Beyond the Desktop: Embedded Modeling and Cloud Based Real-Time Monitoring and Control

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Beyond the Desktop: Embedded Modeling and Cloud Based Real-Time Monitoring and Control

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engineers | scientists | innovators

OptiRTC
Real-Time Consulting

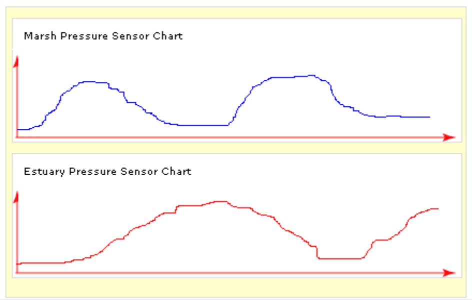
WERF
Water Environment Research Foundation
Collaboration. Innovation. Results.

Overview

- Background:
  - Initial Research Problem
  - The Internet-of-Things (IoT)
  - Types of Cloud Computing
  - Development of the IoT for Infrastructure Monitoring and Control (DRTC/OptiRTC)
- Modeling-as-a-Service (MaaS)
- What does all of this look like in the real world?
- Closing thoughts

Initial Research Problem

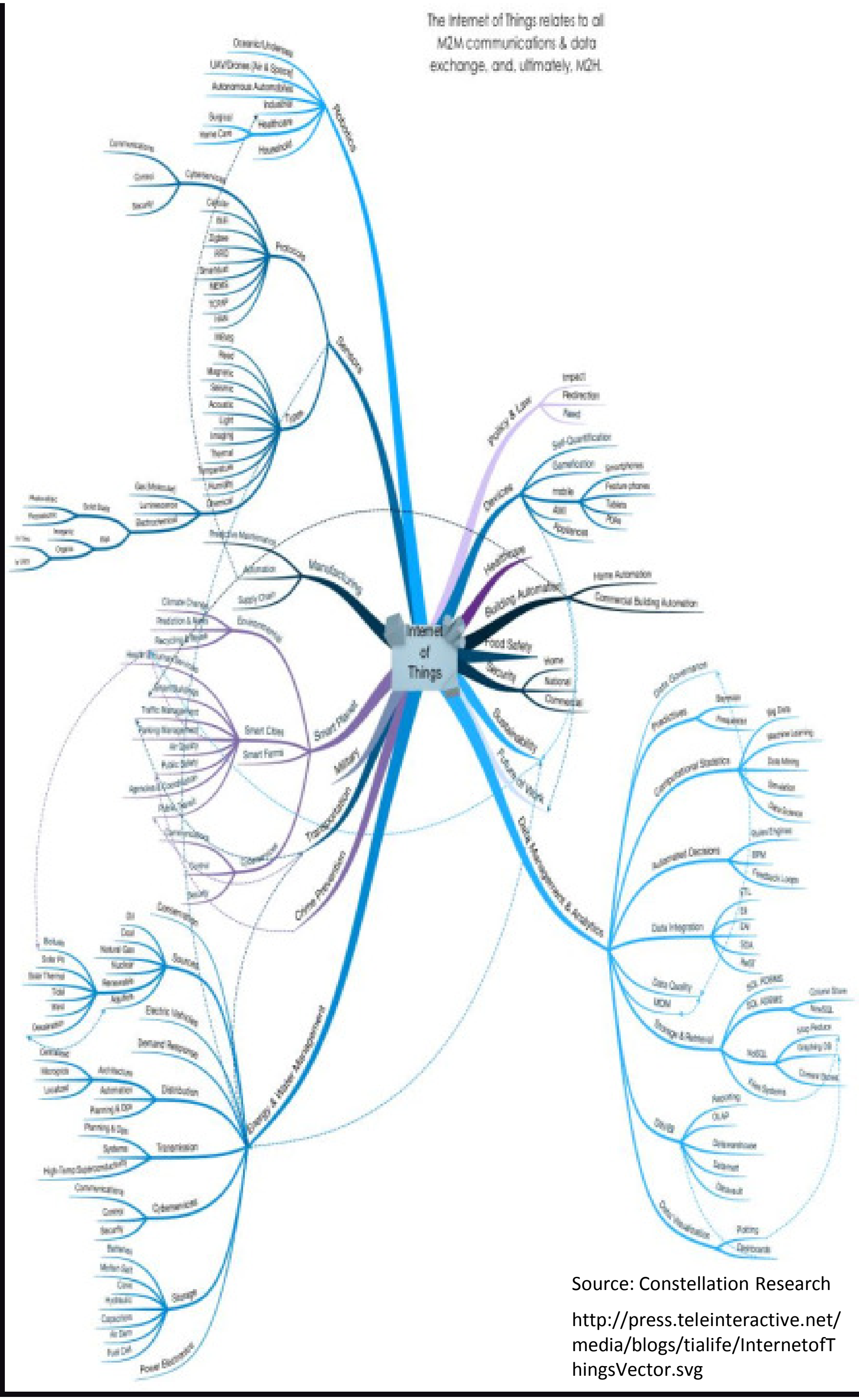
- Find the least expensive most flexible means for monitoring and controlling the physical environment and integrating internet based datastreams.



Patent # 60/350,600 and 11/869,927

Internet-of-Things (IoT)

- Definitions:
  - Extending the virtual internet to physical objects
  - Physical computing
  - Enabled through IP based field deployed gateways



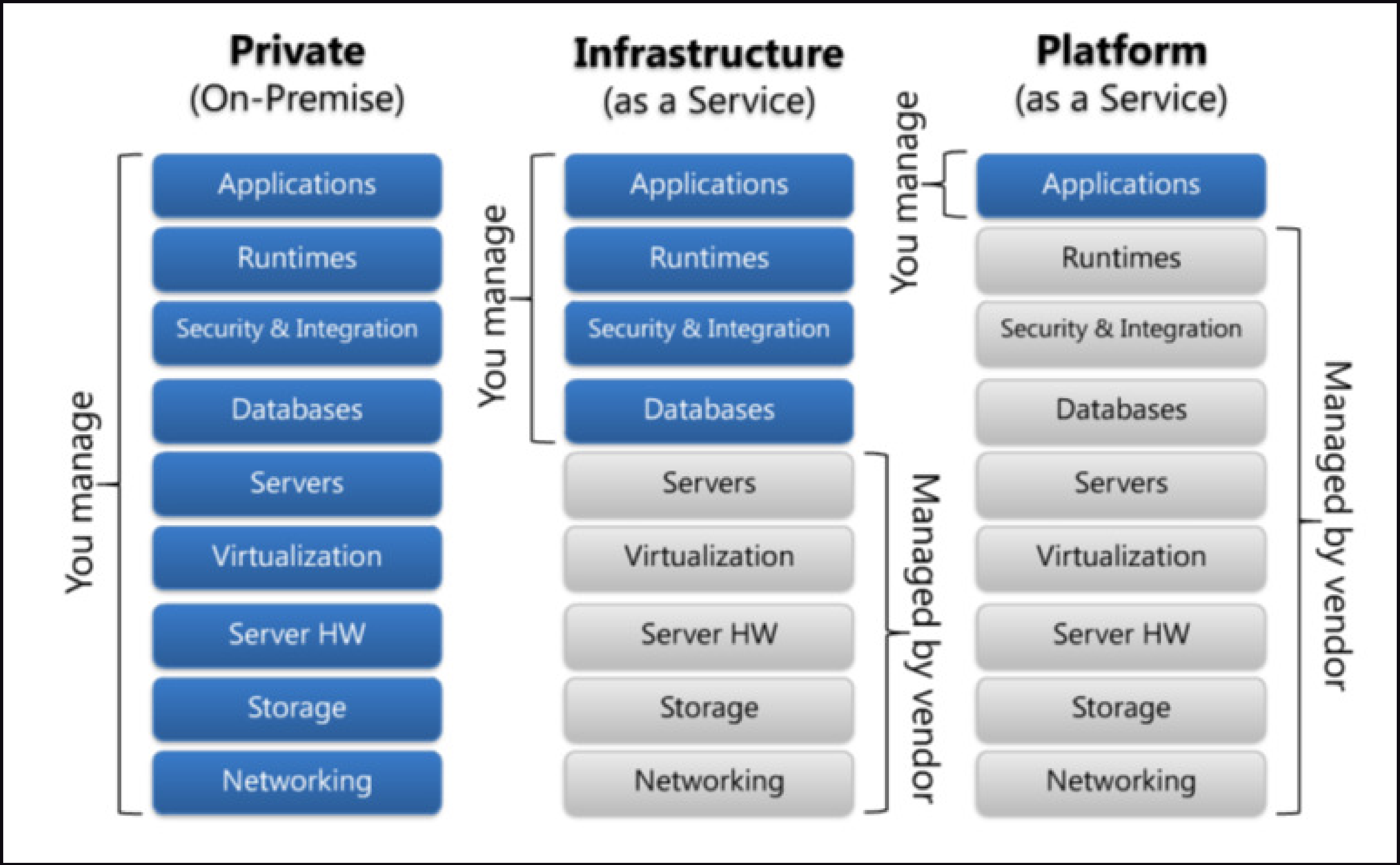
Source: Constellation Research

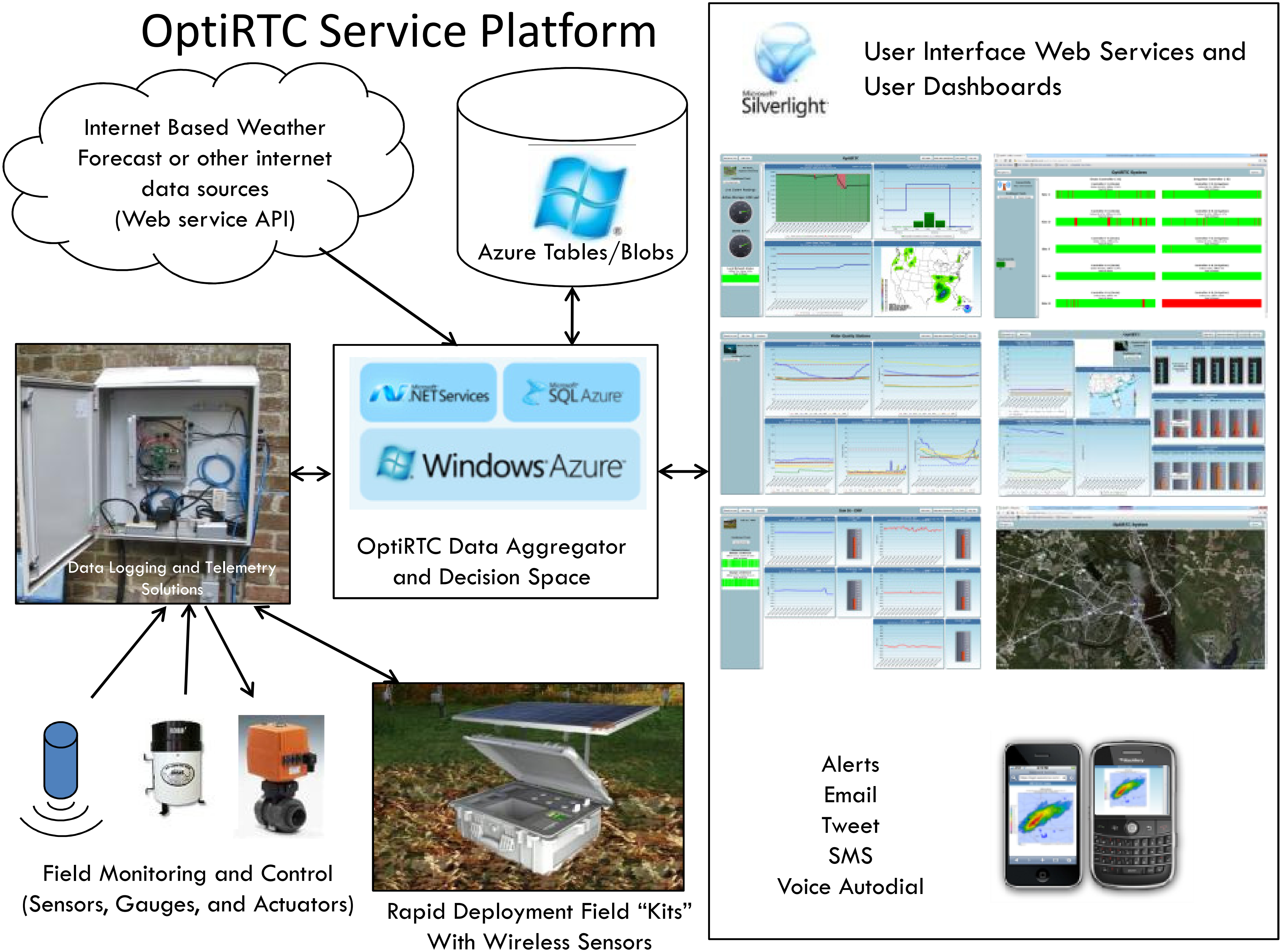
http://press.teleinteractive.net/media/blogs/tialife/InternetofThingsVector.svg

Perspectives on Internet-of-Things

- National Intelligence Council - “Disruptive civil technologies: six technologies with potential impacts on US interests out to 2025”
- Likely rapid adoption and ubiquity in a number of civil environments (e.g., water)
- Cisco IBSG predicts there will be 25 billion devices connected to the Internet by 2015 and 50 billion by 2020.

