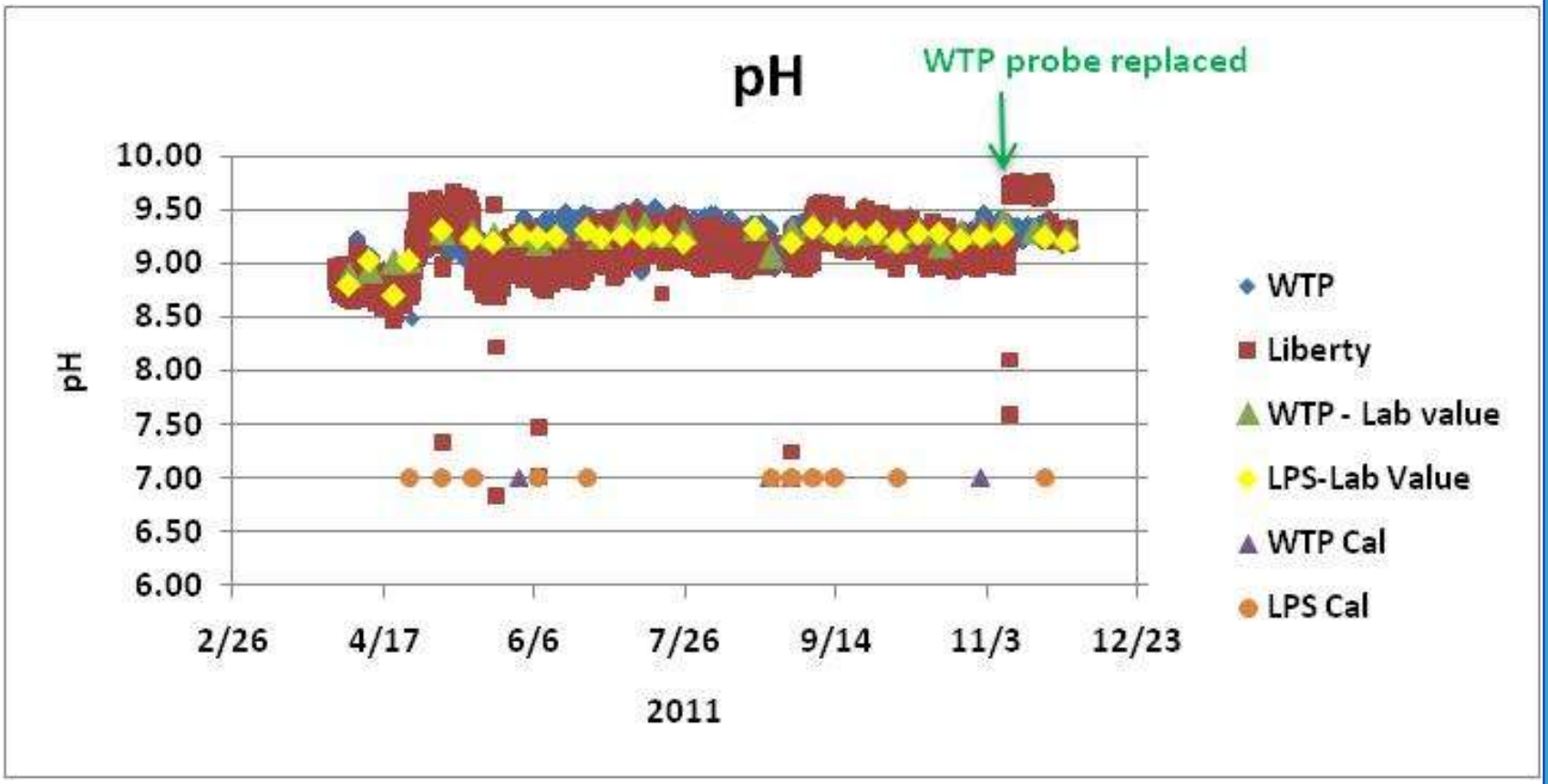
Data Results- LDO



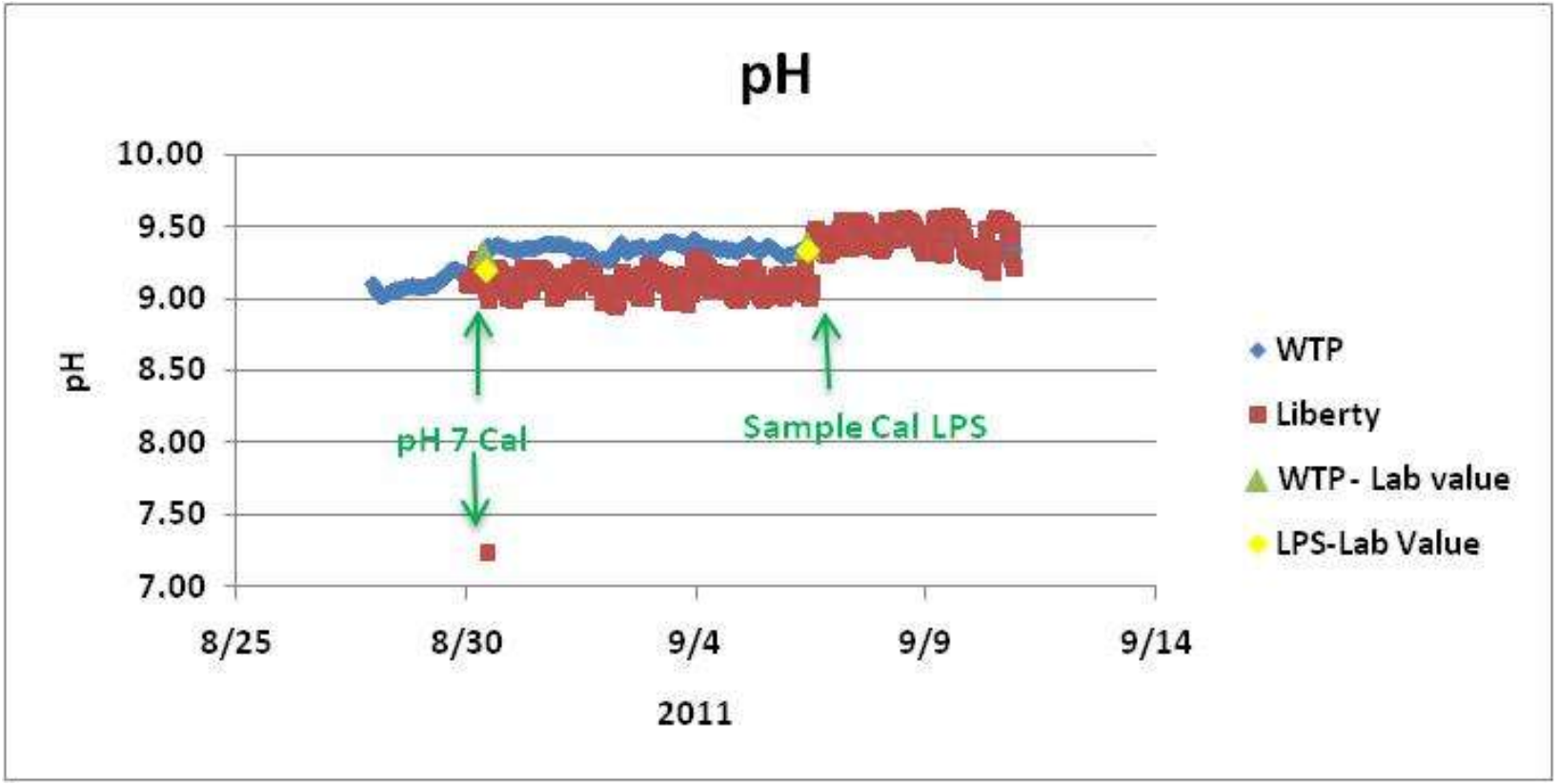
Observations - LDO

- DO lower in summer than winter – expected based on temperature impact on concentration
- DO is consistently supersaturated
- Liberty reflects combination of WTP and water age

