Overview of Continuous Monitoring and Adaptive Control for Enhancing or Converting Approved Stormwater BMP Types in the Chesapeake Bay Watershed *presented to the Urban Stormwater Work Group October 20, 2015*
revised February 9, 2016 - see Examples and References section
revised May 9, 2016 - Considerations for Use of CMAC in the Chesapeake Bay Watershed

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There are now reliable, robust, and secure solutions for cost effective continuous monitoring and adaptive control (CMAC) of stormwater infrastructure. These solutions have an important role to play in accelerating the enhancement and conversion of existing stormwater facilities and construction of new facilities. CMAC solutions integrate information directly from field deployed sensors with real-time weather forecast data (i.e., NOAA forecasts) to directly monitor performance and make automated and predictive control decisions to actively manage stormwater storage and flows. The approach is non-proprietary, commercially deployed throughout the county for other stormwater management applications, and the outcomes have been verified by separate independent research efforts.

Specifically CMAC BMPs can improve environmental outcomes by:

- Using a facility's storage volume to detain flow across all storm sizes.
- Dramatically improving water quality from facilities by increasing residence time and/or improving unit process effectiveness (e.g., settling, denitrification).
- Restoring pre-development hydrology and base flows by actively modulating release rates based on forecast information.
- Increasing the volume retained on site.
- Intelligently detaining flows in combined sewer systems for release during dry weather.
- Reduce the frequency of flooding events.
- Enabling durable and adaptable designs that are less dependant on site specific conditions.
- Being adaptable to future climatic conditions or changes in site characteristics without new infrastructure and with only operation changes.

and reduce technical, regulatory, and compliance risk by:

- Providing auditable performance and supporting data without additional cost.
- Increasing uptime of facilities through alerting of operational or maintenance issues.
- Providing direct verification of facility performance.

State of the Practice and Technical Discussion:

Through empirical research, modeling, and widespread field deployments, CMAC solutions have been shown to result in significant increases in the performance of a range of existing stormwater BMPs while reducing operational and outcome risk.

Example Field Deployments and Existing Research:

- **EPA and the Water Environment Research Foundation (WERF)** published a report "*Transforming our Cities: High Performance Green Infrastructure"*, which was a pilot level study at eight locations around the country (WERF, 2014). The study concluded that distributed real-time control of green infrastructure can: significantly reduce contributions to combined sewers and mitigate post-storm combined sewer overflows, reduce stormwater runoff, conserve water, with particular benefits in drought-inclined areas, maximize reuse for irrigation. No other BMP can simultaneously accomplish these goals
- **Center for Research in Water Resources at the University of Texas at Austin and Geosyntec (2015)** showed that a passive dry pond conversion to a CMAC wet pond resulted in a facility that achieved a 73% reduction in Nitrate+Nitrite (Geosyntec, 2015) and a six fold reduction (from an average of 0.66 mg/L to 0.11 mg/L) in Nitrate+Nitrite over the pre-retrofit dry basin.
- **Muchalla et al. (2014)** found that retaining water using real-time rainfall-driven controls resulted in a 48 to 60% increase in removal of small particles from captured stormwater. "The removal efficiency for suspended solids could be significantly increased by all control strategies and the hydraulic peaks were reduced by at least 50%... [CMAC solutions] provide significantly higher removal efficiency for suspended solids and a possible flexible adaptation to future demands". Increasing retention time without increasing storage volume, such as with a dry pond to wet pond retrofit, has been shown to increase total suspended solids removal from 39 to 90% and ammonia-nitrogen removal from 10 to 84% (Carpenter et al., 2014 and Gaborit et al., 2012).
- **An analysis of the performance of the addition of CMAC on the harvesting systems installed in at USEPA headquarters in Washington DC** greatly improved the system's ability to mitigate stormwater volumes and flow rates and improve water quality. Total mass reductions estimated from this system during a one year monitoring period indicate removals based on residence time of 89% (TSS), 14% (TP) and 77% (TN), (Debusk, 2015).

Typical Applications in the Chesapeake Bay Watershed:

CMAC of stormwater storage can have a particularly positive impact on the water quality improvement performance of existing approved best management practice (BMP) approaches while also restoring predevelopment flows. CMAC provides a mechanism for achieving both the BMP Conversion and BMP Retrofit categories of retrofits recognized by the Chesapeake Bay Program Expert Panel to Define Removal Rates for Urban Stormwater Retrofit Projects (Scheuler et al., 2012) using existing approved retrofit approaches.

Stormwater BMPs with forecast-based adaptive control achieve better pollutant removal and runoff reduction outcomes because, among other benefits, they can increase the amount of time that stormwater remains in the treatment facility without compromising capture rate while also reducing the frequency of erosive flows. Further, the technology used to deploy the CMAC also collects performance continuously, allowing for accurate and precise quantification of a BMP's actual (not theoretical) performance. Direct continuous monitoring of facility performance should be the gold-standard in the Chesapeake Bay Watershed for quantifying and verifying load reduction credits and verifying implementation plan results. This direct documentation is available using CMAC solutions with approved BMP types.