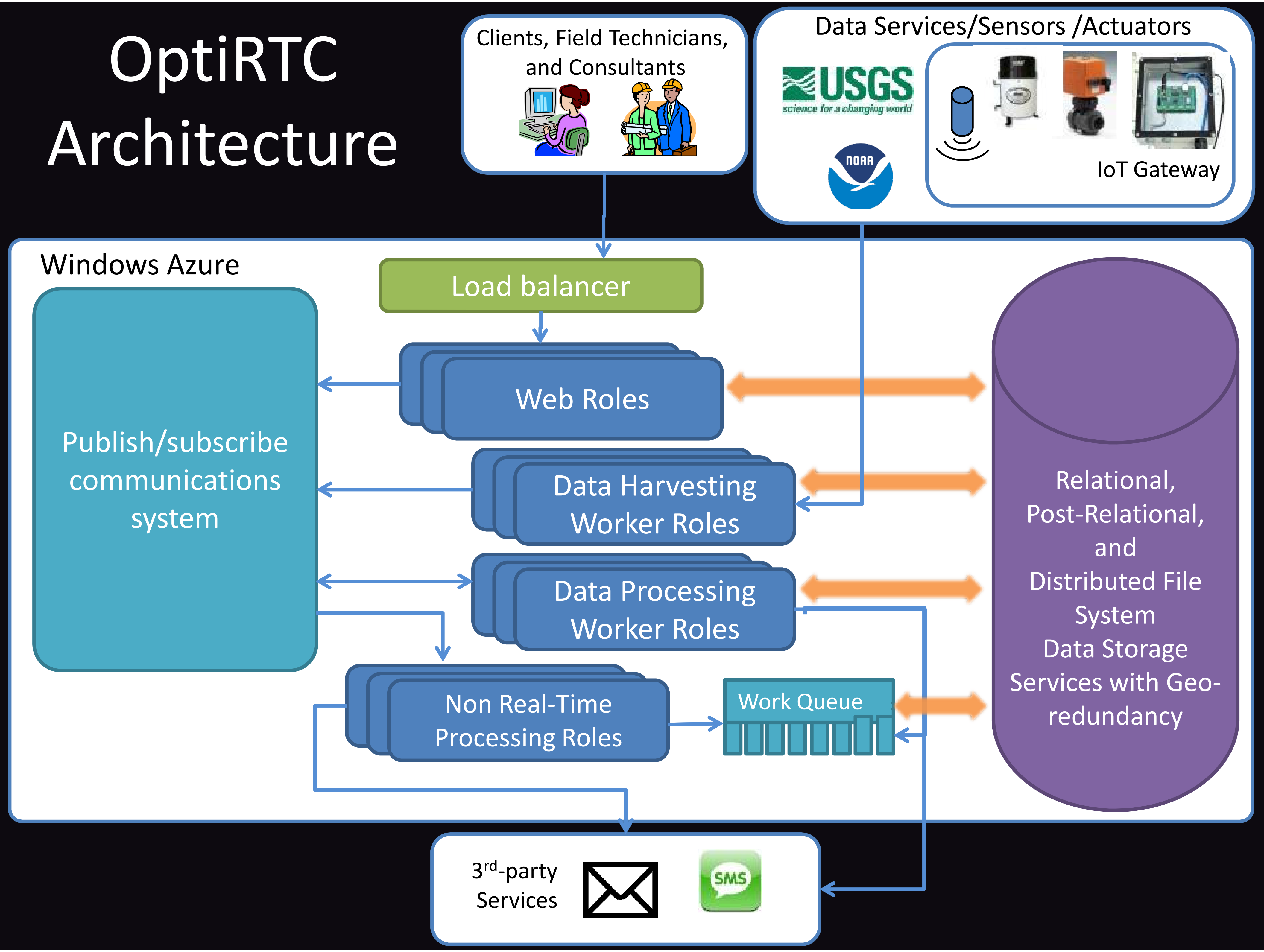
Types of Clouds

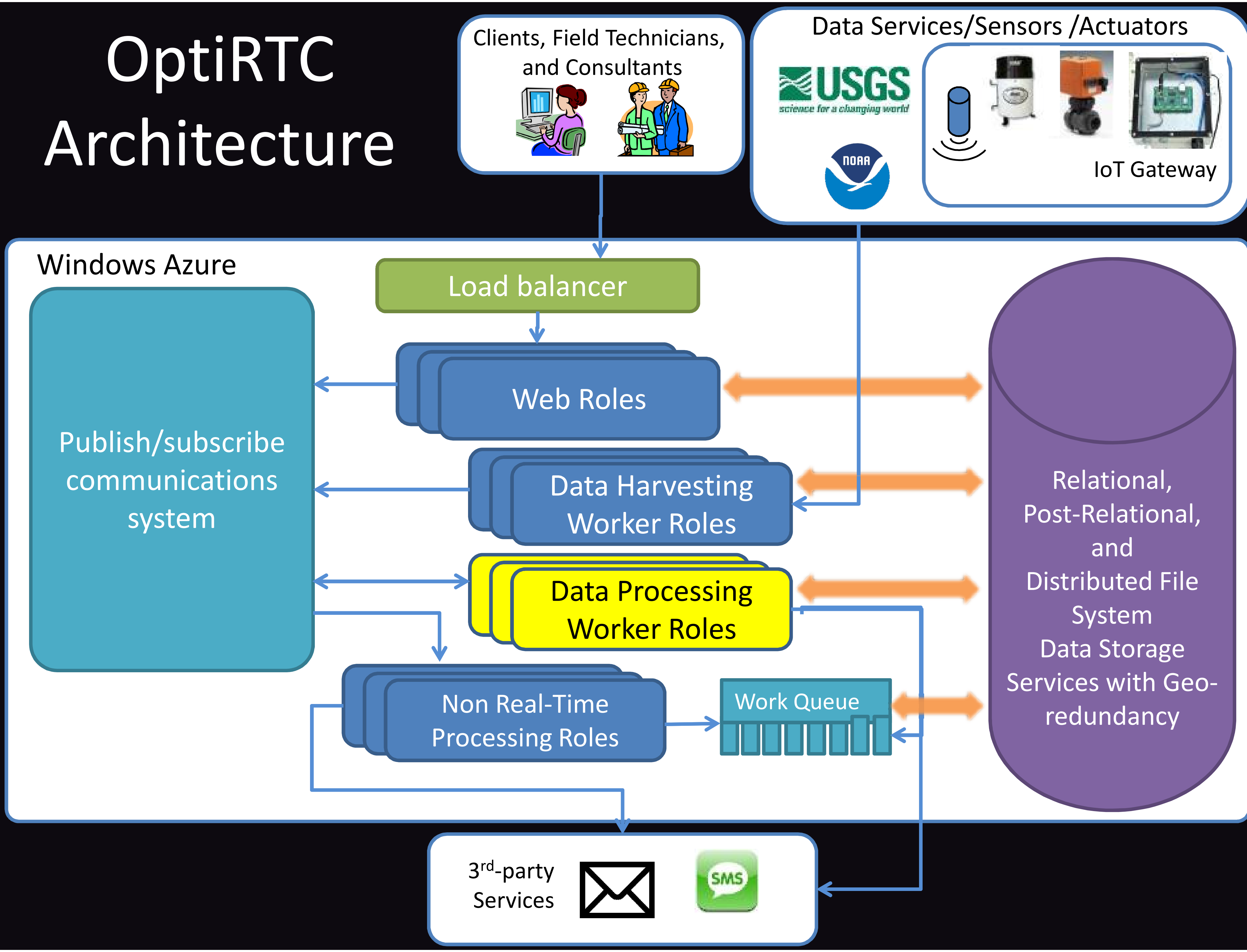



OptiRTC Service Platform
Internet Based Weather Forecast or other internet data sources (Web service API)
Azure Tables/Blobs
Silverlight
User Interface Web Services and User Dashboards
.NET Services
SQL Azure
Windows Azure
OptiRTC Data Aggregator and Decision Space
Data Logging and Telemetry Solutions
Alerts
Email
Tweet
SMS
Voice Autodial
Field Monitoring and Control (Sensors, Gauges, and Actuators)
Rapid Deployment Field "Kits" With Wireless Sensors

Architecture Highlights

- Redundant across all cloud infrastructure.
- Fully virtualized for fast recovery and upgrades without downtime.
- Capable of allocating Compute resources differently for different tasks (web services, data harvesting, real-time and non real-time processing.
- Reliable, flexible, accessible, secure, and proactively adaptive IT basis in Windows Azure.


OptiRTC Architecture
Clients, Field Technicians, and Consultants
Data Services/Sensors /Actuators
USGS science for a changing world
NOAA
IoT Gateway
Windows Azure
Load balancer
Web Roles
Publish/subscribe communications system
Data Harvesting Worker Roles
Data Processing Worker Roles
Non Real-Time Processing Roles
Work Queue
Relational, Post-Relational, and Distributed File System Data Storage Services with Geo-redundancy
3rd-party Services
SMS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Relational, Post-Relational, and Distributed File System Data Storage Services with Geo-redundancy
3rd-party Services
SMS

Data Processing Roles
“Post-Actions”

- Algorithms within .NET implementations compliant with the OptiRTC post-action sequence interface.
- Include simple logical operations, remote control operations, alerting and email notifications
- …and complete advanced modeling routines.
- This is just “Modeling-as-a-Service” (MaaS)
- Shift from thinking that models are “products”

MaaS SWMM Implementation

- Downloaded SWMM 5.0.022 computational engine from http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/swmm50022_engine.zip
- Re-targeted compilation at x64 platform
- Rebuilt SWMM engine for 64-bit Windows environment
- Added startup installation of 64-bit C++ runtime library to OptiRTC DataProcessor VM image
- Developed C# wrapper around SWMM engine interface
- Configured DataProcessor VM emulation of NFTS file system to provide cache for SWMM engine I/O

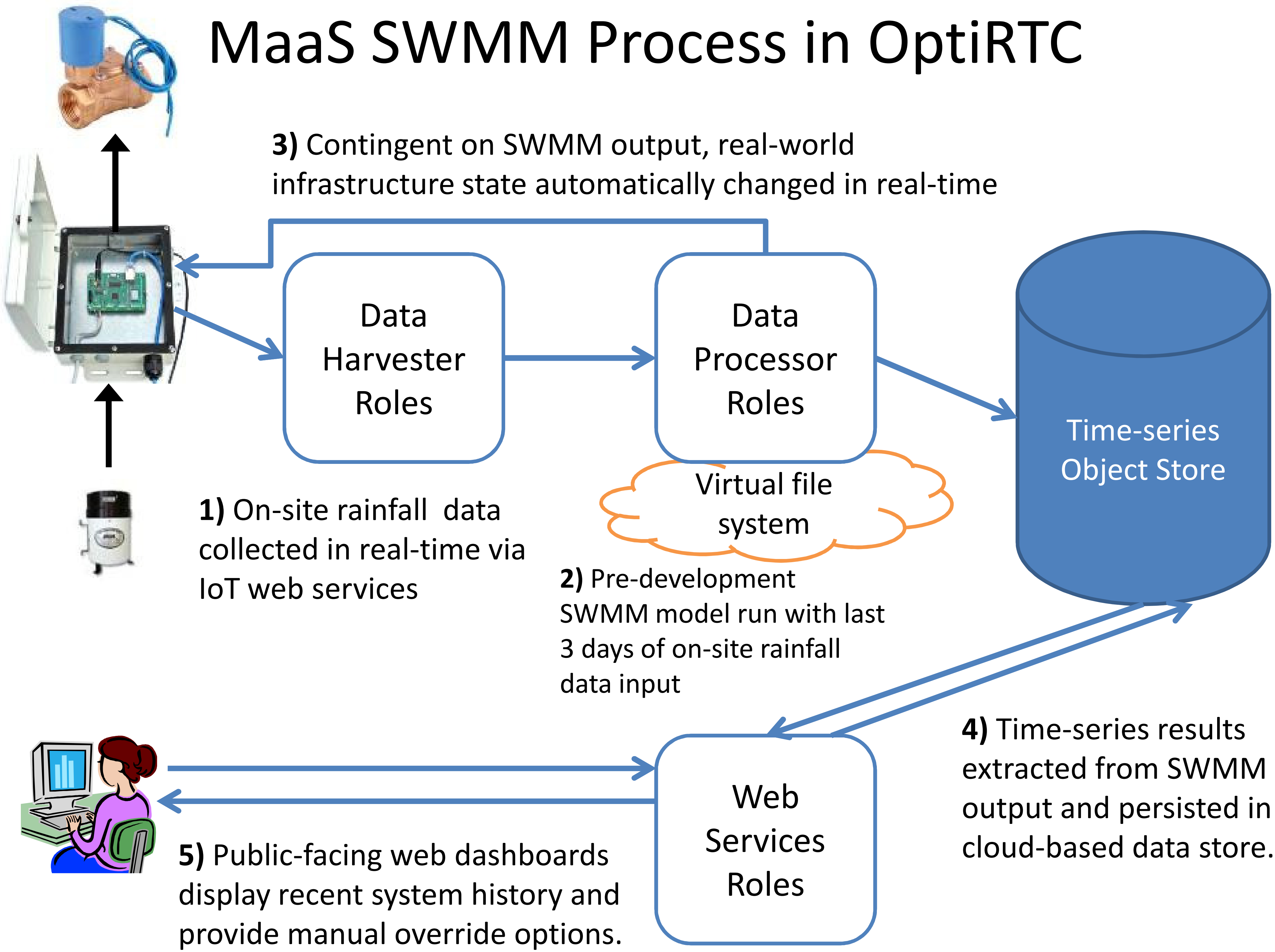
Example Use Case for SWMM MaaS

- Use SWMM 5 to evaluate pre-development hydrologic conditions for a site in real-time
  - Use pre-development SWMM model
  - Use historical site precipitation record
  - Add last 48 hours conditions to calculate expected state. (or generate hot-start file from previous conditions)
- Report output to Data Processor Roles
  - Real-time dashboard reporting
  - Use in distributed infrastructure control
  - “Match” Pre-development conditions (above Qc and below Qmax)
  - Distribution and publication via OptiRTC HTTP API

Example of MaaS Workflow - Setup

- Edit model .INP input file to allow for run-time configuration of file system directory structure
- Upload input file and necessary input data files to OptiRTC cloud storage
- Determine real-time data source to use as current precipitation record
- Determine which model objects to report
- Link results datastreams via control post-actions
- Eventually completely through web API as well

MaaS SWMM Process in OptiRTC



Some Other Use Cases for MaaS

- Self-calibration of models from streaming empirical data
- Hydrologic/Hydraulic forecasting and control
  - DSS
  - Reservoir Operation
  - Light weight flood warning systems
- Batch Model Processing (scale up/scale down)
- Other boundary conditions (stream flow)
- Adaptive management
- “time shifted” hydrology
- Integrated QA/QC – everything is preserved
- There are many more….

What does this look like in the real world?

Collaborators

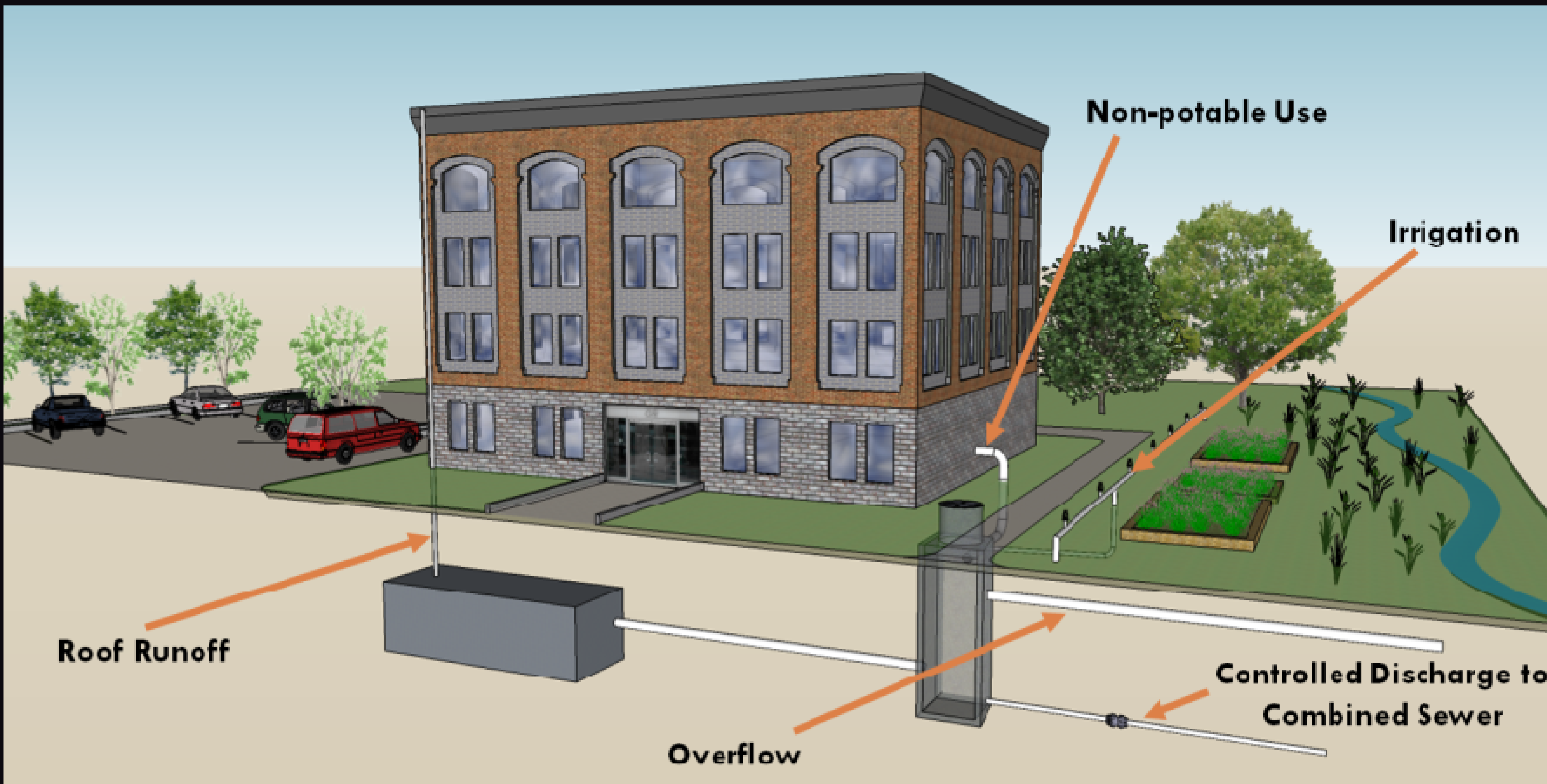
WERF

Water Environment Research Foundation

Collaboration. Innovation. Results.