Data Results - pH



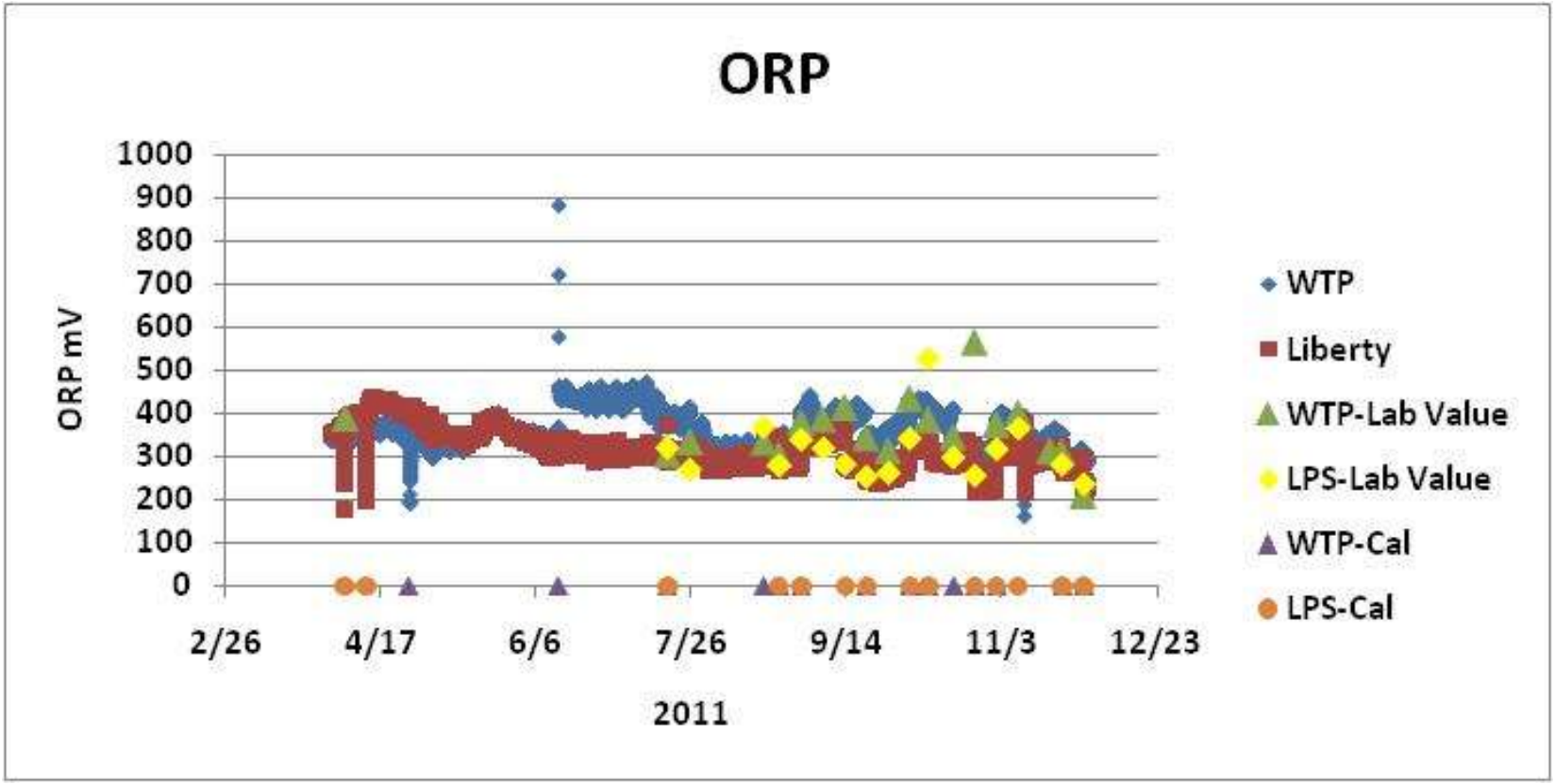
Data Results - pH



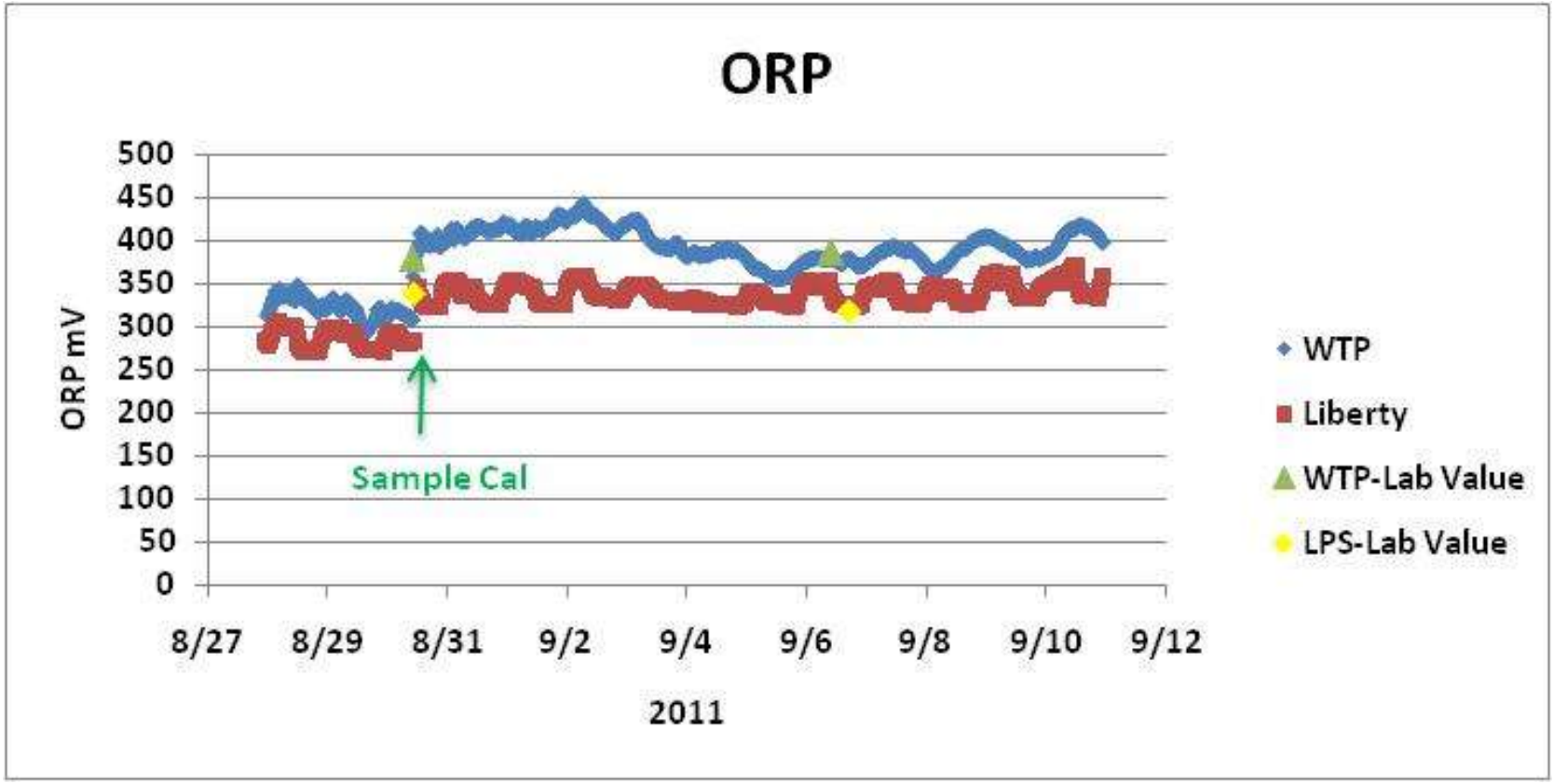
Observations - pH

- Consistent pH expected since controlled by WTP
- Do see decreases with water age in Liberty Reservoir
- Outliers often but not always related to primary calibration events.