Considerations for Use of CMAC in the Chesapeake Bay Watershed

CMAC is merely one component of a successful restoration project and can be used in conjunction with other retrofit activities to achieve restoration credit. As with all stormwater installations, the proposal to credit CMAC retrofit techniques should be fully vetted by the responsible governmental entity(ies) and comply with all state and local requirements, including dam safety requirements, for the proposed facility(ies). The design, installation, and operation of CMAC facilities must account for potential failure of the physical and control systems. Specifically CMAC enabled facilities must be designed to explicitly address loss of communication or power, lack of maintenance, intentional vandalism, and other potential failure modes. CMAC systems should be held to the same standards as existing controls. Beyond the requirements for designing and building inherently safe facilities we are particularly encouraged more broadly that CMAC systems are able to alert to conditions of potential concern.

Recommend additional verification requirement: Proof of contractual agreement between CMAC service provider and facility owner or entity responsible for the facility.

CMAC provides a reliable, cost effective means for continuous monitoring and adaptively controlling new and existing stormwater quality facilities. Given that CMAC can provide significant and auditable performance enhancements to approved BMP types, credit should be given for directly demonstrated outcomes. Specifically:

- In the current credit system, a wet pond only gets credit for its volume. However, with CMAC, the precise volume that meets treatment requirements is continuously measured. Therefore, credit can and should be given for the actual treated volume, increasing the credit derived from an existing BMP.
- CMAC is an enhancement to BMPs; therefore, no new BMP types are required to be approved by the expert panel.
- Annual reporting of CMAC integrated project performance should accompany annual compliance reports under implementation plans. These reports should be verified by a professional engineer in the state of record.

Conclusions

Over the past decade, significant advances in hardware, software, communications infrastructure (i.e., the internet) and scalable computing architectures (i.e., cloud computing) have made it cost-effective to deploy reliable, secure, highly intelligent continuous monitoring and adaptive control solutions to help address some of our most challenging water quality issues. We have a significant opportunity to leverage these new technologies alongside the significant existing work of the Working Group and Expert Panel reports to help protect and restore the Chesapeake Bay.

Examples and References

The following examples demonstrate how two different CMAC retrofits and credits would work in practice, submitted in accordance with the Process for Handling Urban BMP Decision Requests, approved by the USWG on January 19, 2016. Table 1 (attachment) provides CMAC retrofit descriptions for Category A, B, and C BMP types recognized by the Chesapeake Bay Program and watershed jurisdictions (CBP, 2009). The following examples demonstrate how the retrofit removal adjustor curves for total phosphorus, total nitrogen, and sediment can be used to credit CMAC retrofits in accordance with the Recommendations of the Expert Panel to Define Removal Rates for Urban Stormwater Retrofit Projects (Schueler and Lane, 2012).

Retrofit Example 1: Enhancing the Performance of an Underperforming Wet Pond

An existing wet pond in Montgomery County, MD was under designed relative to the current watershed development and the current regulatory targets. Over time, the storage capacity of the pond has also diminished due to sedimentation and lack of maintenance. The pond currently provides adequate water quality treatment for 0.22 inches per impervious acre. The pond is retrofit with CMAC to use the storage between the existing passive outlet invert and the existing 2-year storm event overflow weir as extended detention water quality volume.

The retrofit involves installing an actuated valve on the existing passive outlet, a level sensor in the pond, and communication hardware to connect the valve and sensor to cloud-based decision software with forecast integration. The pond's water quality volume is increased to 1.2 inches per impervious acre by retaining stormwater in the available space above the permanent pool after storm events, while also protecting against flooding by actively monitoring the water level and forecast, and making a decision about when and how to draw down the extended detention volume in advance of the next storm. The retrofit removal adjustor curves for ST practices are then used to determine the incremental pollutant removal rates associated with the pond restoration, as follows:

	TP	TN	TSS
Restored Rate (1.2 inches)	55%	34%	69%
Existing Rate (0.22 inches)	26%	17%	35%
Incremental Rate	29%	17%	34%

Retrofit Example 2: Dry Pond to Wet Pond Conversion

A dry pond was built in 1988 in Prince George's County, MD that was designed to provide flood control only and receives no water pollutant removal credit. A CMAC retrofit is deployed that enables full capture and extended detention for 2 acre-feet of stormwater runoff, or 1.25 inches per impervious acre.

The retrofit involves modification of the passive outlet structure with an actuated valve and installing a level sensor in the pond storage area. Communication hardware connects the valve and sensor to cloud-based decision software with forecast integration. The pond's water quality volume is increased to the full 1.25 inches per impervious acre, as the software is configured to retain stormwater in the pond for 48 hours after a storm. When multiple events are forecasted within that period, the software responds by opening the valve to set the pond volume such that the flood storage capacity is adequate. Part of the design process for a specific facility is to install CMAC such that channel protection, flow-duration, and peaks meet state and local requirements. This is accomplished where needed through outlet valve modulation (adjustable flow independent of head). Furthermore CMAC can often be deployed to greatly exceed requirements without additional cost. This is one of the benefits of the approach.