Technology Application: Advanced Rainwater Harvesting and Harvesting System Retrofits

Technology Application: Advanced Rainwater Harvesting



Simplest Definition: Drain storage in advance of predicted rainfall or other trigger

Pilot System: NC State Advanced Rainwater Harvesting

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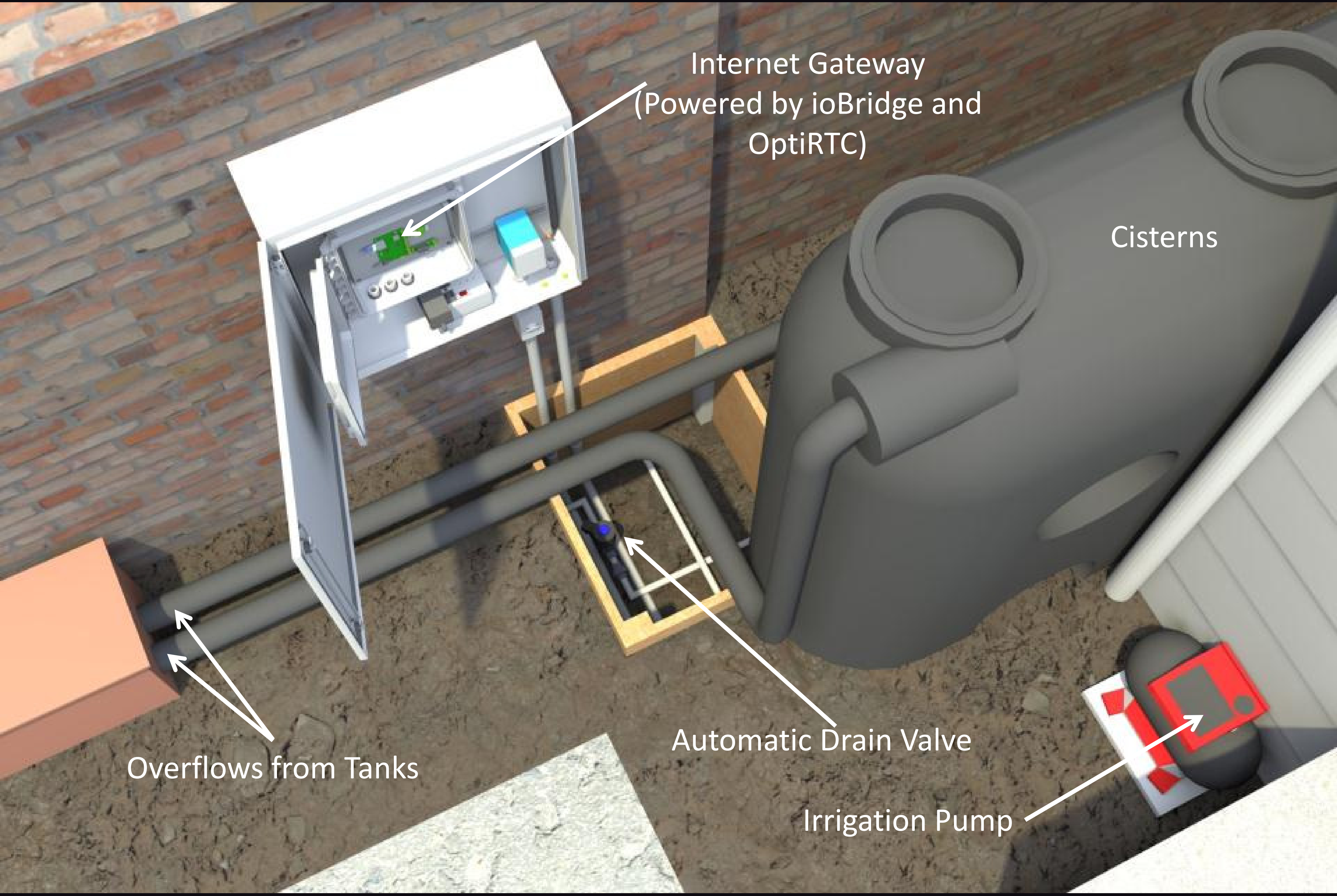
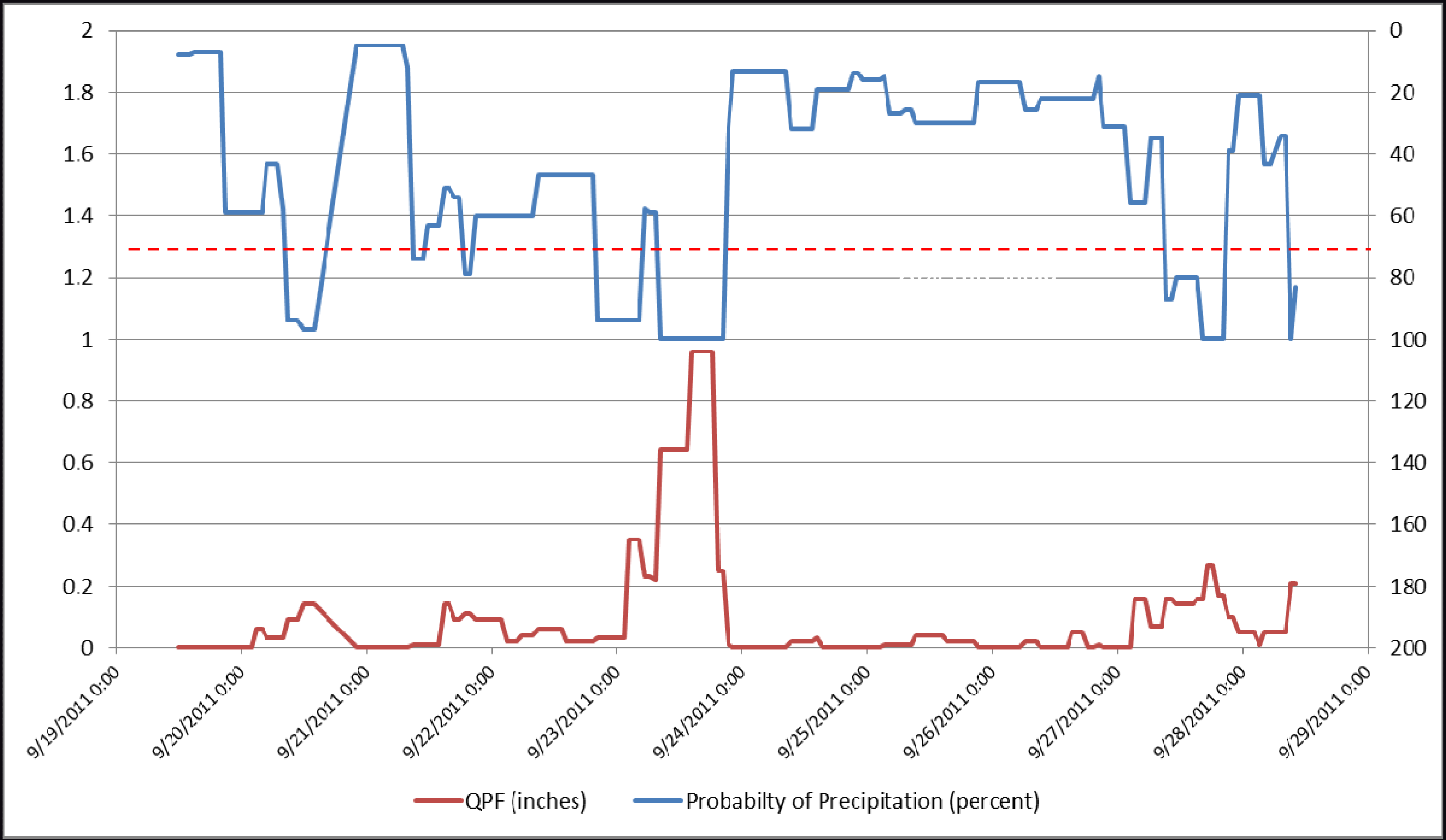
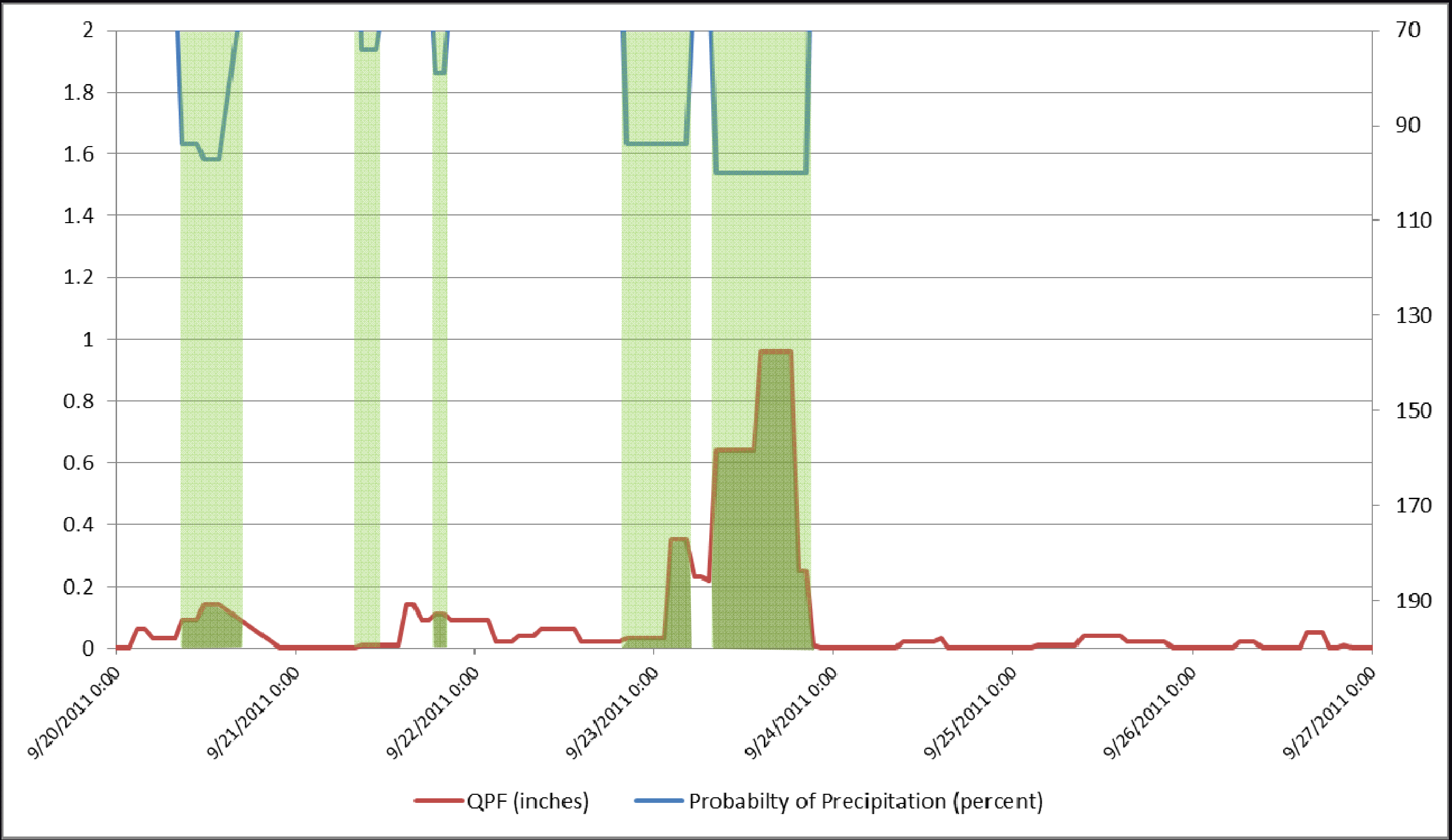


Pilot System: NC State
Advanced Rainwater Harvesting

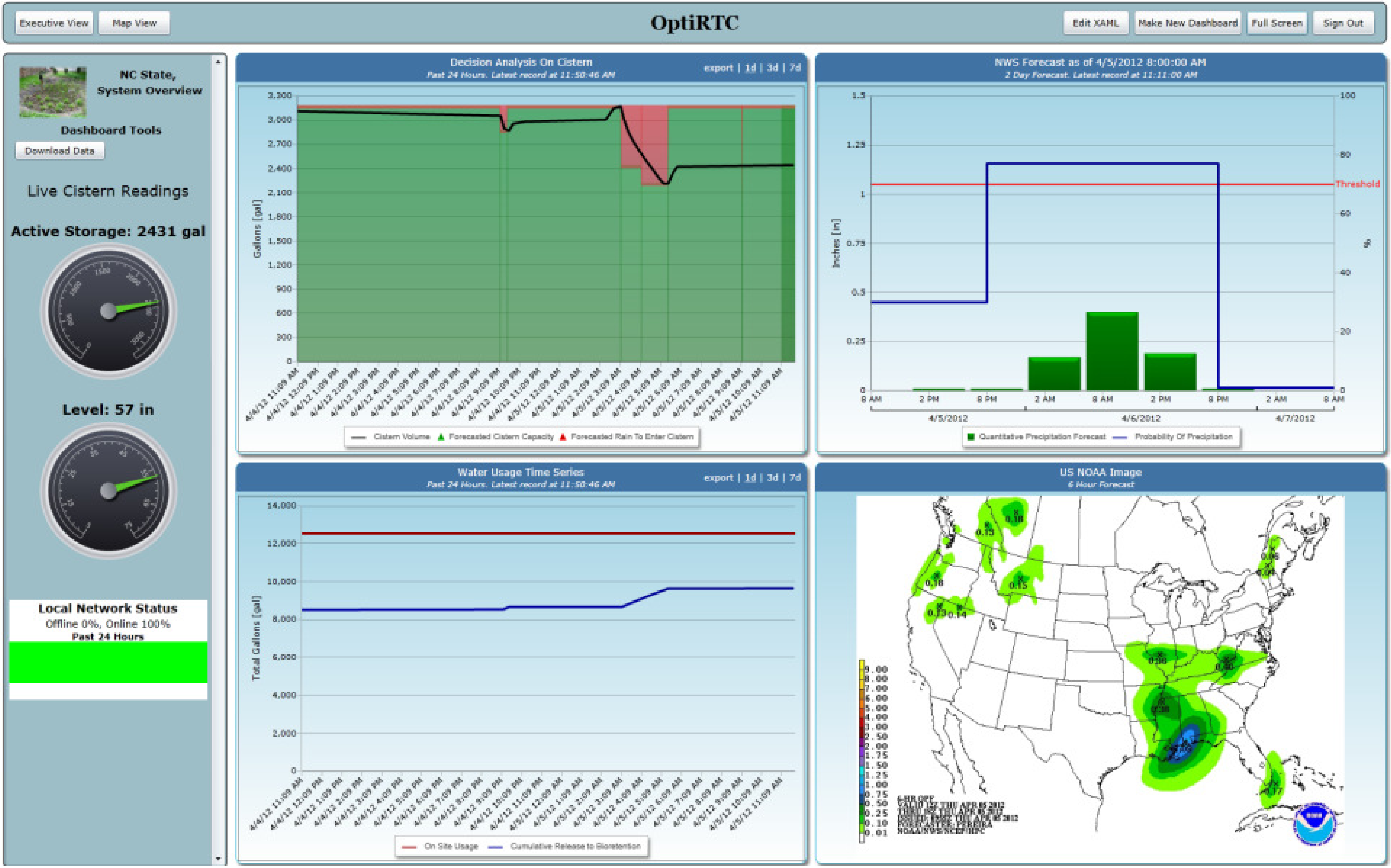
NC State Pilot
System Behavior Week of 9/20/2011
Forecast Datastream



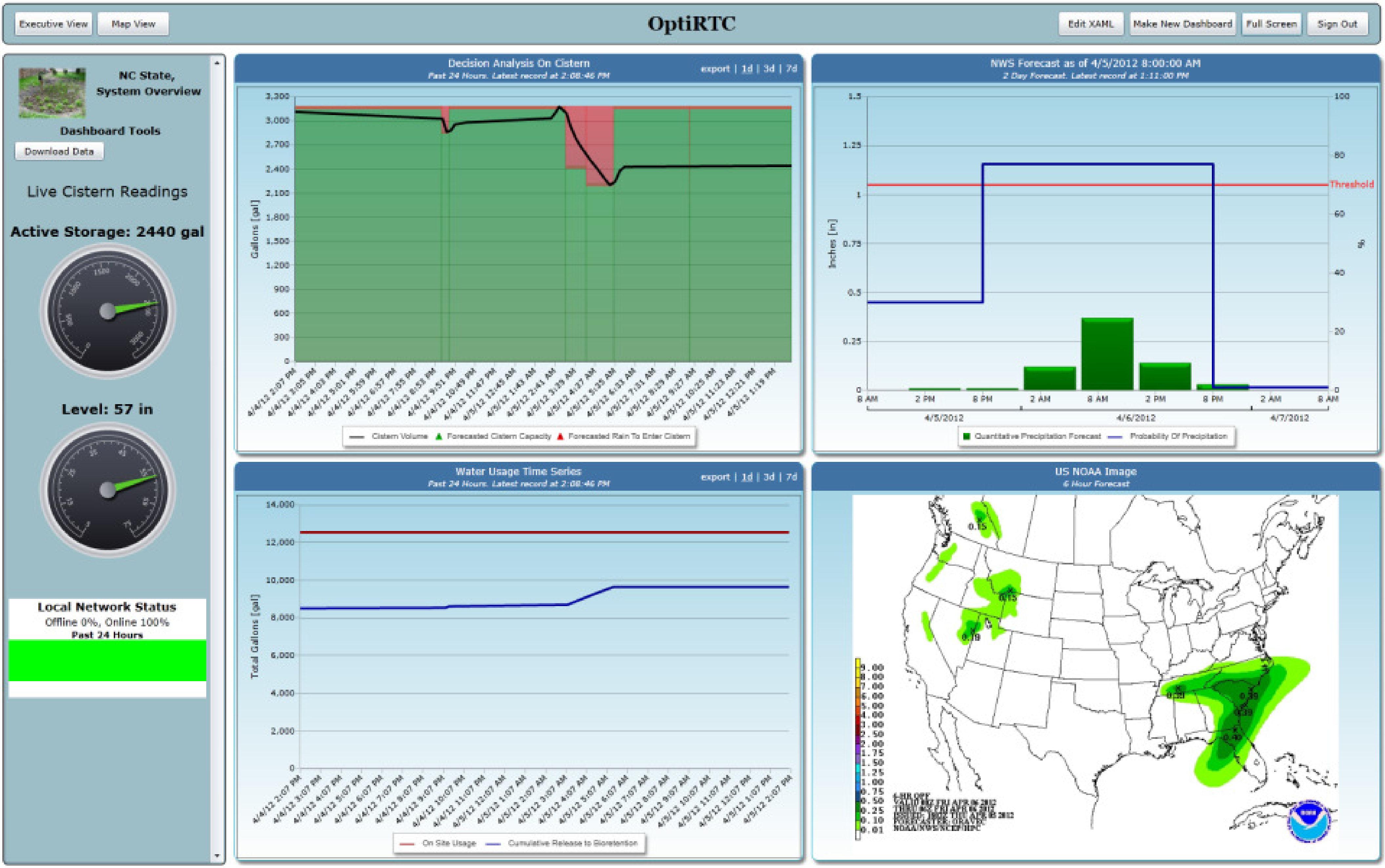
NC State Pilot
System Behavior Week of 9/20/2011
QPF and POP Forecast Datastream (Threshold of 70%)