Data Results - ORP



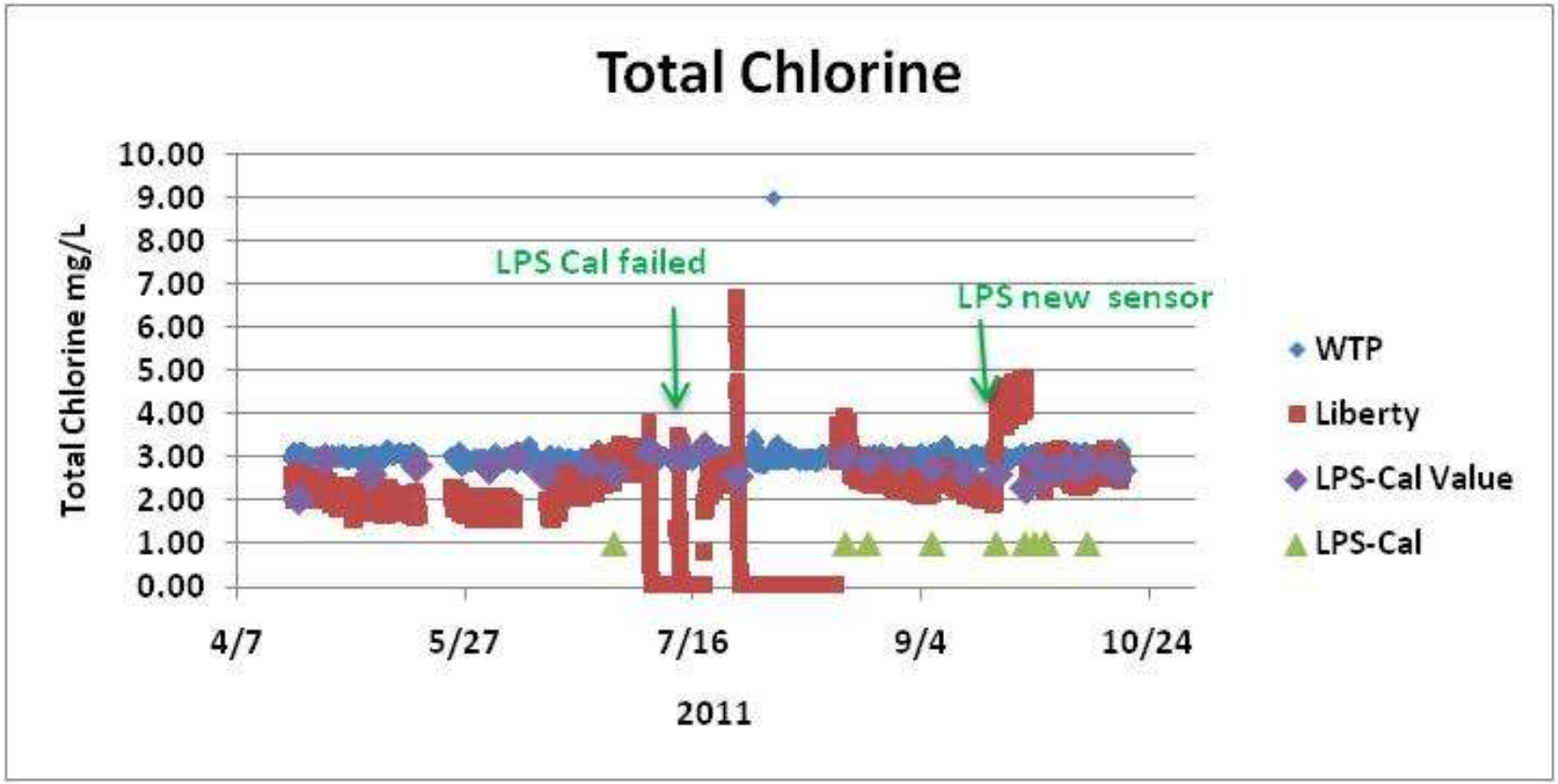
Data Results - ORP



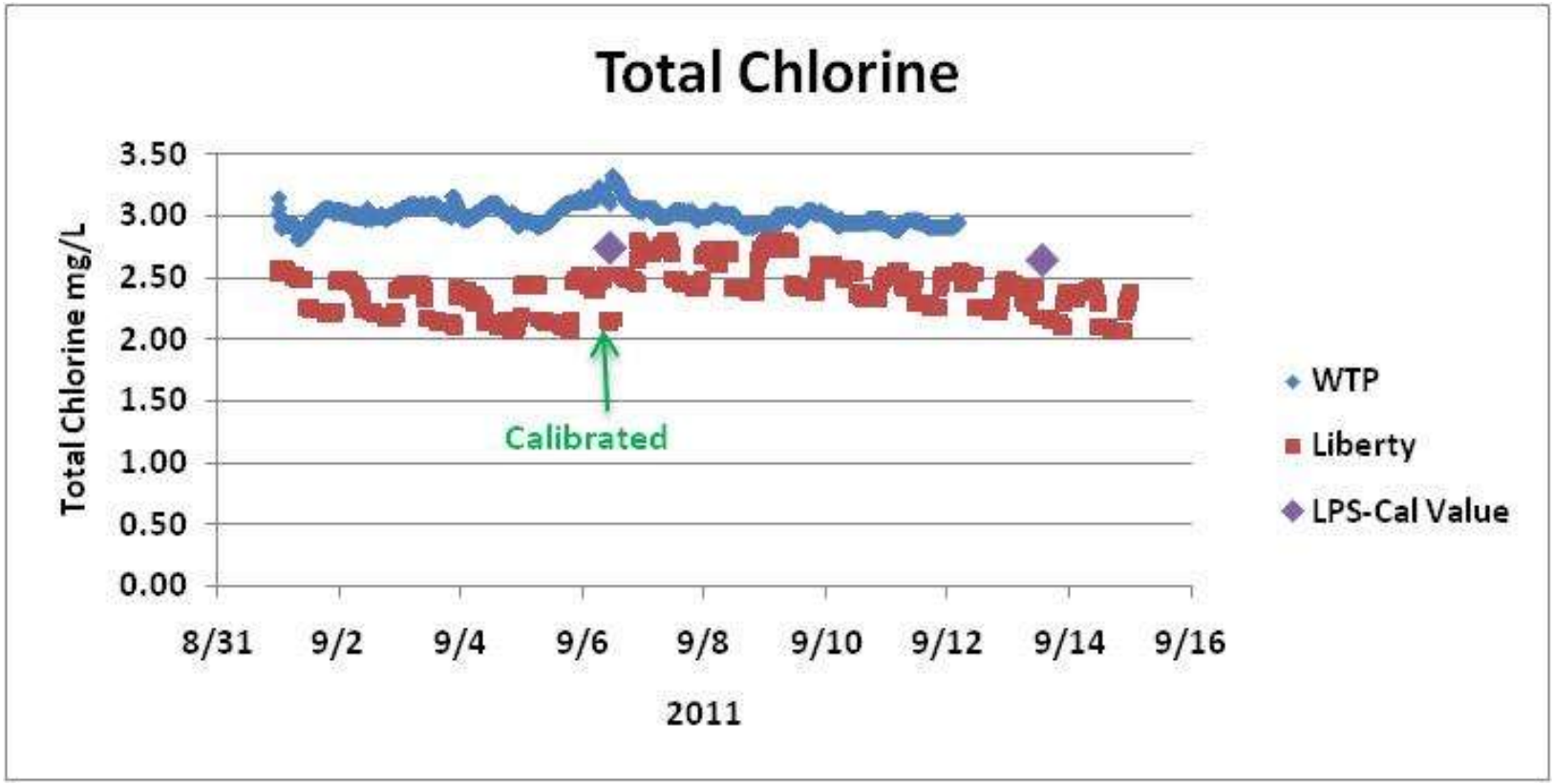
Observations - ORP

- Instrument stability a concern
- Experience at other utilities suggests that ORP is prone to drift and interference
- Water age impact at Liberty observed
- Liberty generally lower conductivity than WTP