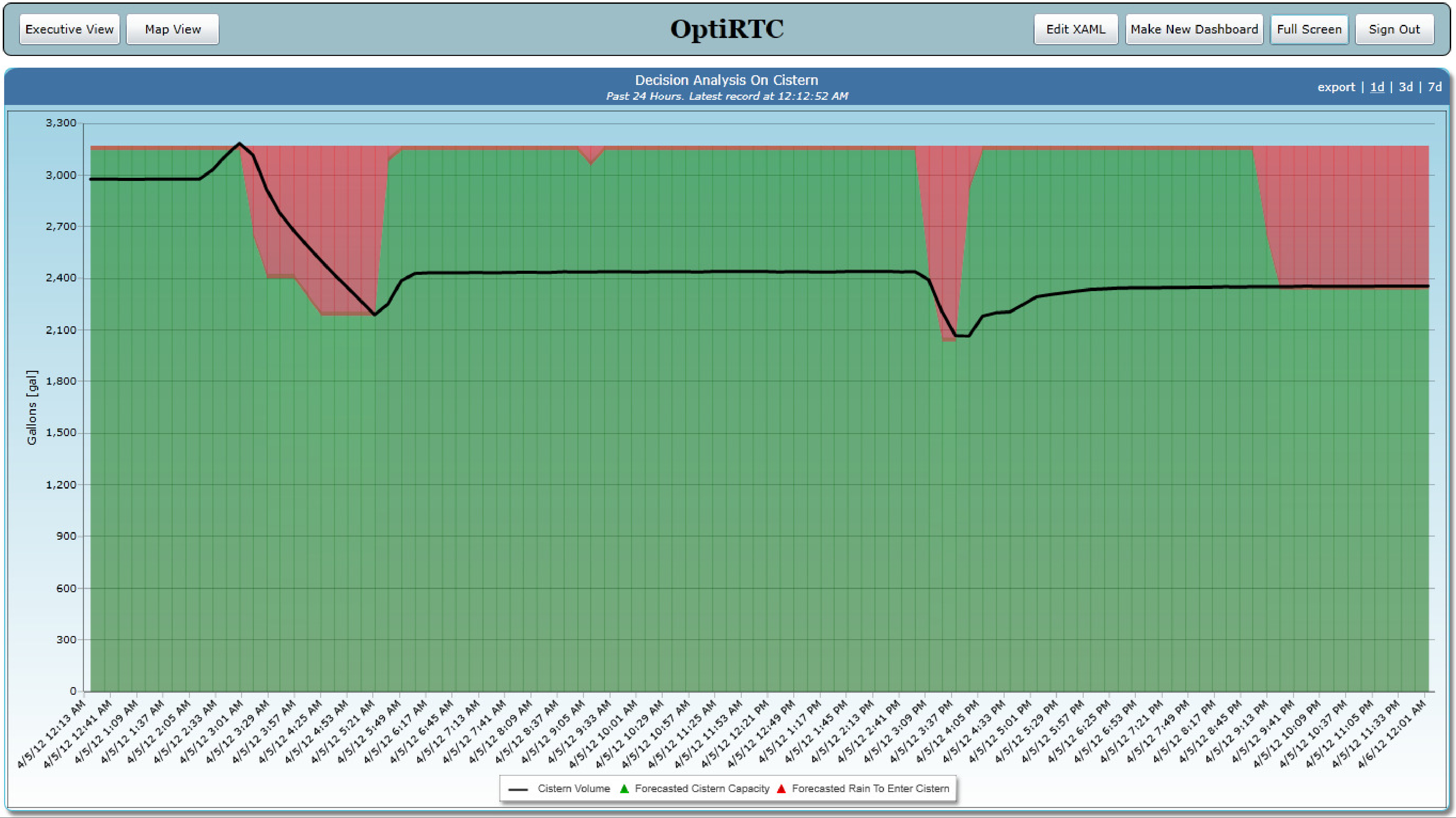
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/5/2012 11:52 AM



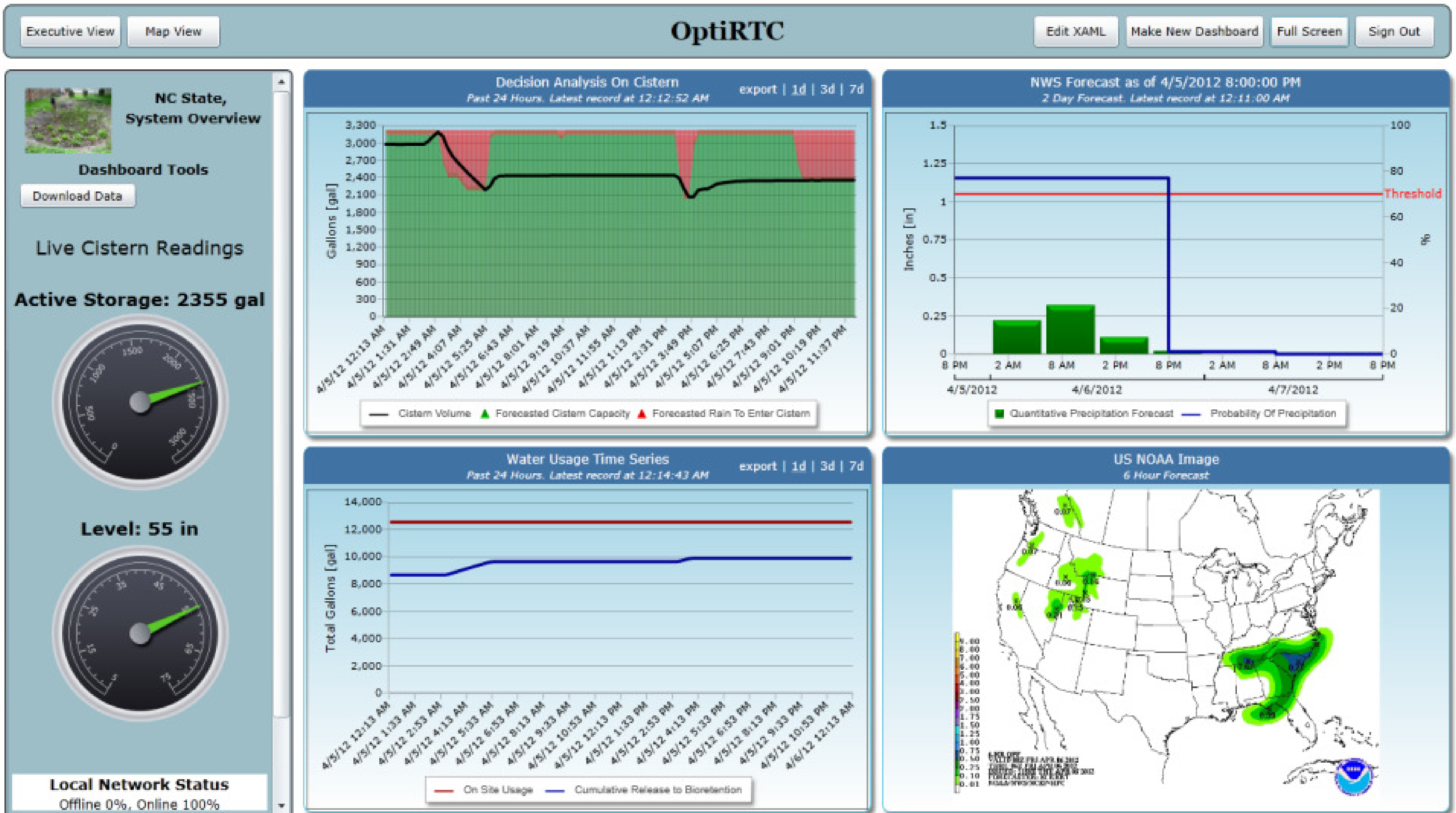
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/5/2012 2:06 PM



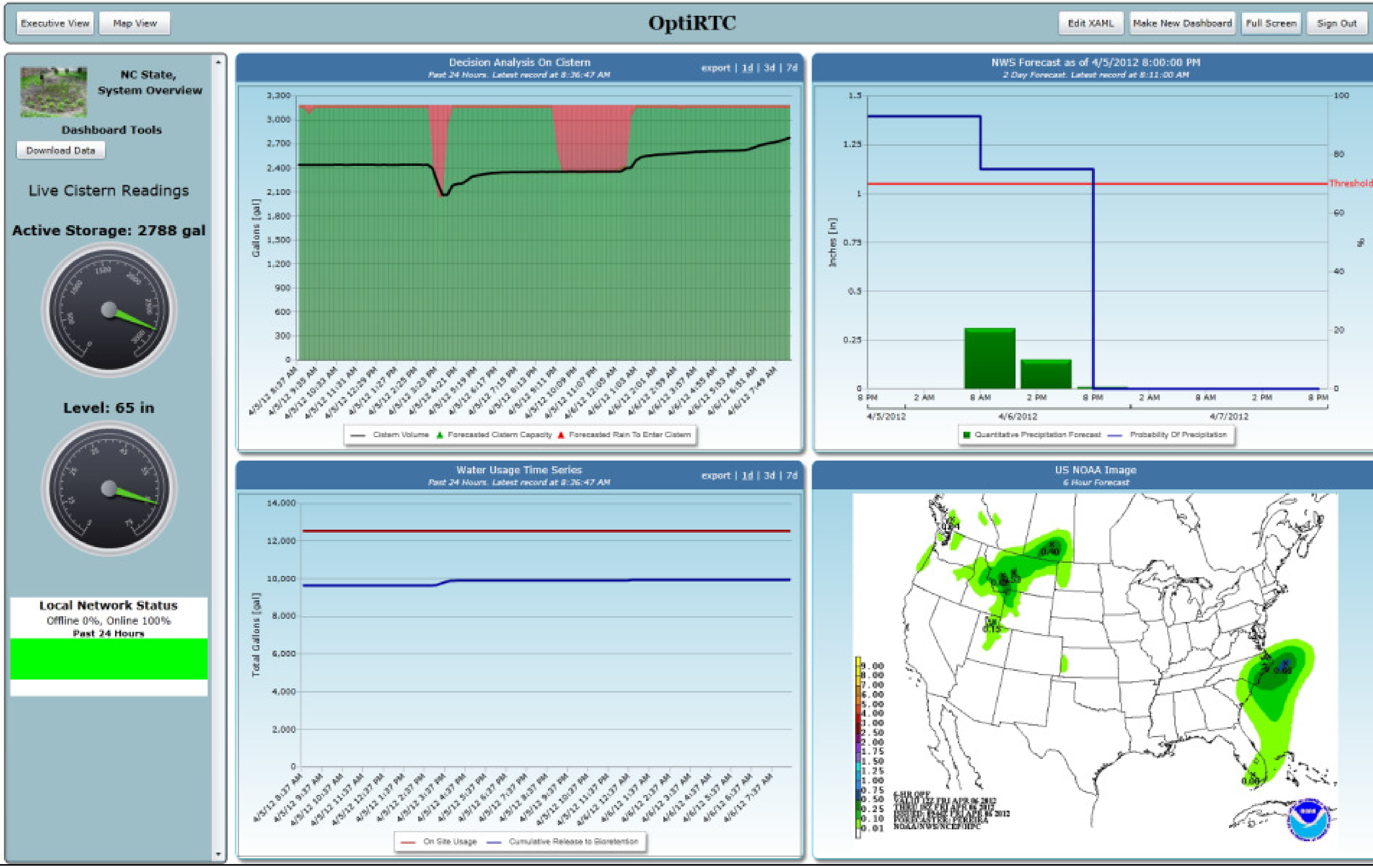
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/6/2012 12:14 AM



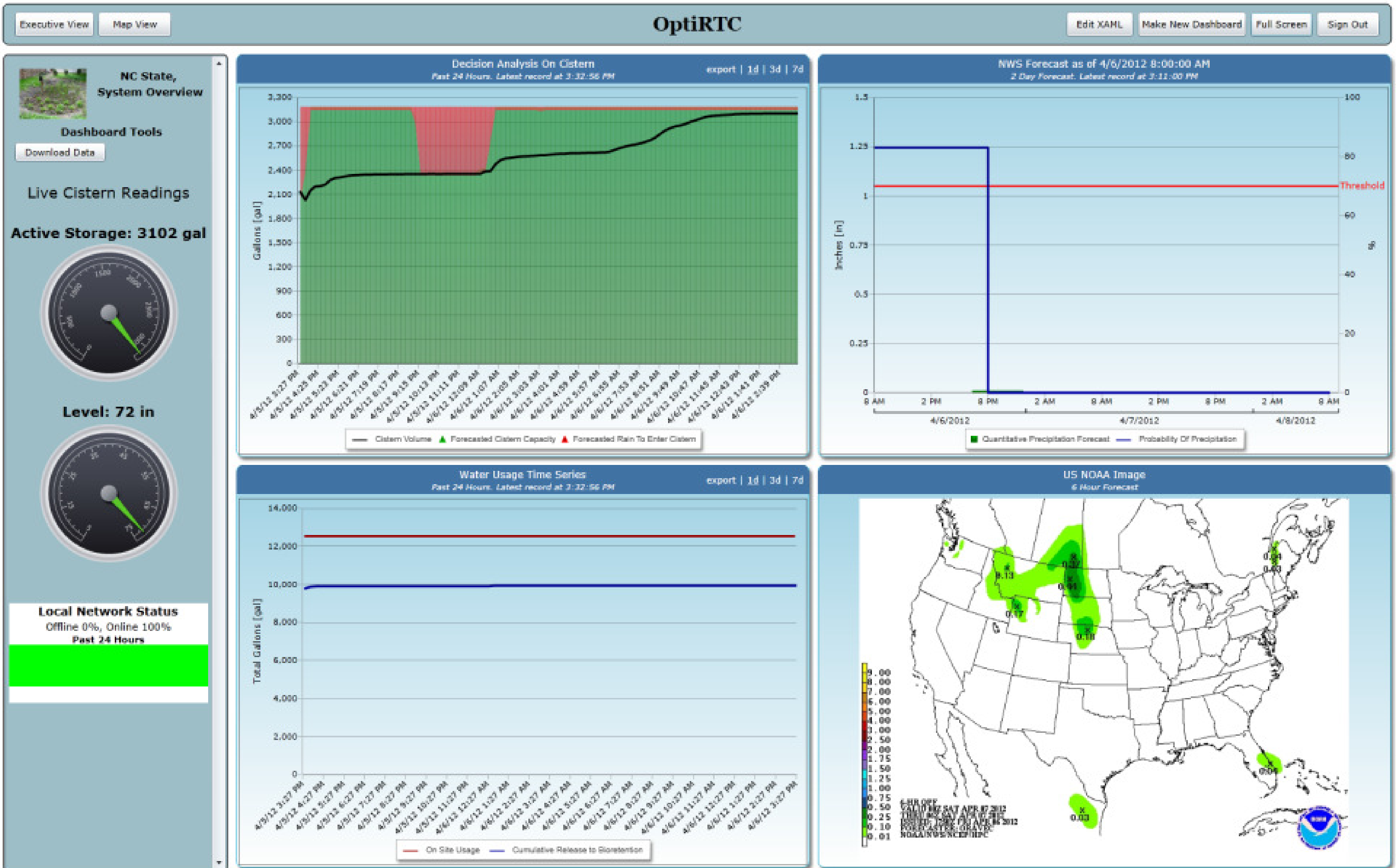
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/6/2012 12:14 AM