Data Results – Total Chlorine



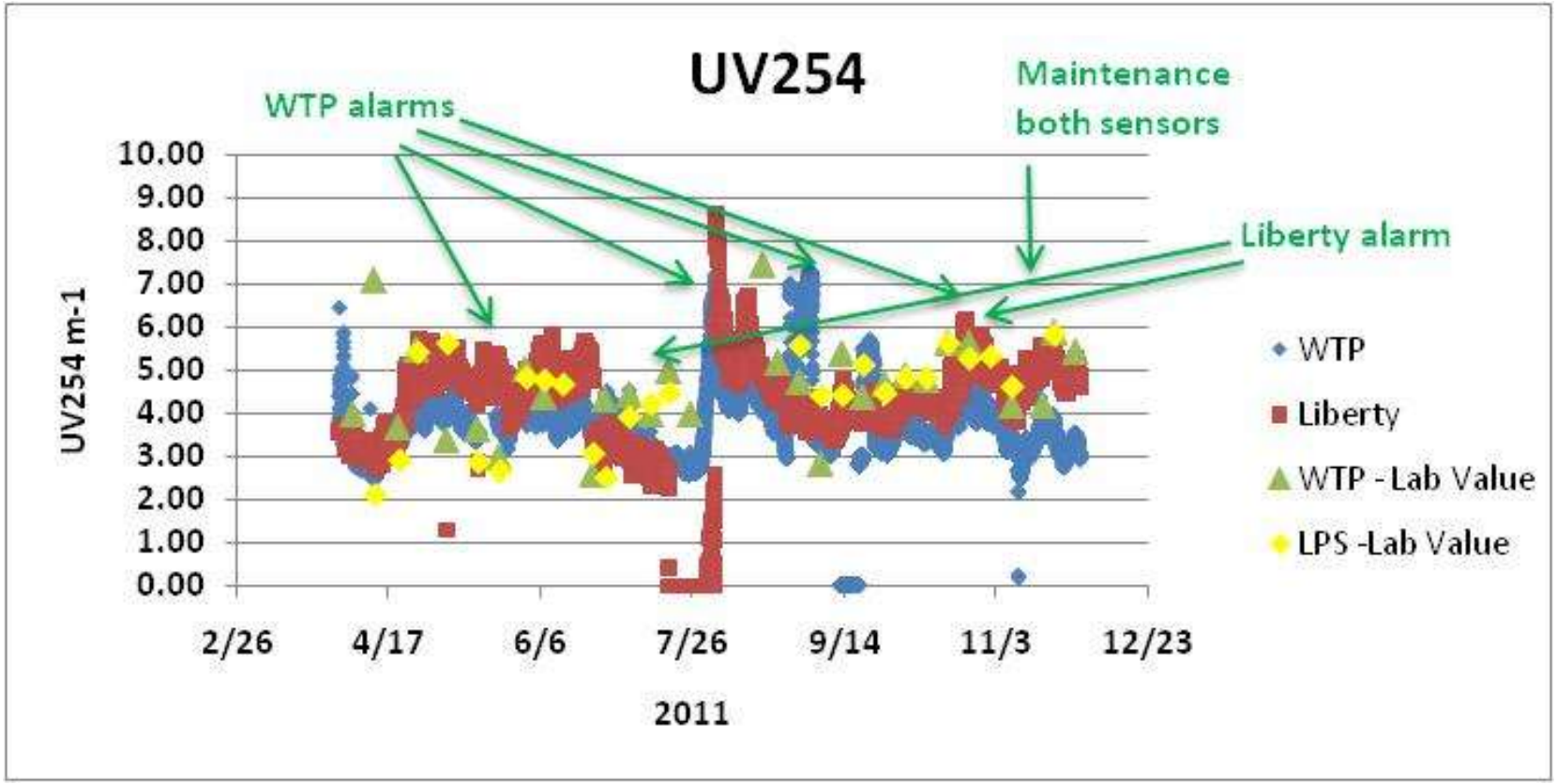
Data Results – Total Chlorine



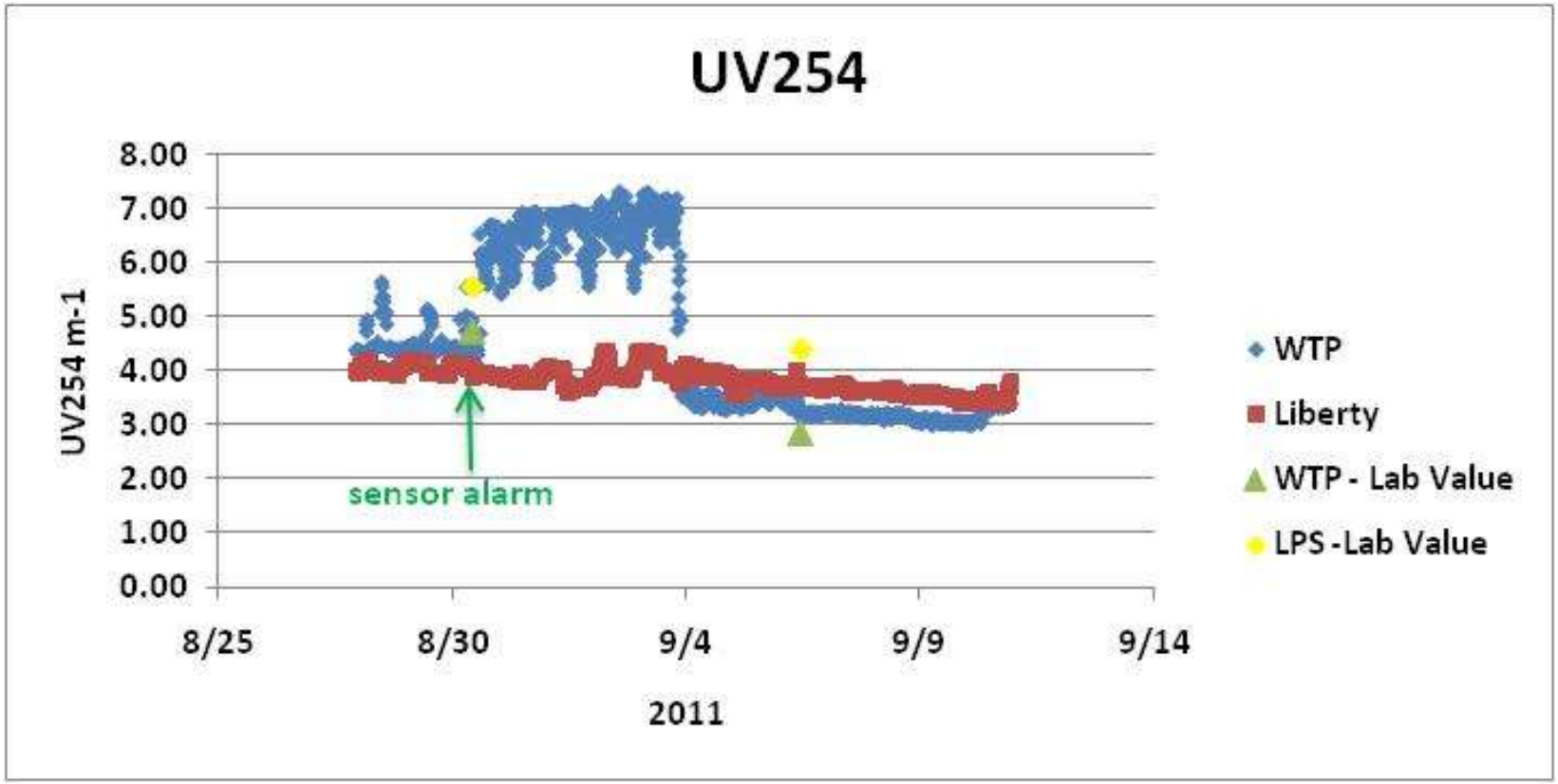
Observations – Total Chlorine

- WTP produces very consistent TRC
- Liberty total chlorine shifts with pumping & water age
- Liberty total chlorine 0.5 to 1.0 mg/L lower than WTP
- Issues with Liberty chlorine meter until fall of 2011

Data Results - UVAS



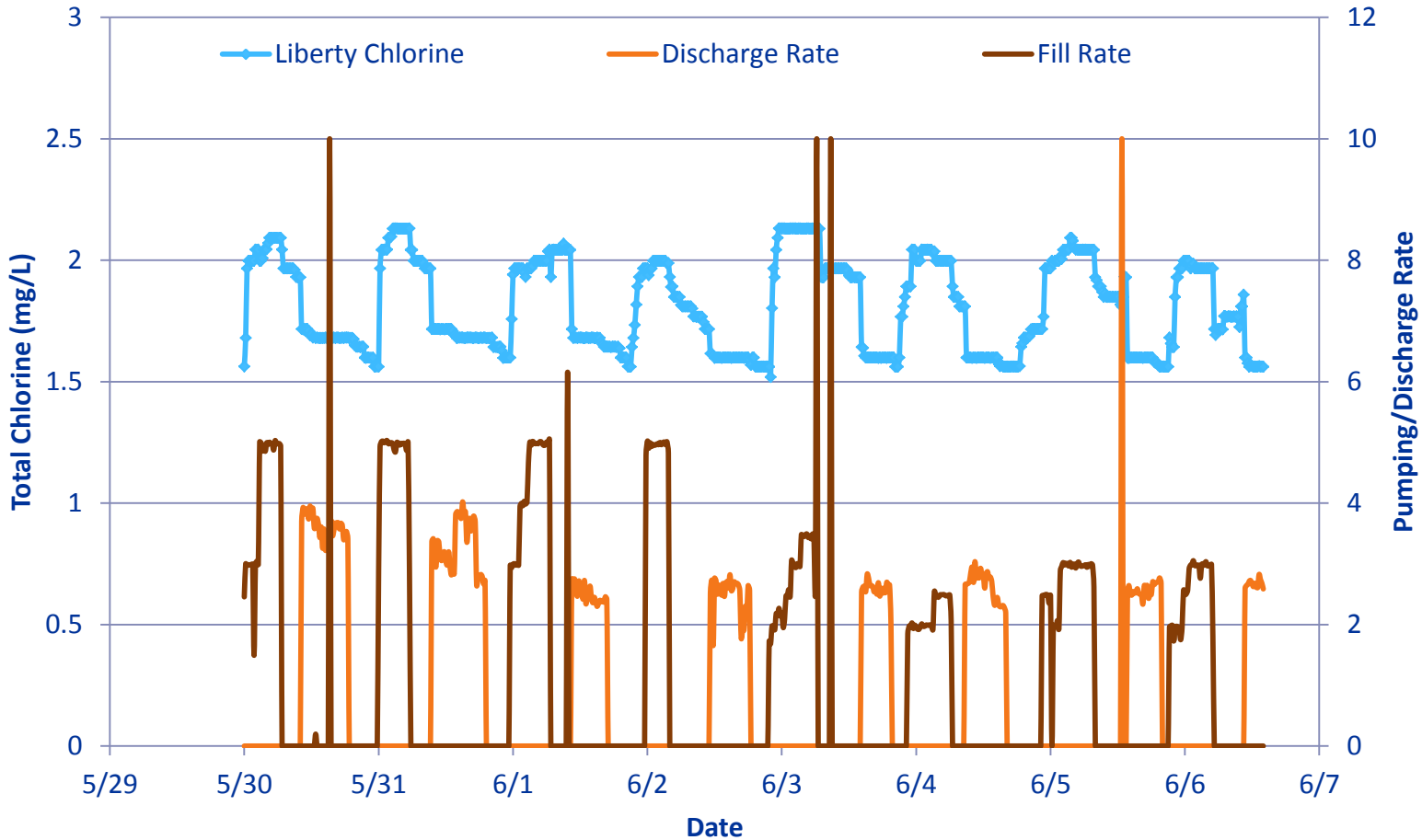
Data Results - UVAS



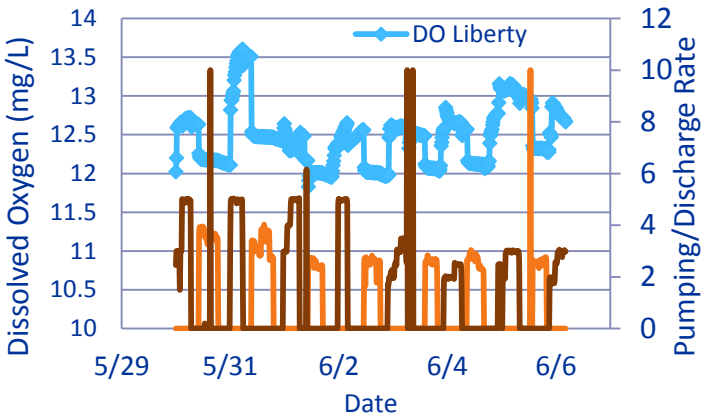
Observations - UVAS

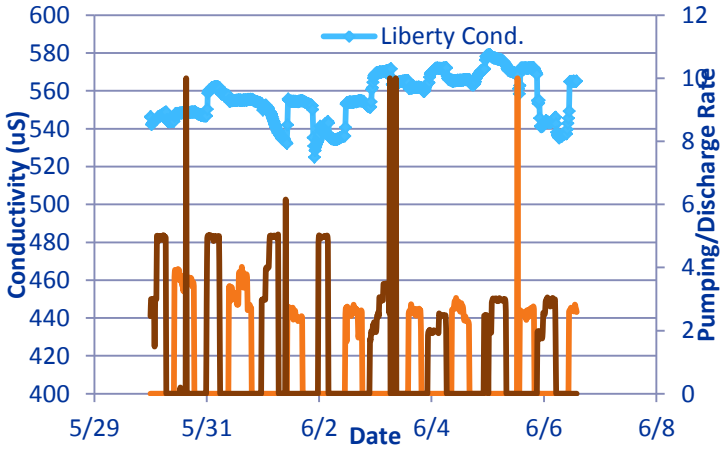
- High variability in data
- Good correlation between WTP and remote site instrument values
- Increased UVAS rates at remote site – cause unknown
- Instrument and lab results show poor correlation - instrument can only be factory calibrated

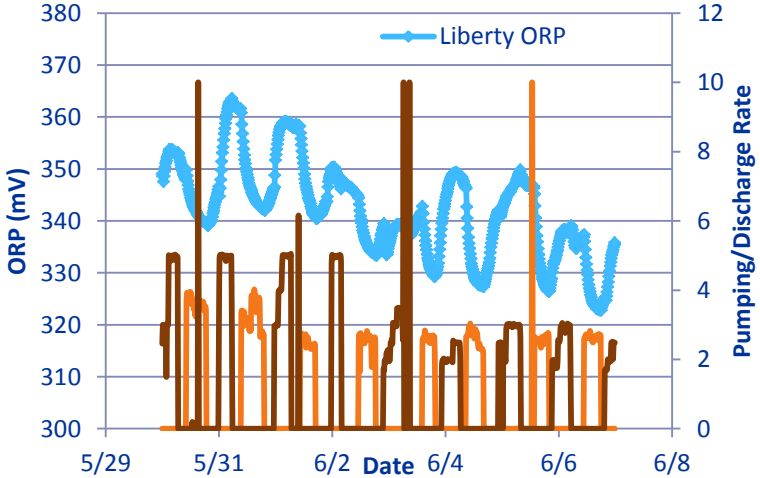
Liberty Operations

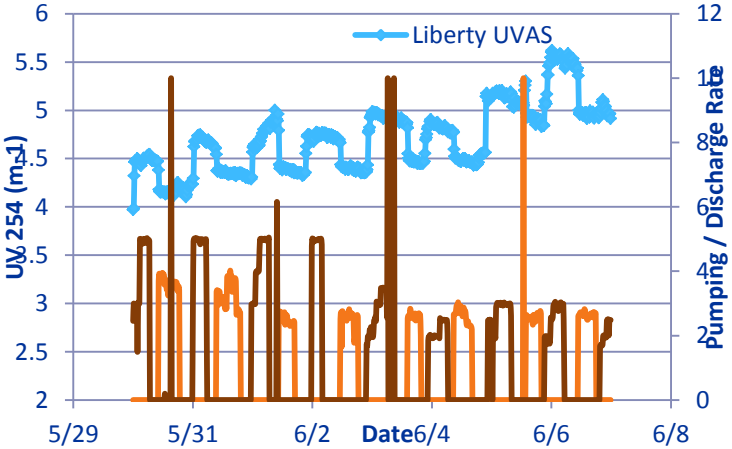


Liberty Operations









Observations – Liberty Operations

- Water Age in Liberty Reservoir demonstrates degradation of water quality
- Observed for multiple parameters
  - Total chlorine
  - Dissolved Oxygen
  - pH
  - ORP
  - UVAS
  - Conductivity?

Maintenance

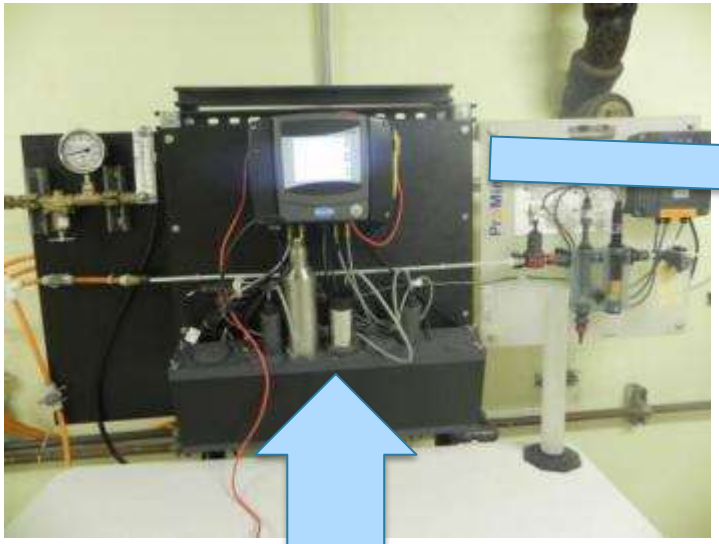
Sensor	Quarterly	Biyearly	Annual
pH	Clean sensor	Replace salt bridge and buffer solution	
ORP	Clean sensor	Replace salt bridge and buffer solution	
LDO	Inspect; clean as needed		Replace sensor cap
Conductivity	Inspect; clean as needed		
UVAS	Inspect; clean as needed		Replace wiper blade Replace O-ring
Temperature	Inspect; clean as needed		
Chlorine	Inspect; clean as needed	Replace electrolyte & sensor as needed	New probe (every two years)

Annual Time & Materials for Monitoring Panel

Activity	Annual Equipment Cost	Annual Labor Hours	Annual Labor Cost at $100/hour
Site visit/Calibration	$165	94	$9,600
Routine maintenance	$1,657	14	$1,400
Replacement Cost	$3,440	0	$0
Contingency (10%)	$526	11	$1,100
Total Planning Level Budget	*$5,800*	*119*	*$12,100*

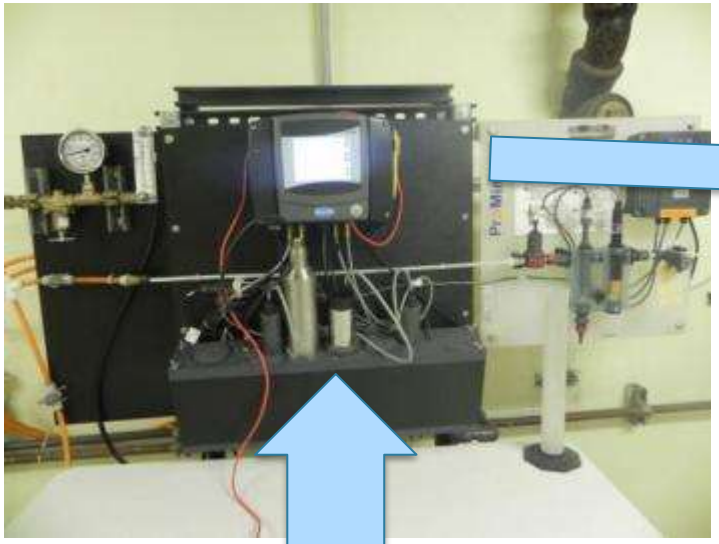
CANARY EVENT DETECTION SYSTEM

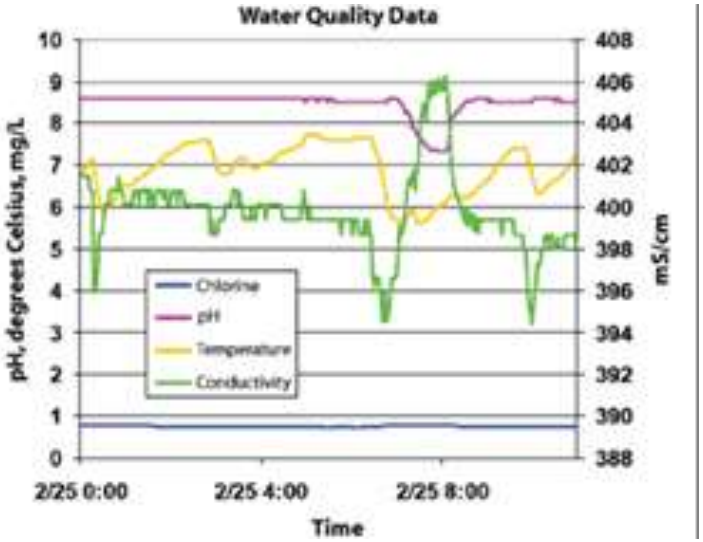
Event Detection System Analyzes Monitoring Data in Real Time



- Conductivity
- Oxidation Reduction Potential (ORP)
- UV $_{254}$ (TOC)
- Dissolved Oxygen (DO)
- Total Chlorine
- pH

Event Detection System Analyzes Monitoring Data in Real Time

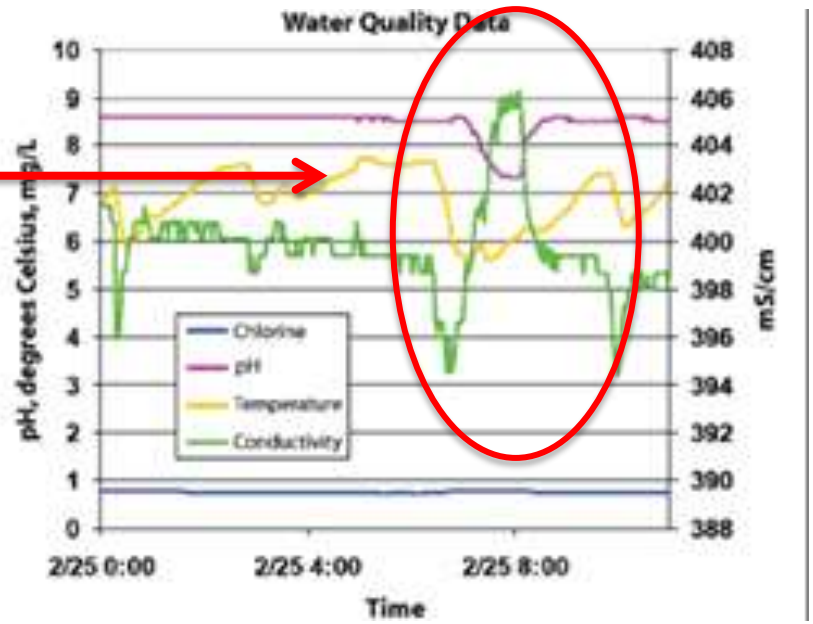




- Conductivity
- Oxidation Reduction Potential (ORP)
- UV $_{254}$ (TOC)
- Dissolved Oxygen (DO)
- Total Chlorine
- pH