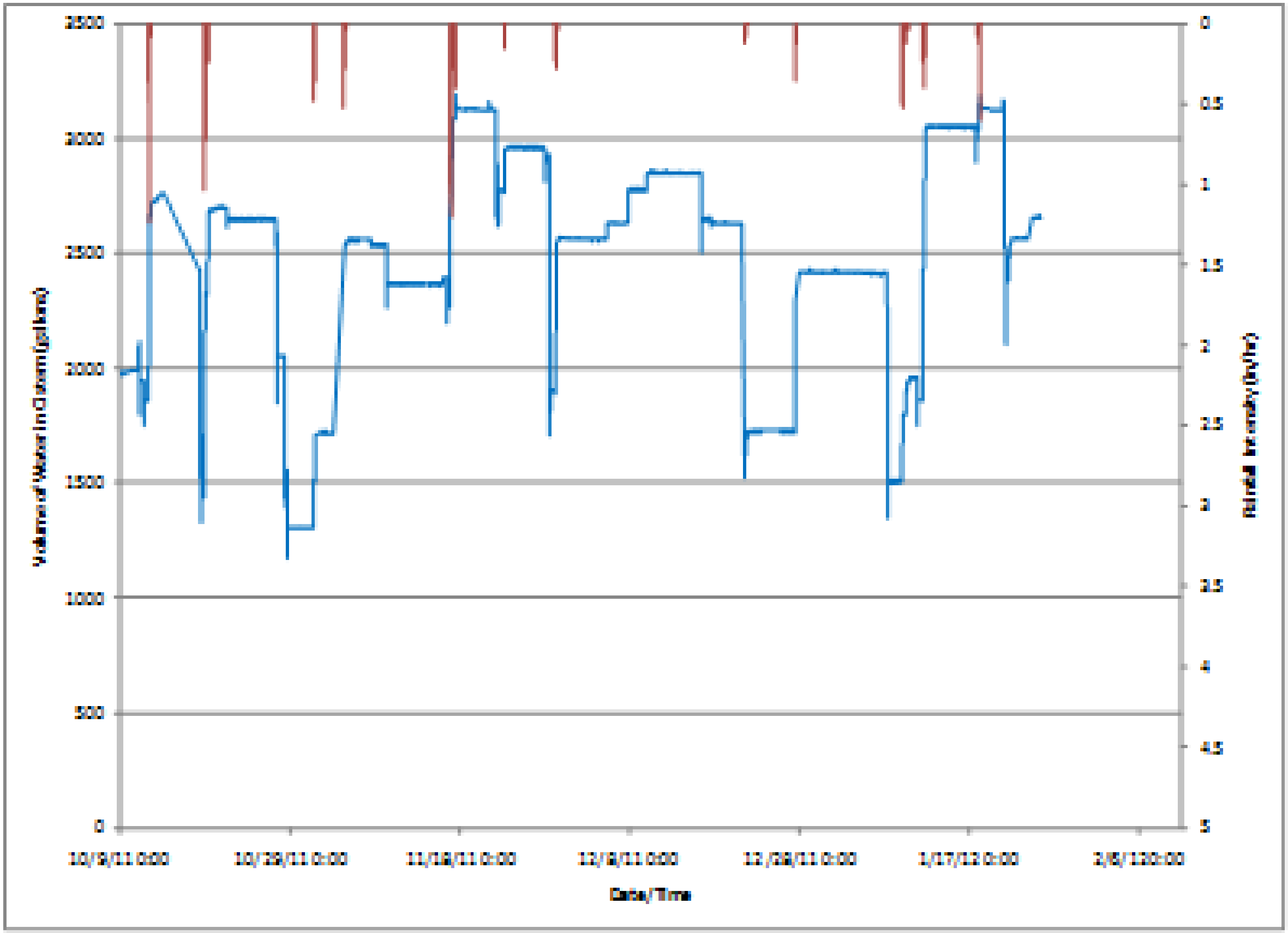
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/6/2012 8:38 AM



NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/6/2012 3:34 PM



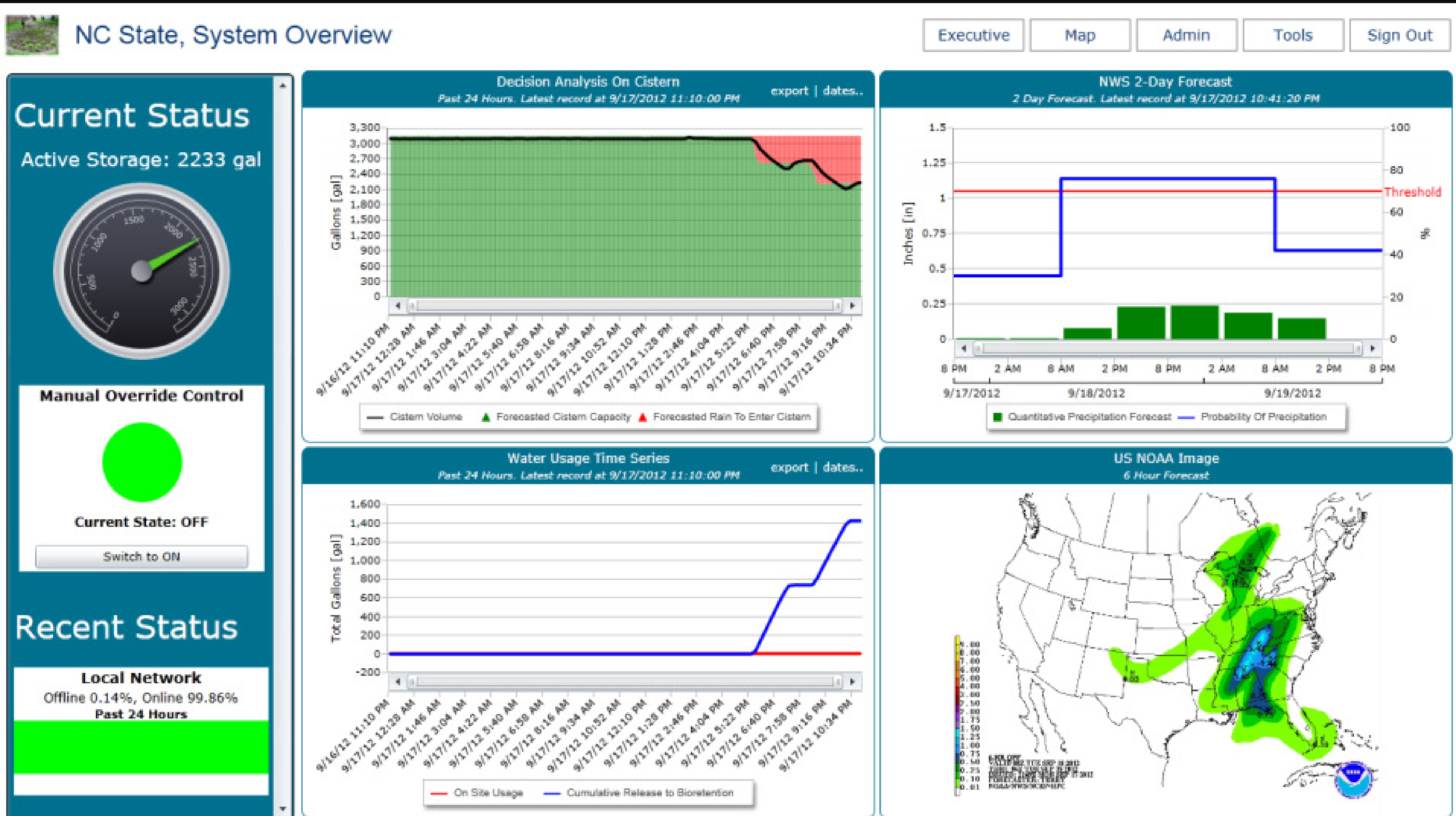
NC State Pilot – Monitoring Results 10/9/11-2/2/12



NC State Pilot
Analysis of Monitoring Results

- **3.5 month period**
- **Captured 90.6% of the total runoff volume.**
- **Conventional rainwater harvesting system with same demand profile would have captured 48.7% of the total runoff volume**