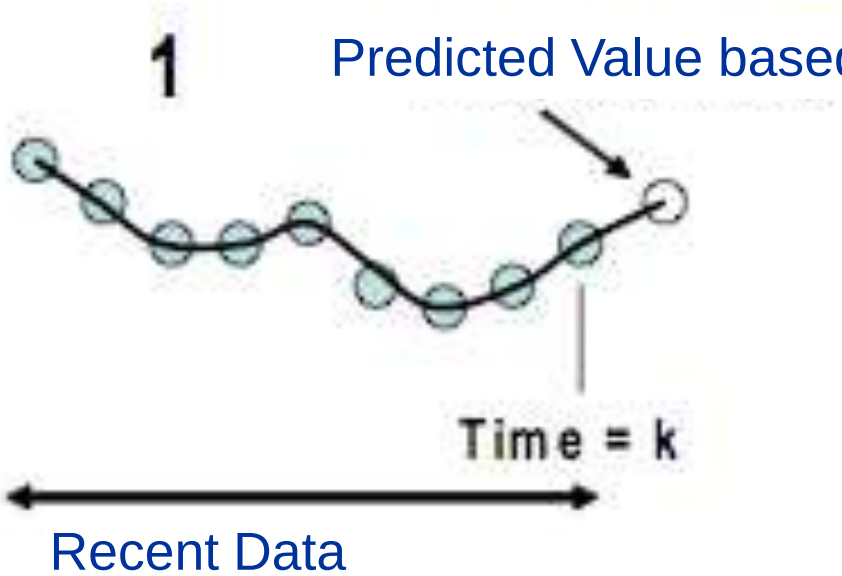
An **Event** Occurs When Water Quality Significantly Deviates from Observed Trends

- Recognize deviation from
  - The most recent data (data spikes)
  - Long-term trends



Process to Detect Events in Real-Time

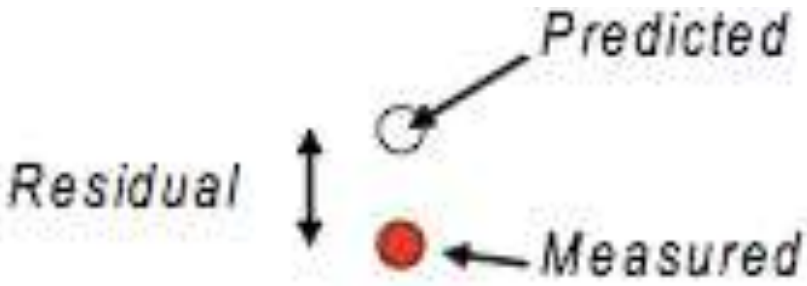
1) Predict what water quality should look like



Process to Detect Events in Real-Time

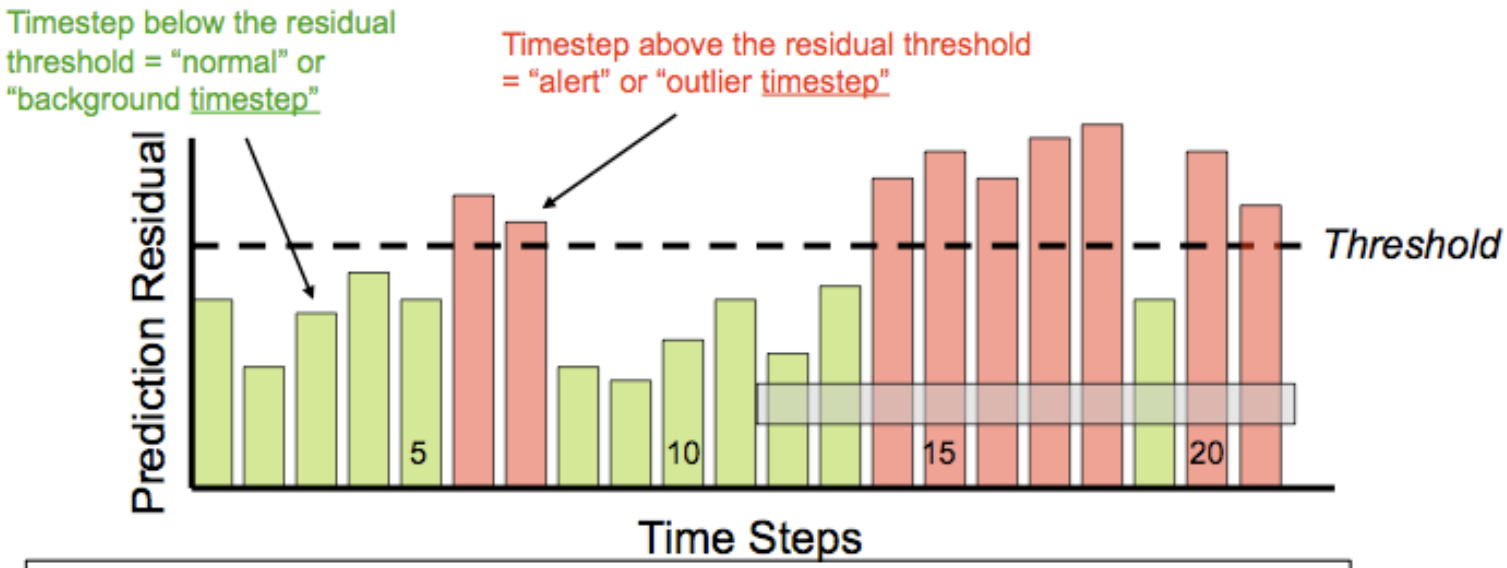
1) Predict what water quality should look like
2) Measure actual water quality
3) Determine the distance between predicted and actual water quality (= residual)

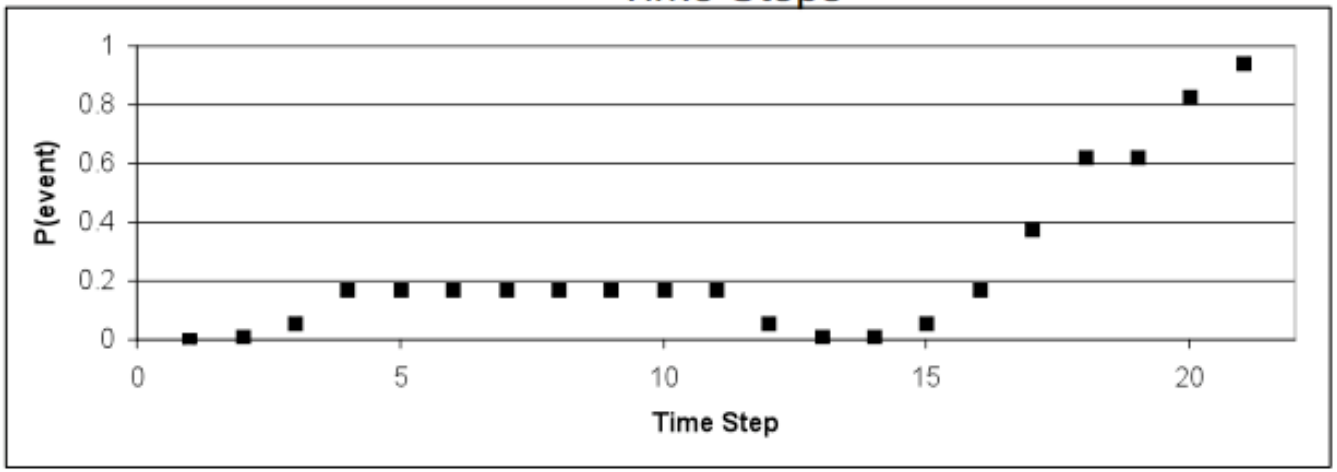
4) Compare residual to a threshold



> Threshold = Outlier

Binomial Event Discriminator used to Distinguish Contamination Events from Random Outliers