NC State Pilot – Dashboard (1-min refresh)
System Behavior 9/172012 11:12 PM



NC State Pilot – Dashboard (1-min refresh)
System Behavior 9/17/2012 11:12 PM

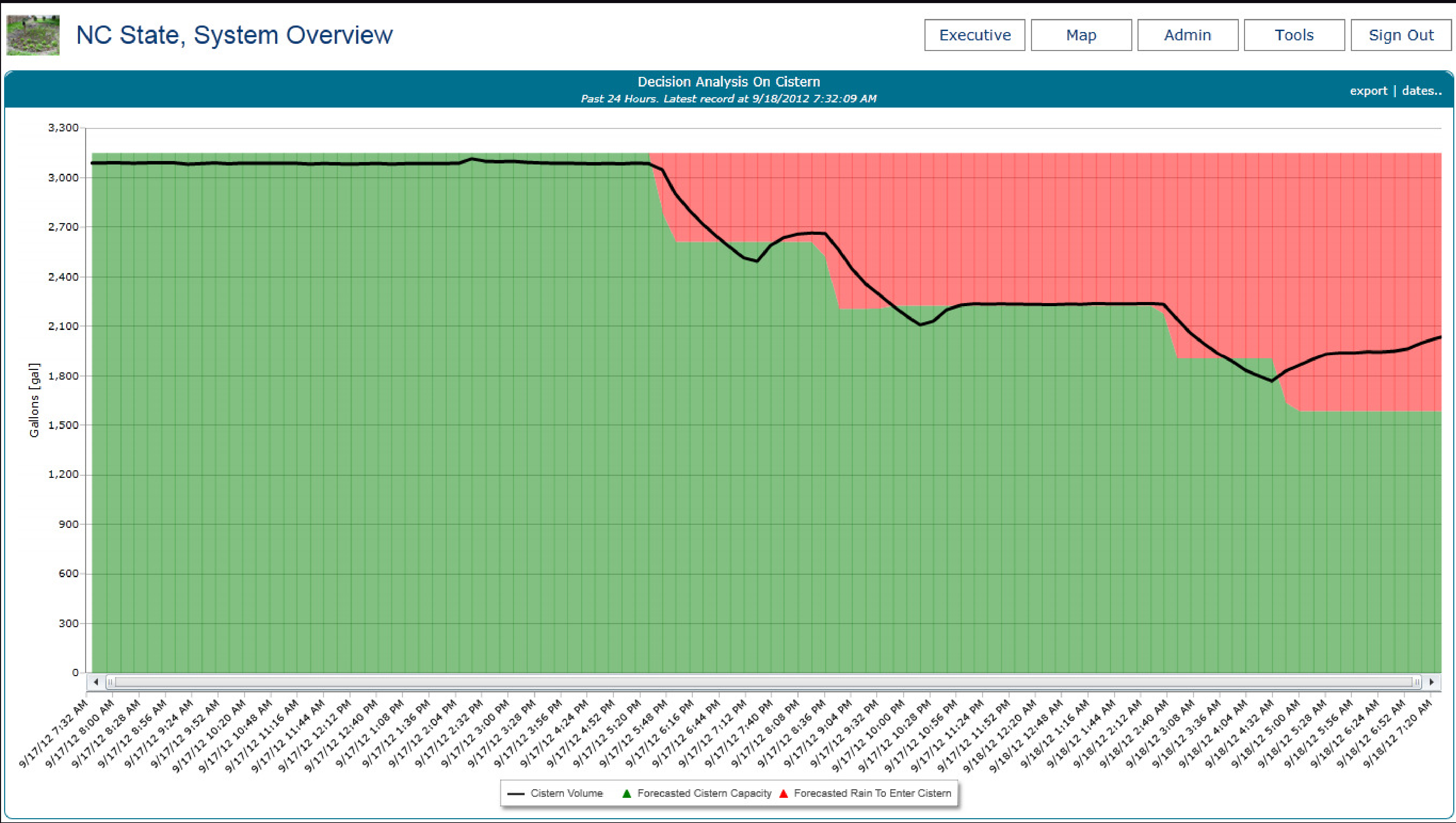
NC State Remote Reality

Executive | Map | Admin | Tools | Sign Out

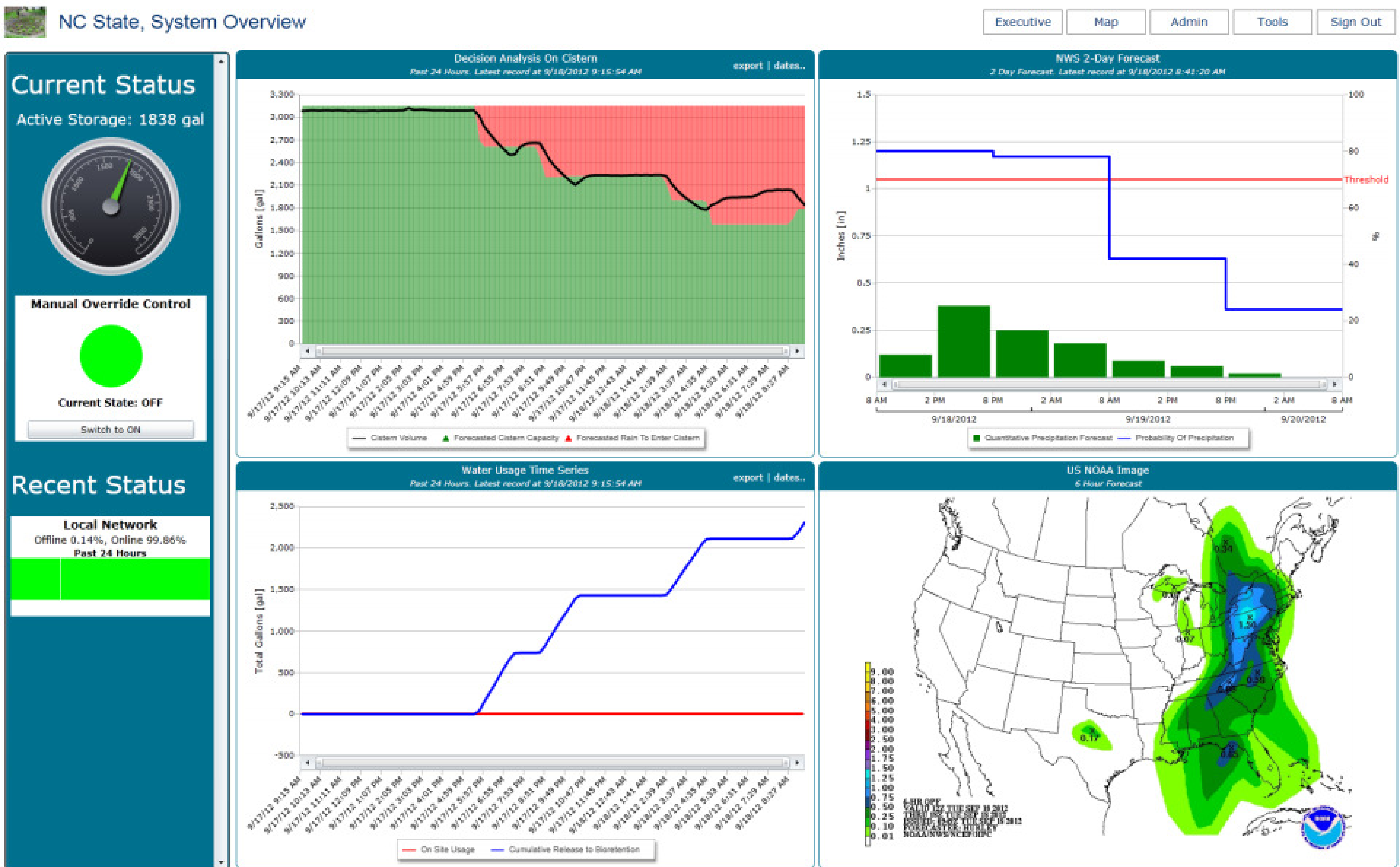
Storage Level

Live Selection of Pre-computed Rendering

NC State Pilot – Dashboard (1-min refresh)
System Behavior 9/18/2012 7:10 AM



NC State Pilot – Dashboard (1-min refresh)
System Behavior 9/18/2012 9:16 AM

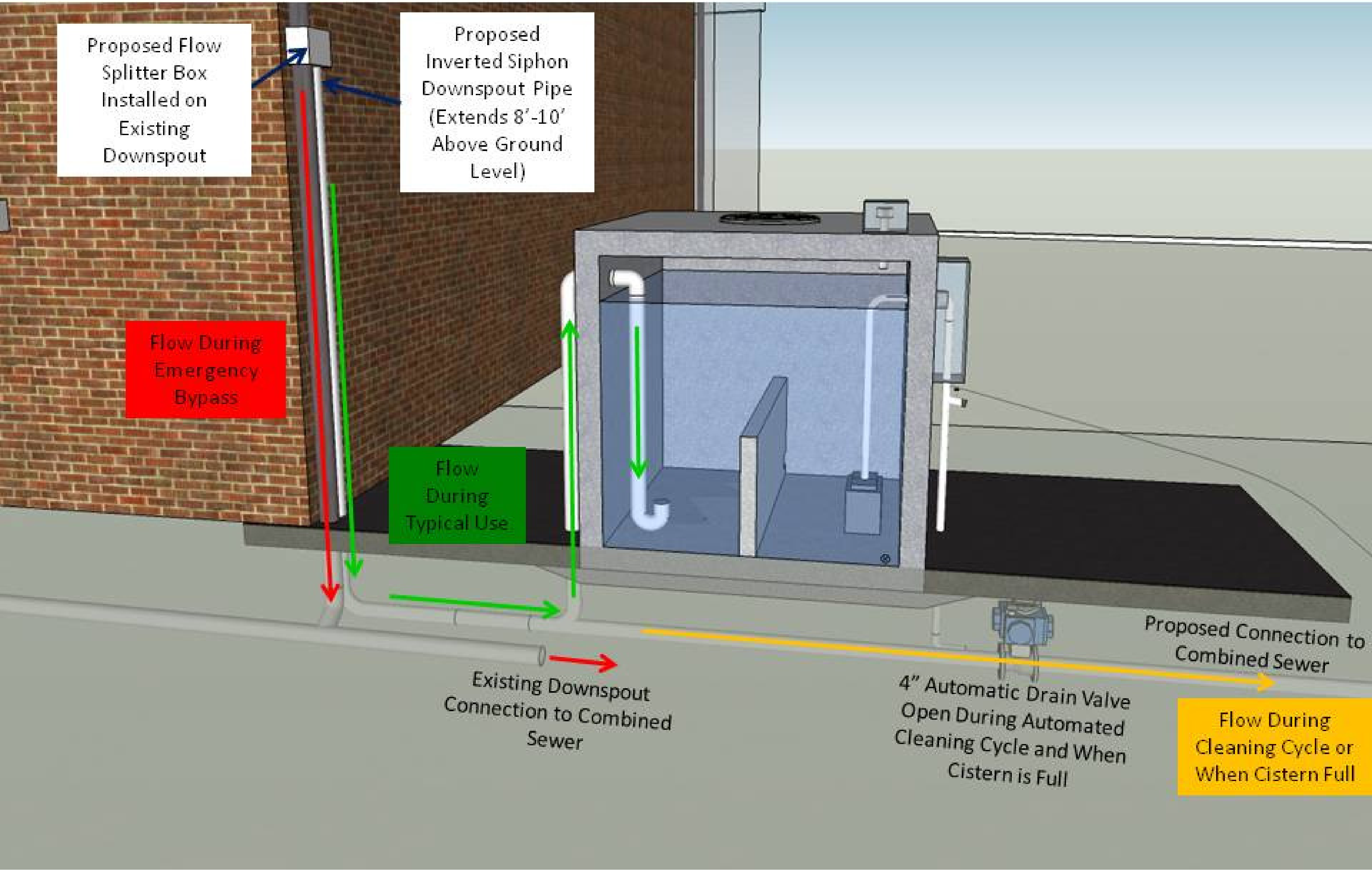


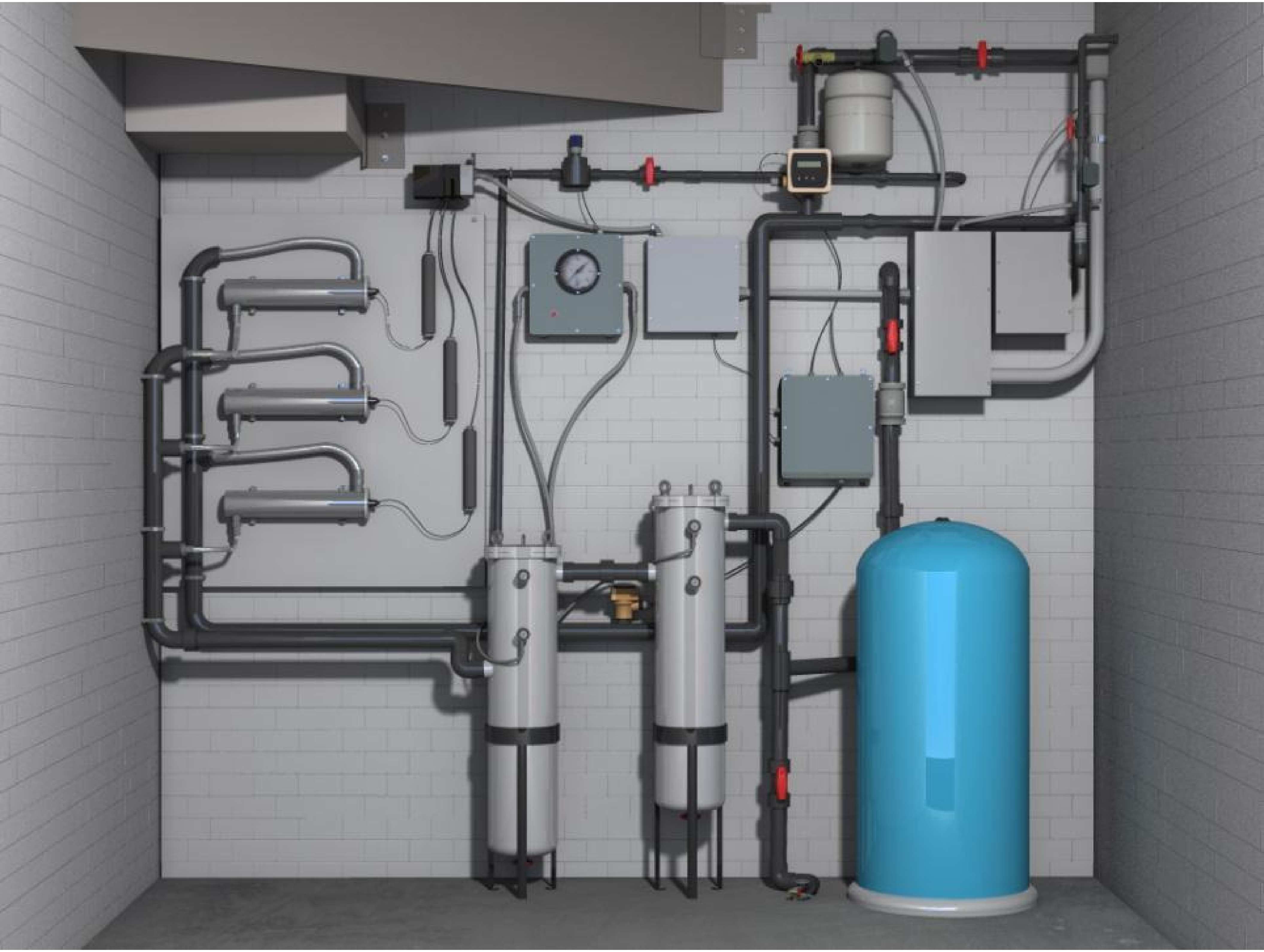
Pilot Site: Washington, DC
Engine House #3

Pilot Site: Washington, DC - Engine House #3: Design

Inverted Siphon Downspout Design

(Note: location of cistern is shown close to building for illustrative purposes only)



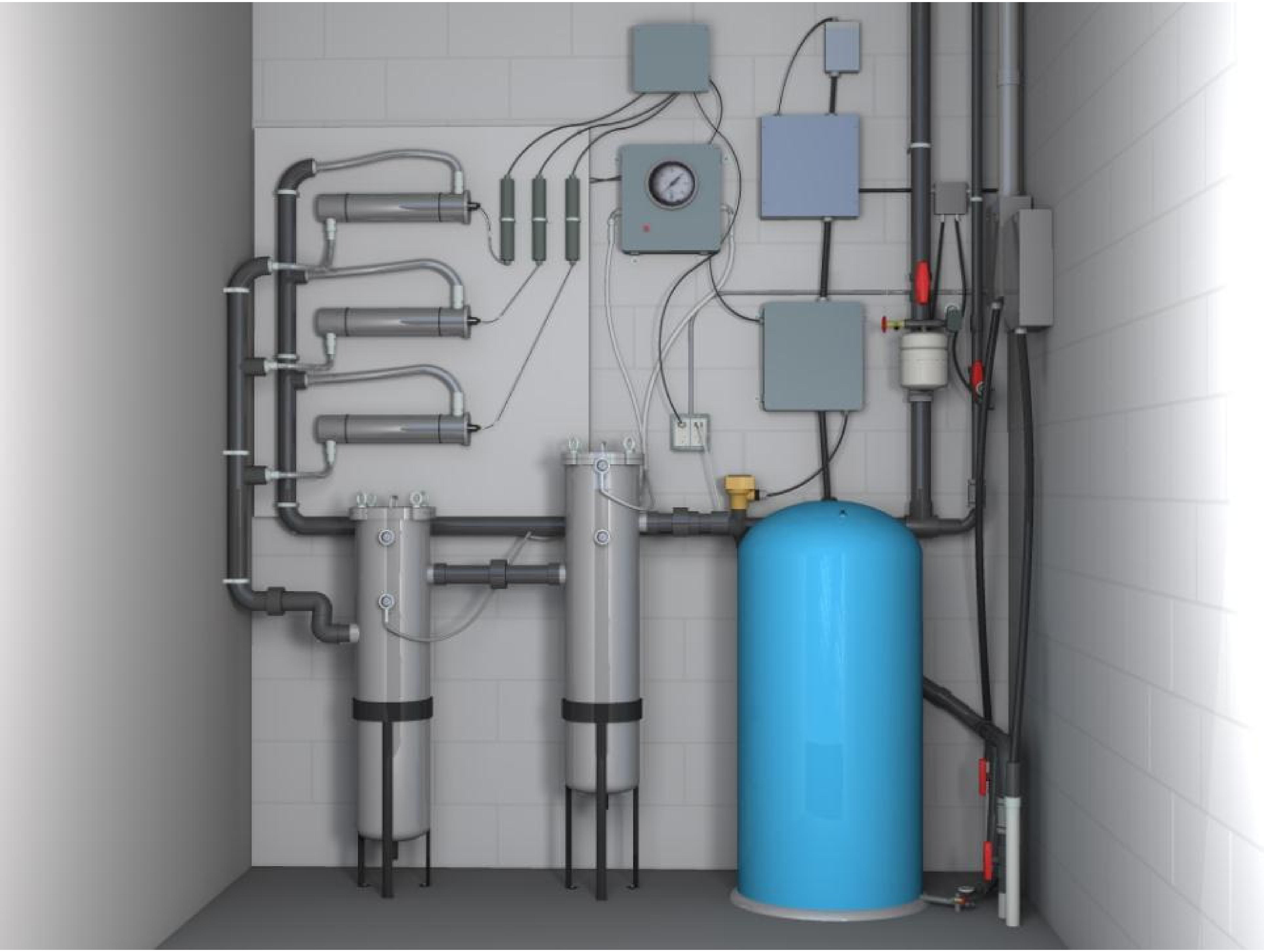




ARRA.


CLEAR FLOW PRECAST
CF
AMERICAST


Engine House 25



DDOE Pilot as Potential Prototype

Conceptual Rendering of Site in Kansas City, MO

Project Site: Rainwater Harvesting Site Locations
St. Louis, MO

Harvesting Garden Rendering

Renaissance Place

Pre-construction

Renaissance Place

Geo-fabric placement

Pad compaction

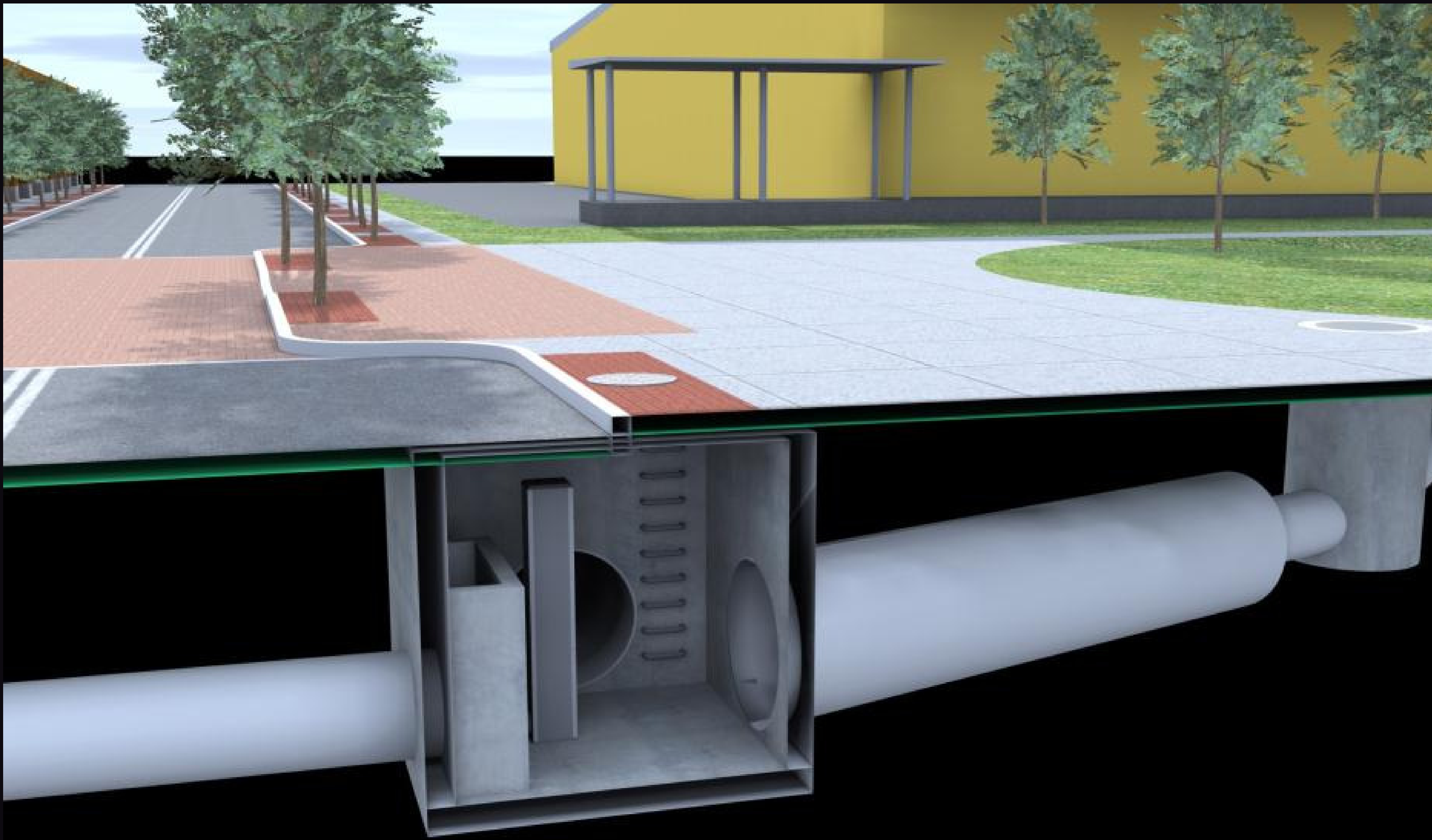
Renaissance Place

Initial excavation

Cistern placement (10,000 gal)

Harvesting system cisterns

Controlled discharge valve



Chattanooga Main Terrain Park Harvesting Retrofit

Chattanooga Main Terrain Park Harvesting Retrofit

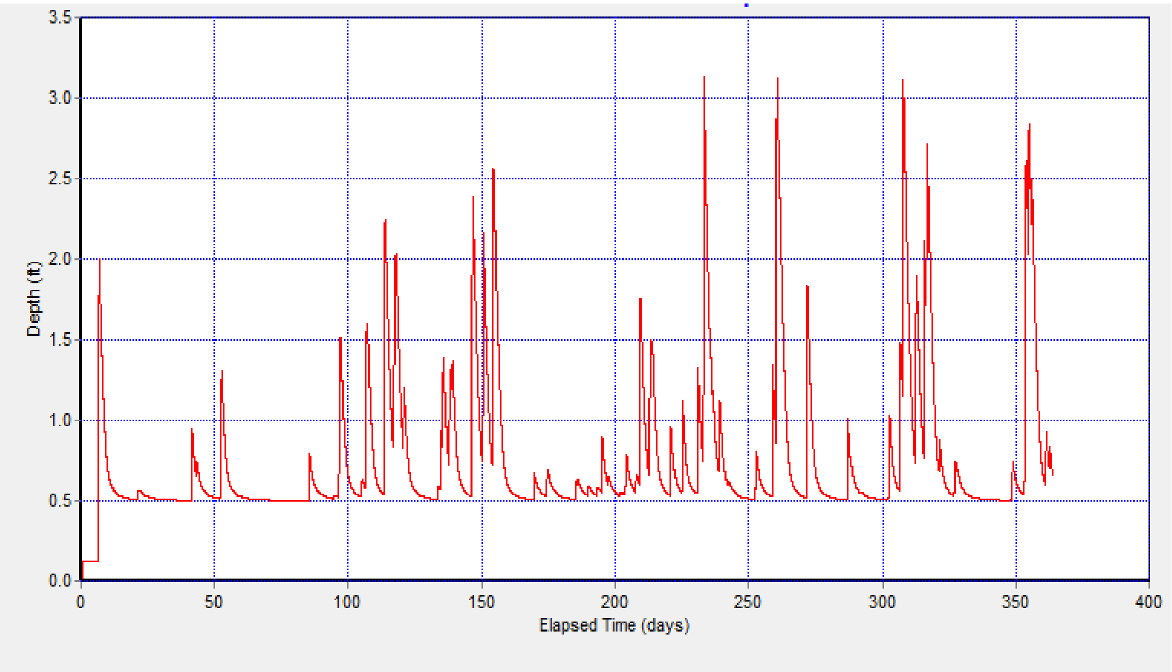
Technology Application: Detention/Retention/Flood Control Retrofits

Technology Application: Modeled Wetland Pond/water Feature Retrofits

North Carolina Design (collaboration with Bill Hunt)

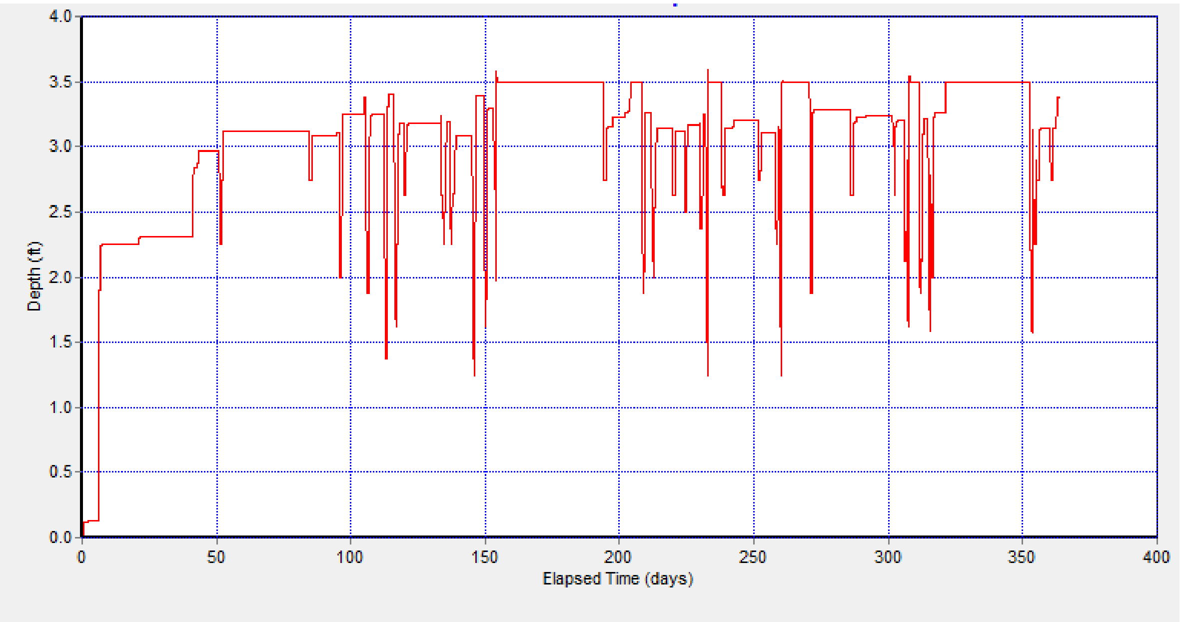
<u>Depth Time Series and Average Hydraulic Residence Time for Passive Outlet</u>

Average Hydraulic Residence Time (hrs)
13 days



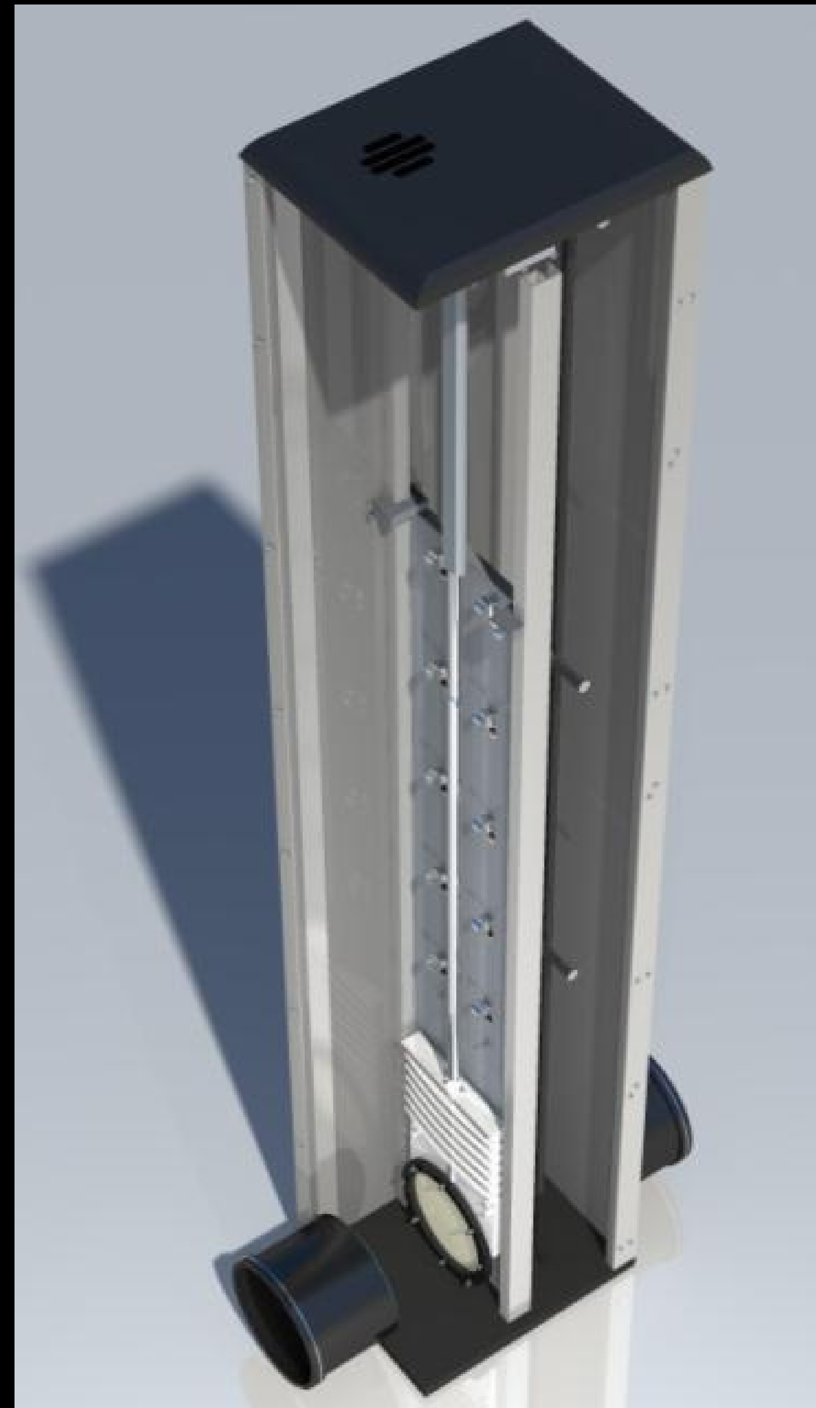
<u>Depth Time Series and Average Hydraulic Residence Time for Actively Controlled Outlet</u>

Average Hydraulic Residence Time (hrs)
24 days



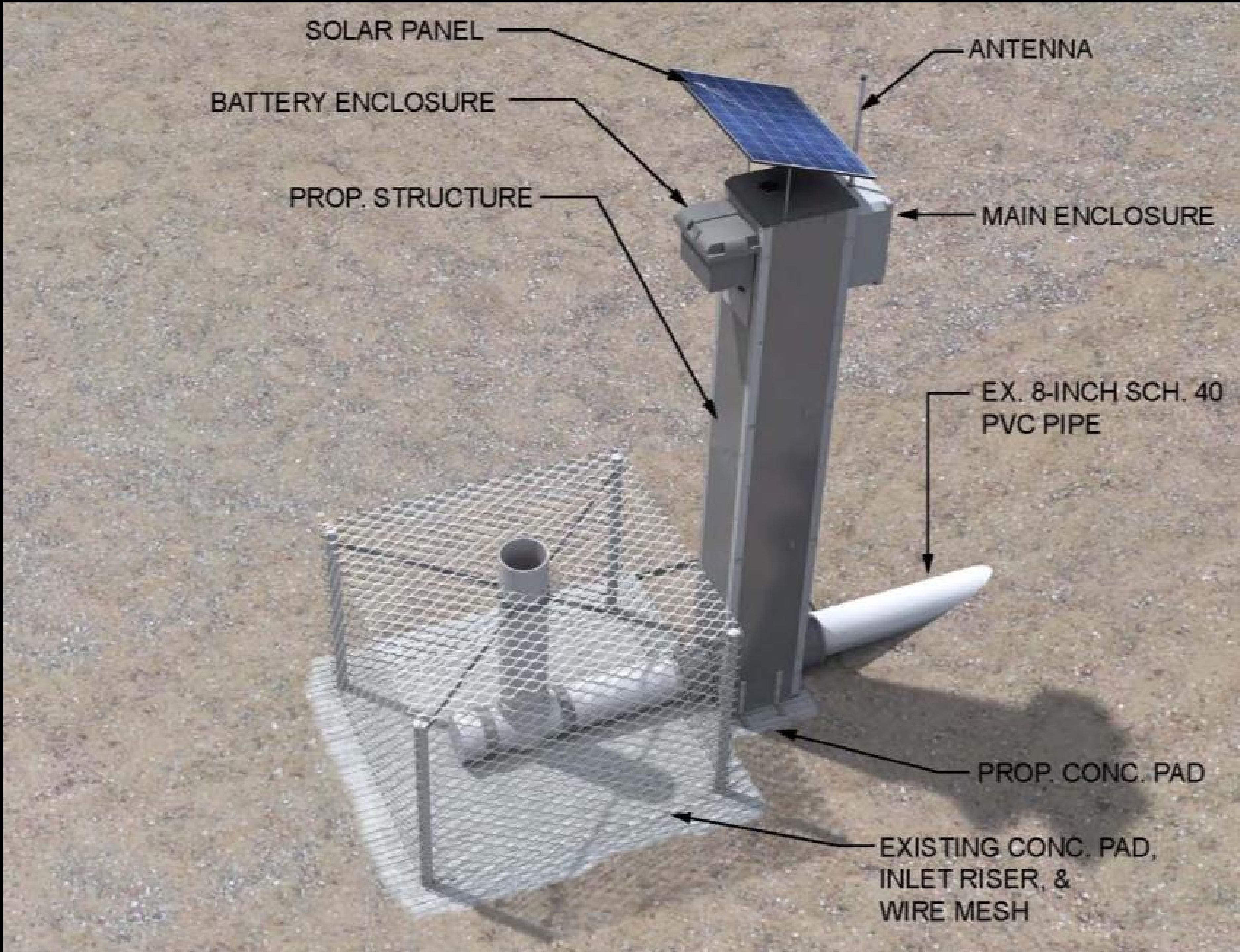
Brooklyn Botanical Garden – Pond Control for CSO Mitigation

Pond RTC Outlet Control Retrofit – Austin, TX



RTC Outlet Control Structure

Existing Pond Outlet Control Structure – Austin, TX



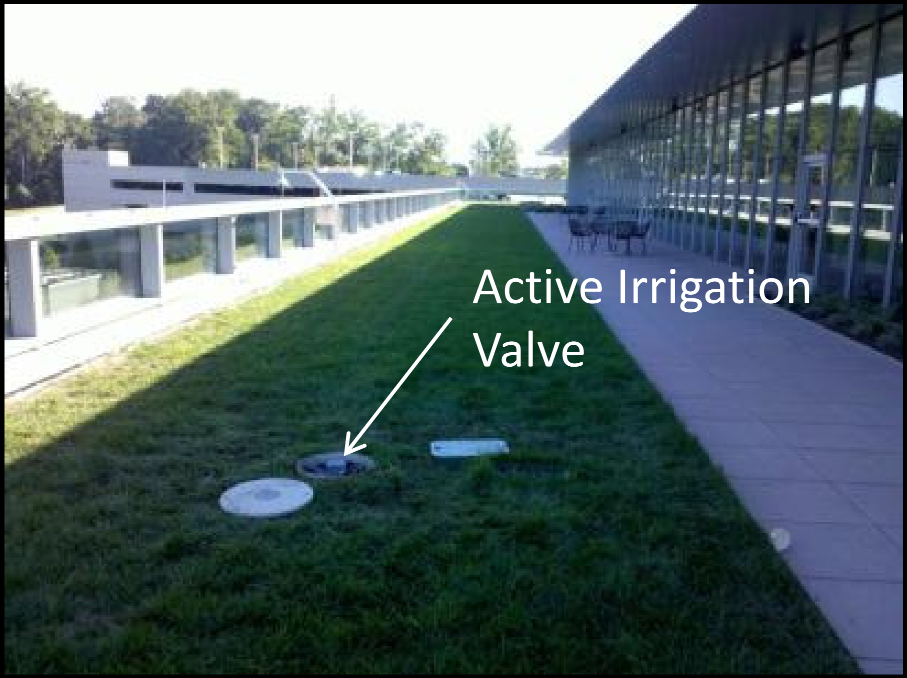
Outlet Control Structure

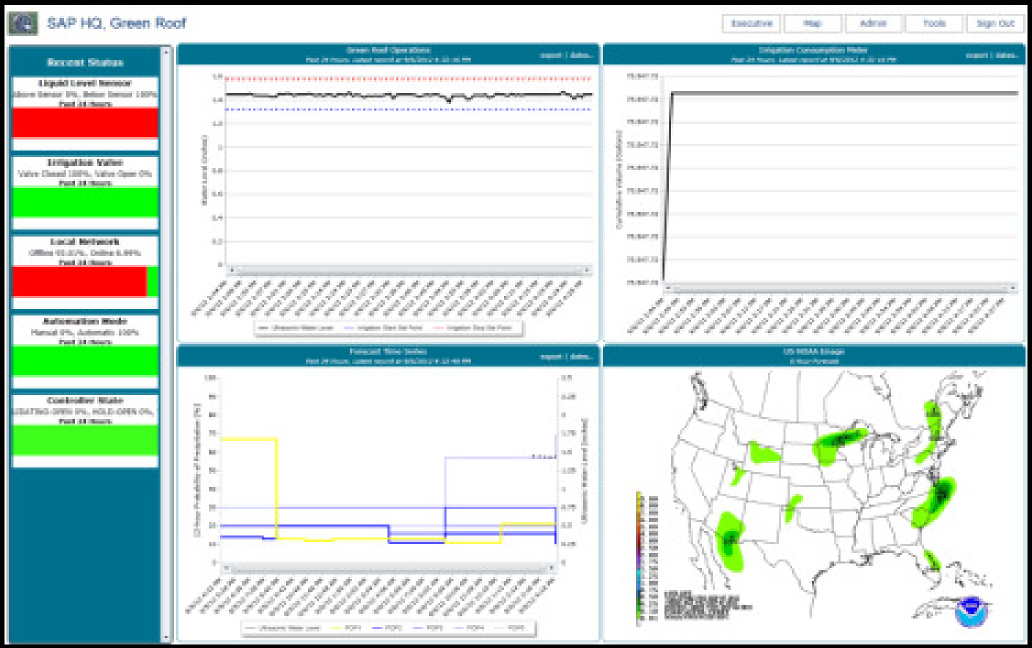
Technology Application: Active Blue and Green Roofs

Technology Application: Active Green Roof

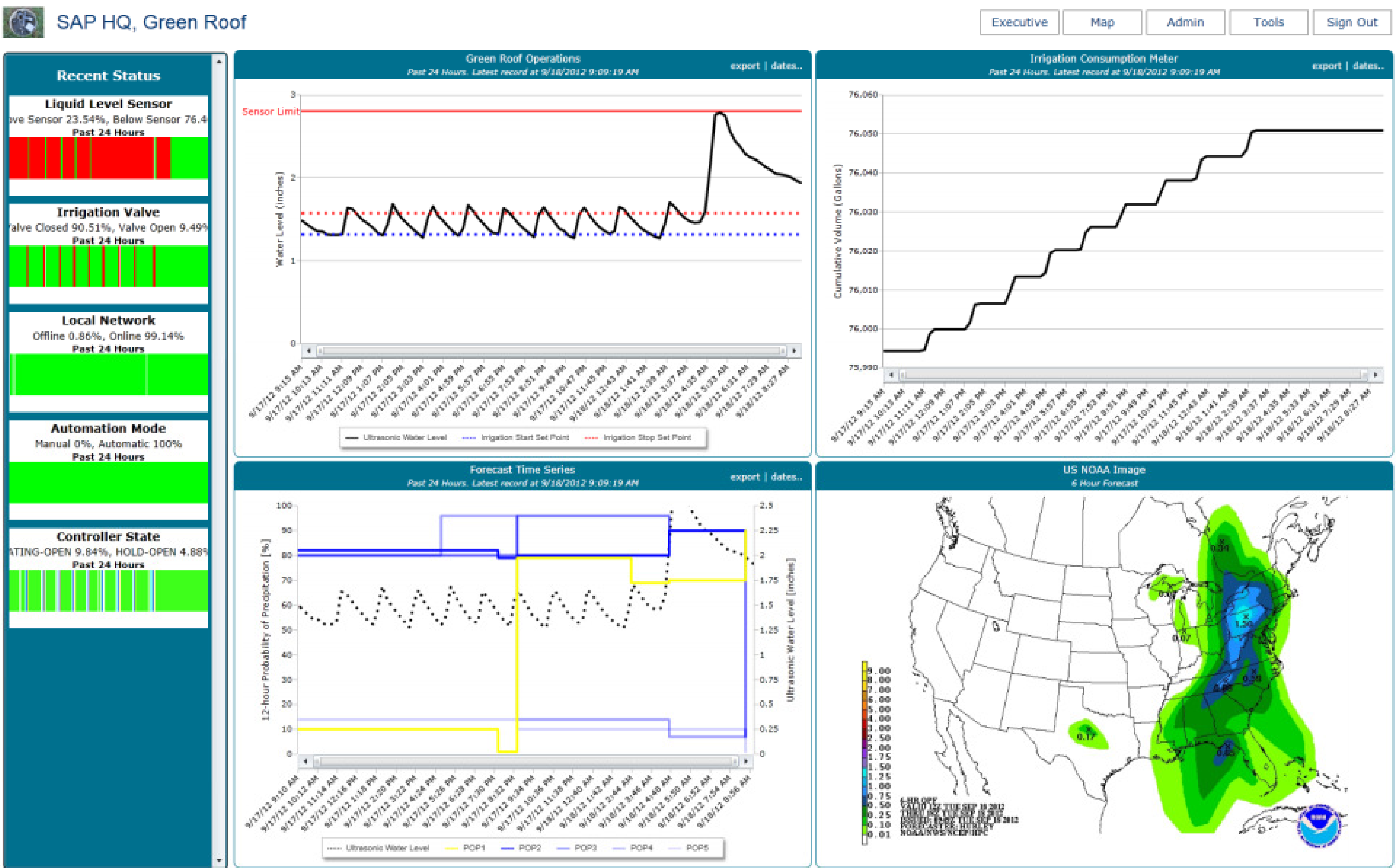
- Make real-time forecast based decisions on when and how much to drain or irrigate the roof
- Make storage volume available for stormwater volume and peak control
- Reduce irrigation waste