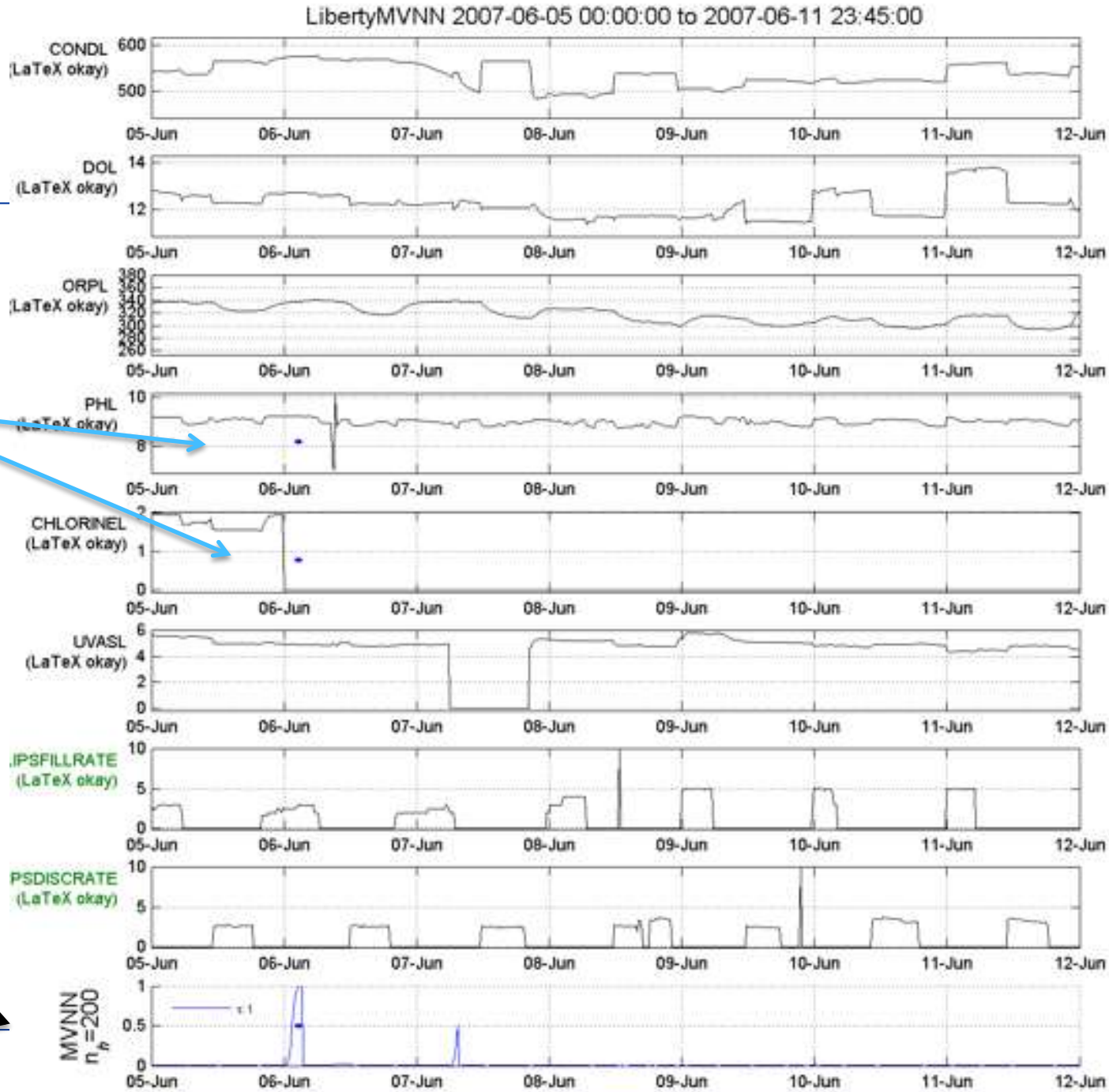
CANARY Algorithms

- LPCF – Linear Prediction Filter
- MVNN – Multivariate Next Neighbor
- SPP – Set Point Proximity

Example: CANARY output

Contributions to alarms

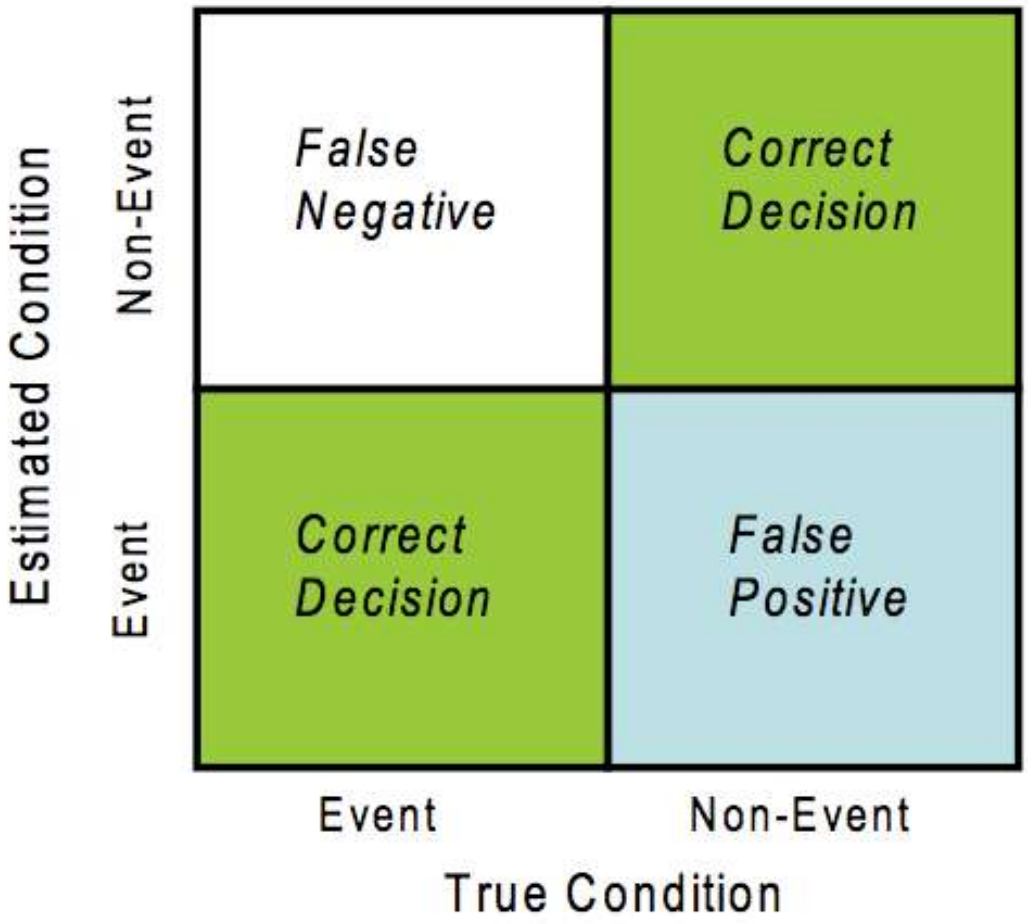
Probability of event



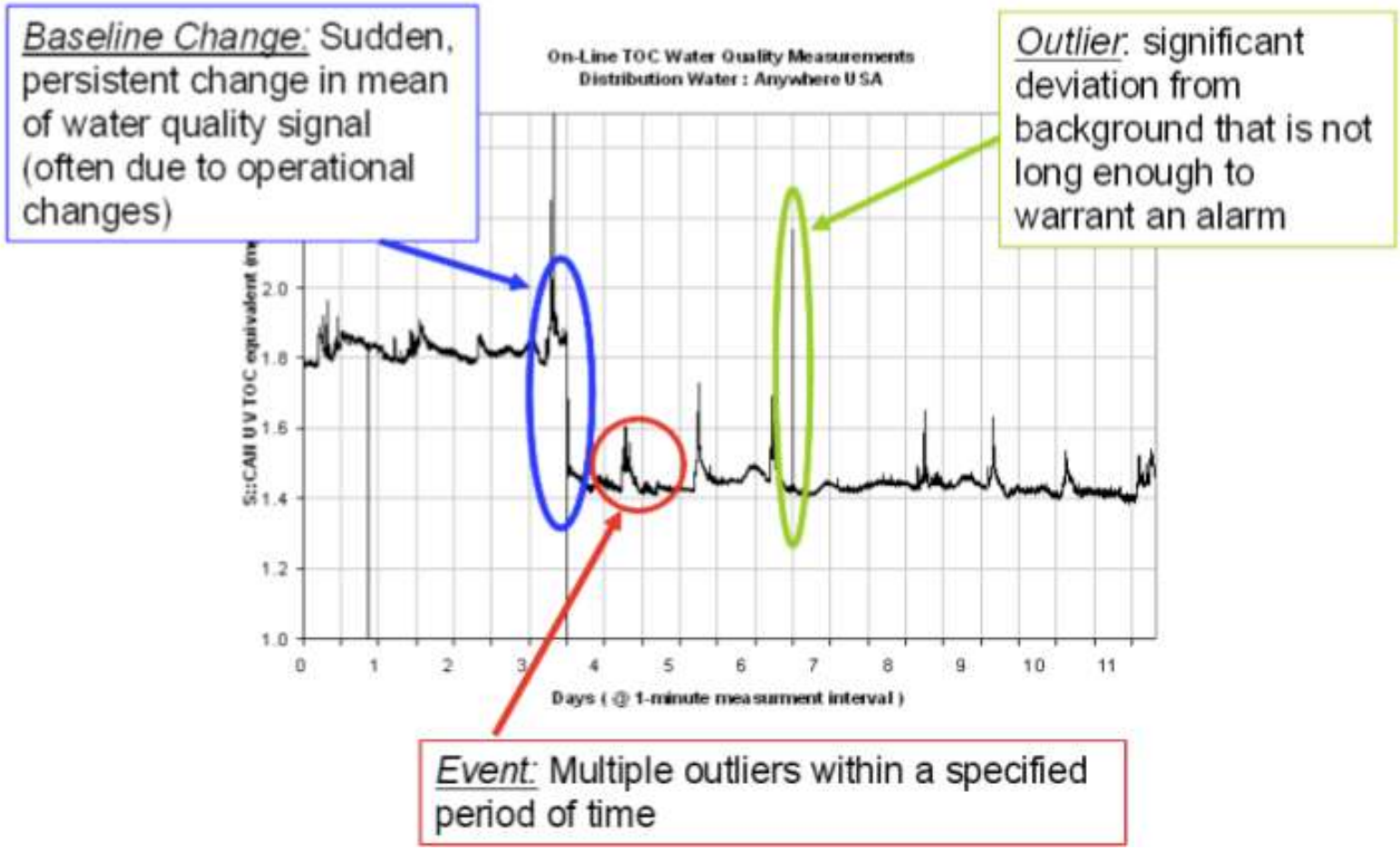
False Alarms

- Natural variation in water quality signals and sensor error makes false alarms common
- Take up time
- Decrease operators' perception of risk
- Want to maintain sensitivity to detect real events (should not allow false negatives)