Actively Controlled Green Roof - SAP Headquarters
(Collaboration with Roofmeadow)





SAP HQ – Dashboard (1-min refresh)
System Behavior 9/18/2012 9:12 AM



Technology Application: Controlled Underdrain Bioretention

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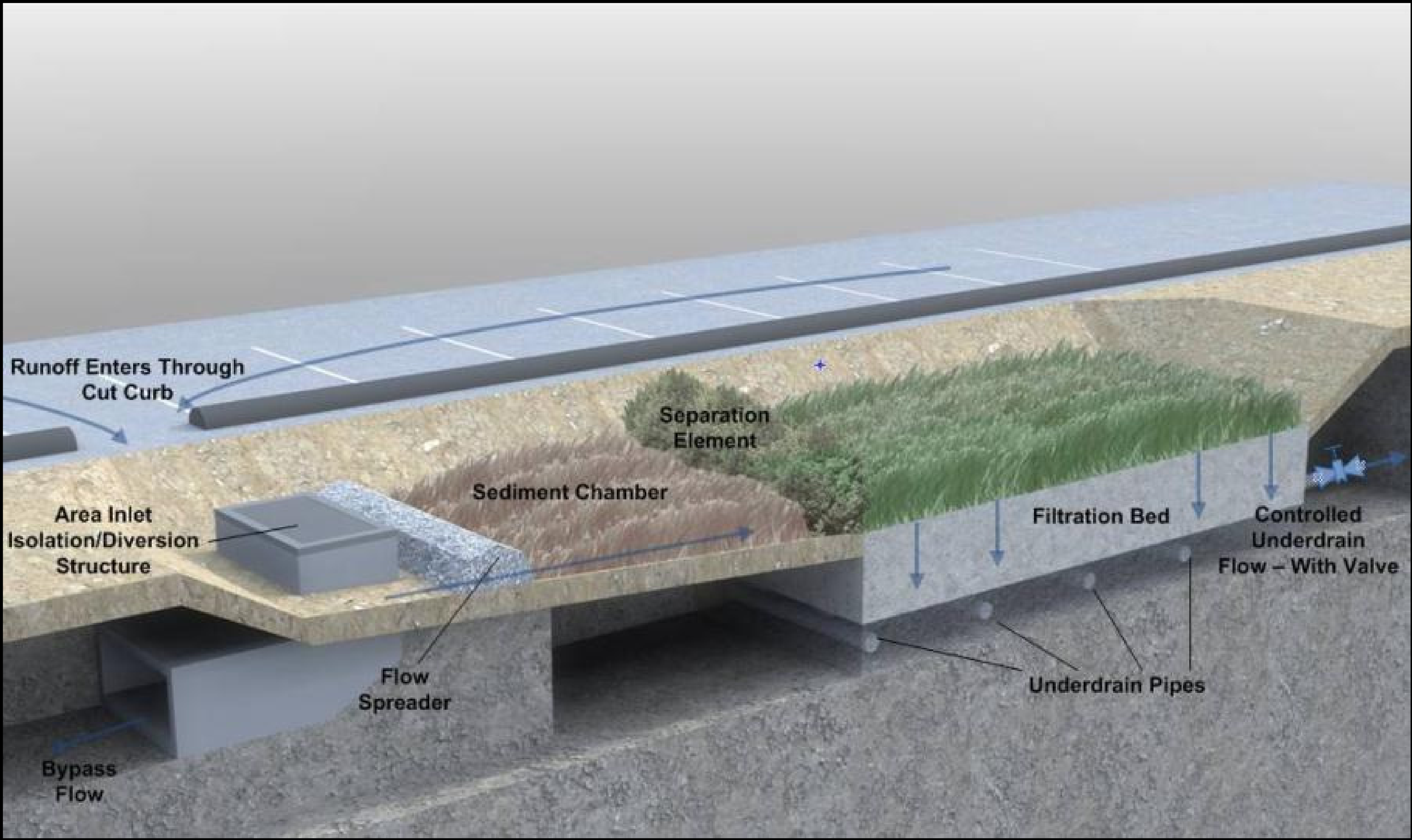


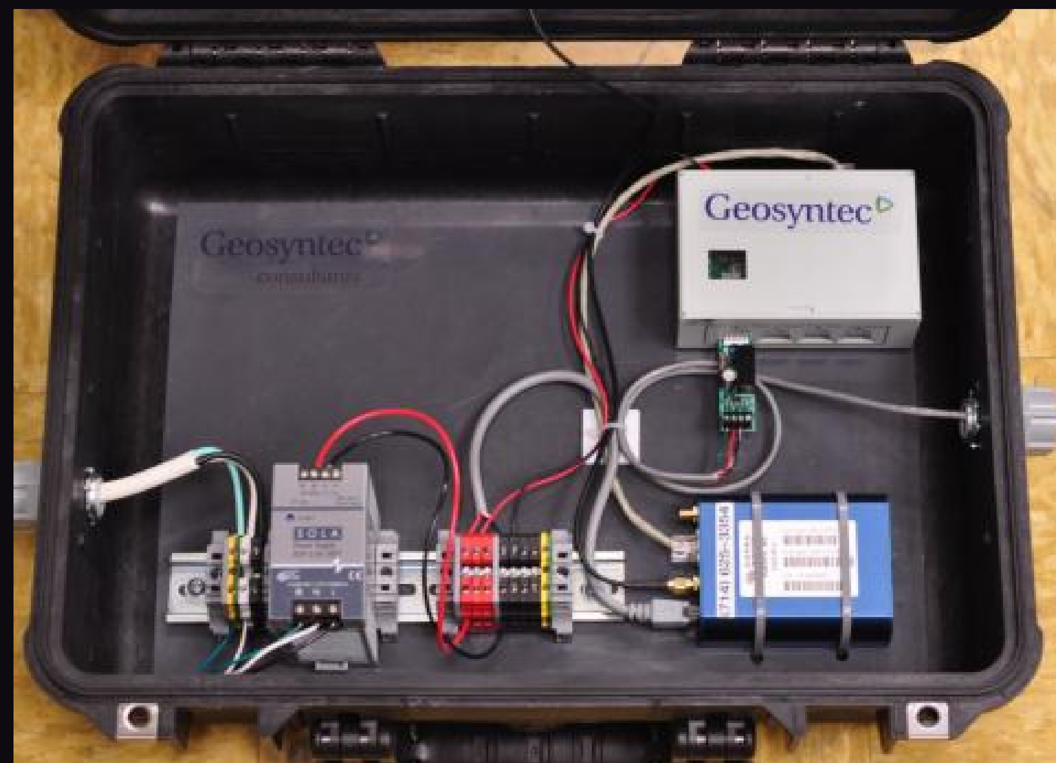



Gwinnett County, GA Controlled Underdrain Bioretention and Cistern Retrofit

Technology Application: Portable and Wireless Sensor RTC Monitoring

Wireless OptiRTC

Portable Field Kits



Cost/Benefit Analysis and Research WERF/GLPF

Cost/Benefit Analysis

Objective Function – Maximize Benefits:

$$Z = \sum_{t=1}^{T} S_I R_{h,t} + \sum_{t=1}^{T} S_I R_{g,t} - \sum_{t=1}^{T} C_O R_{O,t} - \sum_{t=1}^{T} C_S R_{S,t}$$

Where,

S_I = savings of irrigation outflow = \$.03/ft^3

C_O = cost of overflow outflow = \$.08/ft^3

C_S = cost of spill = \$.10/ft^3

$R_{h,t}$ = greenhouse pump outflow at time t

$R_{O,t}$ = overflow of tank outflow at time t

$R_{S,t}$ = spilled outflow of tank at time t

$R_{g,t}$ = grass area pump outflow at time t

Constraints:

$$S_{t+1} = S_t + Q_t + G_t - R_{g,t} - R_{h,t} - R_{O,t} - R_{C,t} - R_{S,t} \qquad for\ all\ t = 1 \ldots T$$

$$R_{O,t} \geq 0 \qquad R_{h,t} \leq I_{Dh,t}$$

$$R_{C,t} \geq 0 \qquad R_{C,t} \leq R_{Cmax,t}$$

$$R_{S,t} \geq 0 \qquad R_{O,t} \leq R_{Omax,t}$$

$$S_t \geq 0 \qquad S_t \leq T_v$$

Where,

S_t = storage of water in tank at time t

$I_{Dh,t}$ = irrigation demand of greenhouse at time t

$R_{g,t}$ = grass area pump outflow at time t

$R_{h,t}$ = greenhouse pump outflow at time t

$R_{O,t}$ = overflow of tank outflow at time t

$R_{C,t}$ = controlled outflow of tank at time t

$R_{S,t}$ = spilled outflow of tank at time t

G_t = inflow into cistern from grass area overflow at time t

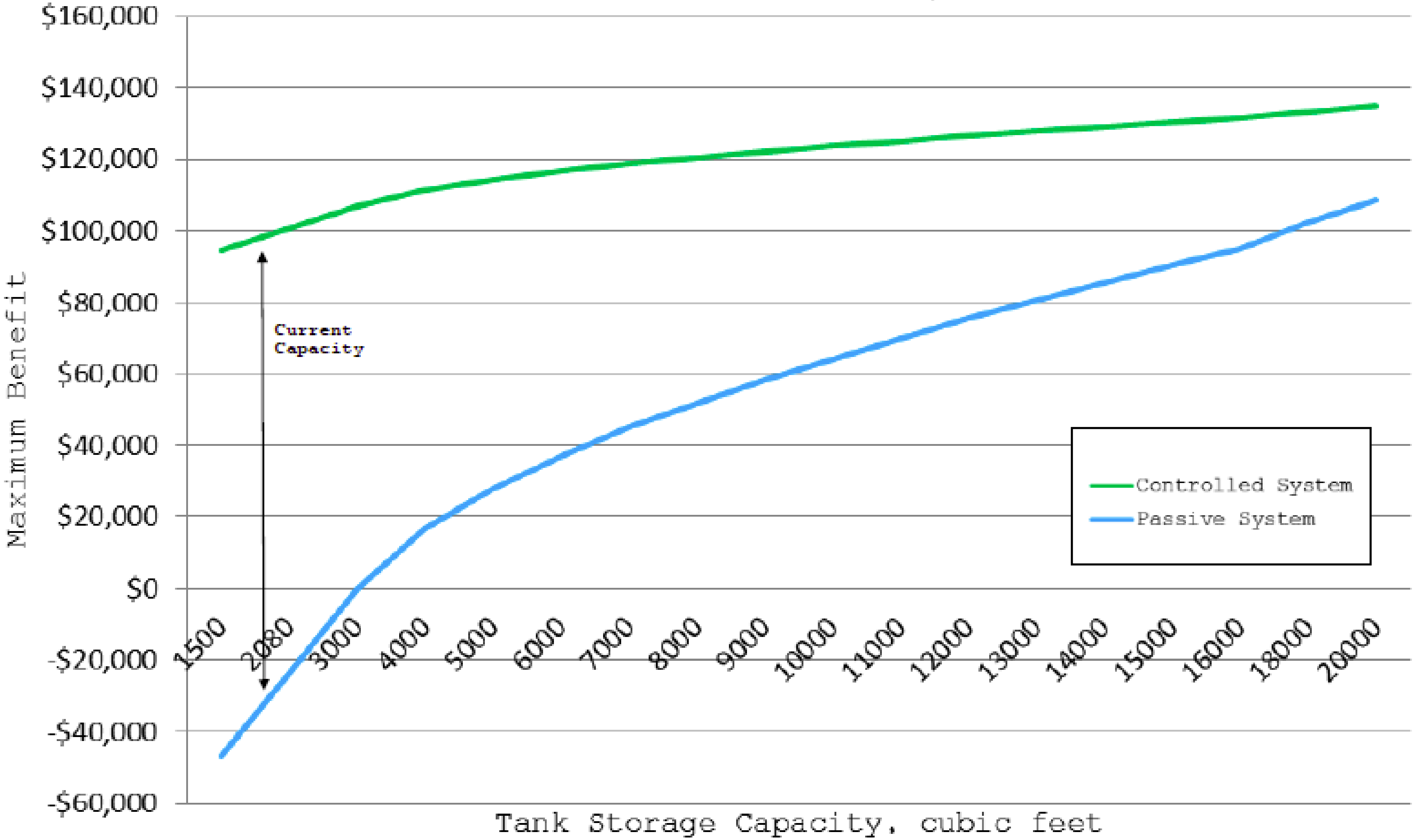
Q_t = inflow into cistern from roof and parking lot runoff at time t

$R_{Cmax,t}$ = maximum controlled outflow at time t = 3130 ft^3

$R_{Omax,t}$ = maximum overflow outflow at time t = 9459 ft^3

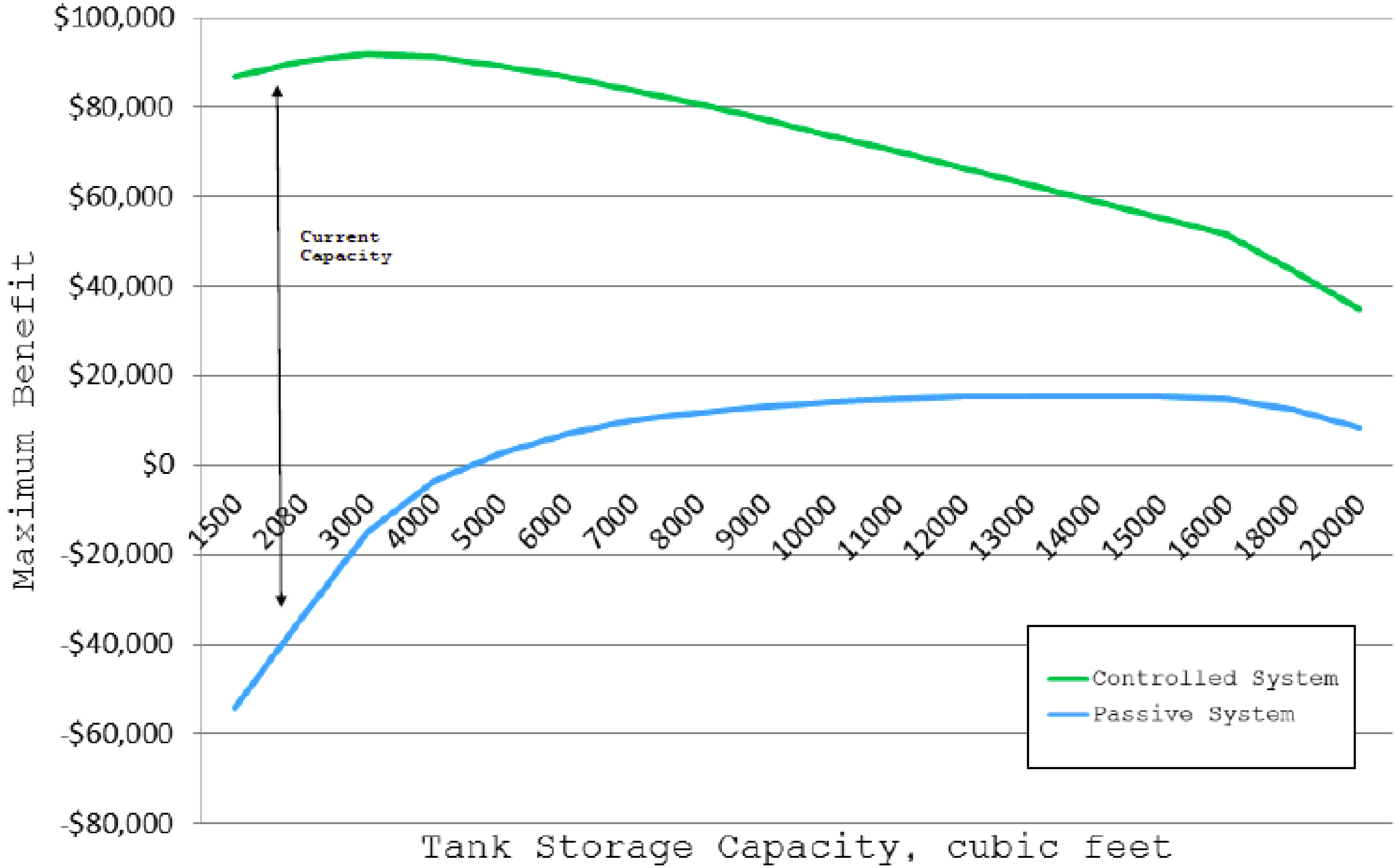
T_v = tank volume

Cost/Benefit Analysis



Comparison of maximum benefit vs. tank storage capacity of controlled and passive system.

Cost/Benefit Analysis



Comparison of maximum benefit vs. tank storage capacity of controlled and passive system with tank costs incorporated ($5.00/ft3)

Closing

- Much more fundamental research to be done
- Solve the general case (if possible)
- Low-cost, reliable, and highly functional sensors and sensor platforms will change everything
- Do not fear “dis”-integration and web API strategies.