Maintaining Sensitivity – monitoring data only contains false positives and true negatives

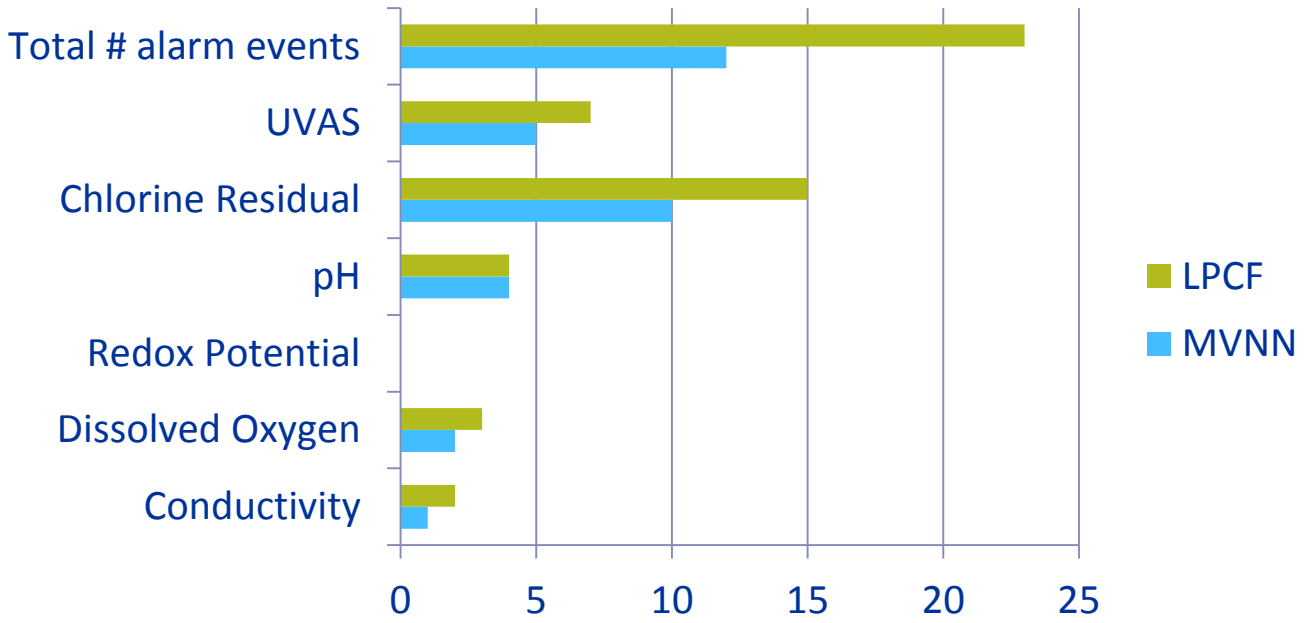


Reducing False alarms



Algorithm Type

- MVNN selected – produces least false alarms
- All parameters held constant:

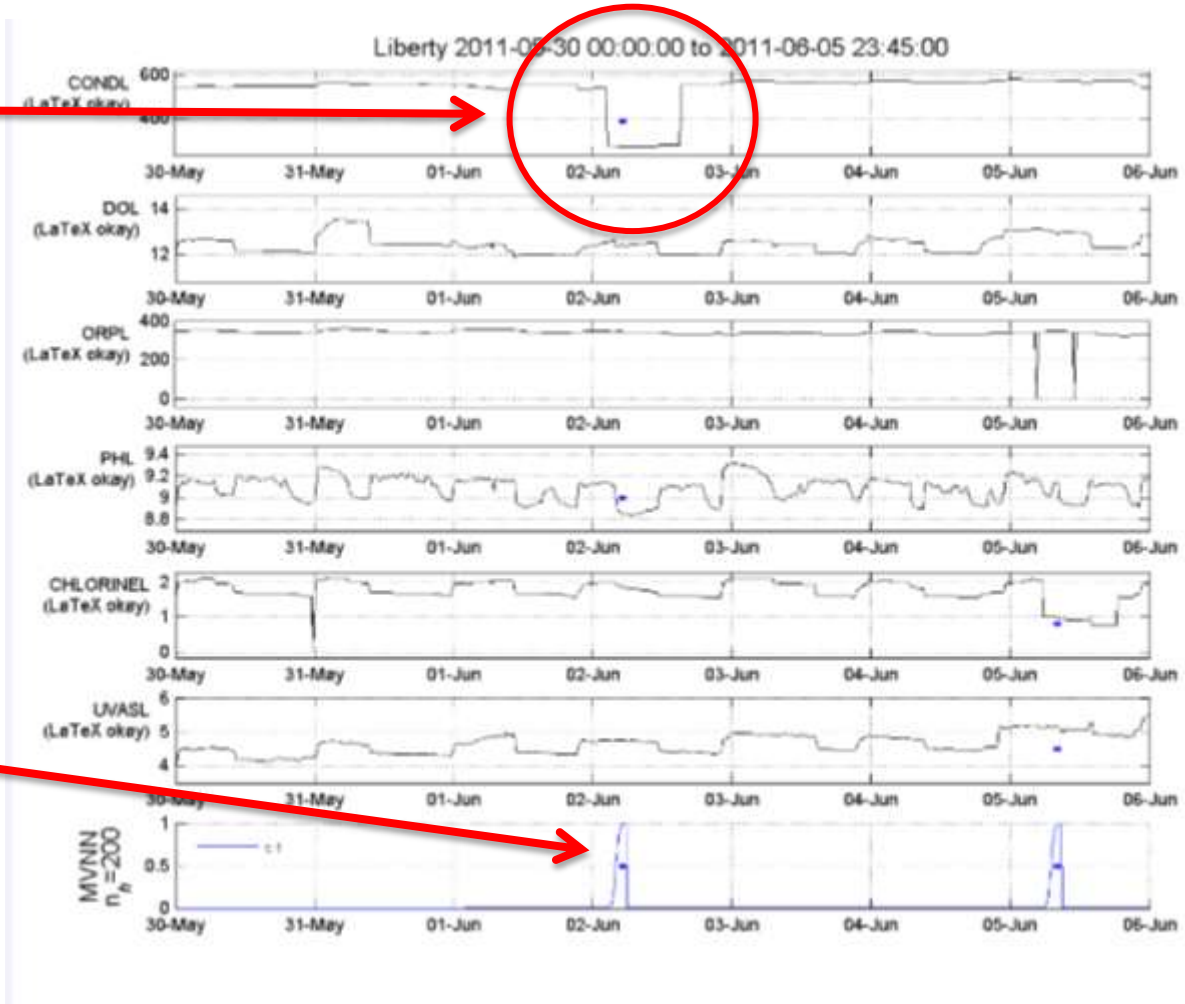


(SPP algorithms produced an error)

Using a simplified adaption of event simulation, multiplied water quality signals by a simulation intensity factor

simulated event

detected



Simulated Events Create True Positives and False Negatives

	Event 1		Event 3	
	Including data anomalies as TP	Not including data anomalies as TP	Including data anomalies as TP	Not including data anomalies as TP
False Positives	2	7	2	9
True Positives	11	6	10	3
False Negatives	2	2	3	2
True Negatives	914	903	914	915
False Positive Rate = FP/(FP+TM)	0.0022	0.0077	0.0022	0.0097
True Positive Rate = TP/(TP-FN)	0.8462	0.7500	0.7692	0.6000

False positive rate less than one percent – sensitivity maintained

Selected Settings

- Binomial Event Discriminator, Event Probability Threshold, and Event Time Out Window not assessed, instead based on CANARY user's manual and settings chosen by Philadelphia Water Utility
- Polling interval only analyzed at 15 minutes – 5 minute interval is better, based on EPA study

Event Detection Parameter	Setting
Timestep (Polling Interval)	15 minutes
Window Size	250 timesteps
Outlier Threshold	1 standard deviation
Algorithm	MVNN
Binomial Event Discriminator (BED)	15 timesteps
Event Probability Threshold	0.9
Event Time Out Window	5 timesteps

CANARY Issues Experienced

- Variability in water quality data and inevitable malfunctions in monitoring equipment cause false alarms
  - False alarms require operator time and reduce operator confidence in the system
  - Failure to detect an event must be avoided
- CANARY output can be difficult to analyze
- Problems were frequently encountered, especially during configuration
- Trouble shooting resources are few and slow

Recommendations

- Continue to utilize existing monitoring station at WTP
- Consider deploying Liberty monitoring station as mobile unit
  - Develop correlations between WTP and each parameter over 1-year period (other reservoirs, elevated tanks)
  - Examine areas with water qualtiy changes due to nitrification or corrosion
  - Full deployment with multiple remote stations not recommended until calibration effort of instruments is reduced (more stable instruments) and EDS is well developed
- Continue to monitor improvements in CANARY and alternate EDSs

Water Quality Monitoring is Only Part of a Contaminant Warning System

Project Team

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Questions?