The retrofit removal adjustor curves for ST practices are used to determine the incremental pollutant removal rates associated with the pond restoration, as follows:

	TP	TN	TSS
Restored Rate (1.25 inches)	56%	35%	70%
Existing Rate (0.0 inches)	-	-	-
Incremental Rate	56%	35%	70%

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Table 1: Continuous Monitoring and Adaptive Control Retrofit Options

BMP Category	BMP Type	Description	Proposed Post-CMAC Retrofit BMP Category	CMAC Retrofit Description	Example Credit Calculations
A: Wet Ponds and Wetlands - Practices that have a combination of a permanent pool, extended detention or shallow wetland equivalent to the entire water quality storage volume. Practices that include significant shallow wetland areas to treat urban stormwater but often may also incorporate small permanent pools and/or extended detention storage.	Wet pond	A stormwater management pond designed to obtain runoff and always contains water.	A	A wet pond can be retrofit into a wet extended detention pond, increasing the water quality volume without compromising peak flow mitigation.	Retrofit Example 1 provided in "Overview of Continuous Monitoring and Adaptive Control for Enhancing or Converting Approved Stormwater BMP Types in the Chesapeake Bay Watershed"
	Wet extended detention pond	Combines the pollutant removal effectiveness of a permanent pool of water with the flow reduction capabilities of an extended storage volume.	A	A wet extended detention pond can be enhanced by increasing the total extended detention volume or improving the extended detention time.	
	Multiple pond system	A group of ponds that collectively treat the water quality volume.	A	A multiple pond system can be enhanced by increasing the total water quality volume without compromising peak flow mitigation.	
	"Pocket" pond	A small pond with little or no baseflow available to sustain water elevations during dry weather.	A	A "pocket" pond can be retrofit to introduce a semi-permanent pool and to increase the total water quality volume.	
	Shallow wetland	A wetland that provides water quality treatment entirely in a wet shallow marsh.	A	A shallow wetland can be retrofit to increase the water quality treatment volume by detaining storm volumes above the marsh surface (extended detention wetland) or by introducing additional treatment processes with hydraulic controls (pond/wetland system)	
	Extended detention wetland	A wetland system that provides some fraction of the water quality volume by detaining storm flows above the marsh surface	A	An extended detention wetland can be enhanced to further extend the retention time of storm flows, especially smaller events, or by adding water quality volume above the existing extended detention volume.	
	Pond/wetland system	A wetland system that provides a portion of the water quality volume in in the permanent pool of a wet pond that precedes the marsh for a specified minimum detention time.	A	A pond/wetland system can be enhanced by extending the retention time of certain hydraulic components, especially for smaller events, or by adding water quality volume above the existing design.	
	"Pocket" wetland	A small wetland with little or no baseflow available to sustain water elevations during dry weather.	A	A "pocket" wetland can be retrofit to introduce a semi-permanent pool and to increase the total water quality volume.	
	Submerged gravel wetland	One or more treatment cells that are filled with crushed rock, designed to support wetland plants.	A	A submerged gravel wetland can be enhanced by extending the hydraulic retention time to facilitate improved water quality treatment conditions, especially for smaller events.	
	Constructed wetland	Systems that perform a series of pollutant removal mechanisms.	A	Constructed wetlands can be enhanced by extending their hydraulic retention time or otherwise modifying hydraulic controls to facilitate improved water quality treatment conditions.	
	Retention pond (wet)	Surface pond with permanent pool.	A	A retention pond can be retrofit into an extended detention pond, increasing the water quality volume without compromising peak flow mitigation.	See Retrofit Example 1
	Wetland basin with open water surface	Retention pond with at least 50% of the permanent pool covered by emergent wetland vegetation.	A	A wetland basin can be enhanced by extending the hydraulic retention time or otherwise modifying hydraulic controls to facilitate improved water quality treatment conditions, or by adding water quality volume above the existing permanent pool.	
	Retention basin	Captures and retains a storm volume until it is displaced in part or in total by the next runoff event, maintaining a significant permanent pool between runoff events.	A	A retention basin can be retrofit into an extended detention basin, increasing the water quality volume without compromising peak flow mitigation.	See Retrofit Example 1
B: Dry Detention, Hydrodynamic Structure - Practices used to moderate flows and remain dry between storm events.	Dry pond	Designed to moderate influence of peak flows and rains completely between storm events.	A, C	A dry pond can be retrofit into a wet pond by adding a permanent pool or into a dry extended detention pond by adding semi-permanent pool (extended detention volume), without compromising peak flow mitigation.	Retrofit Example 2 provided in "Overview of Continuous Monitoring and Adaptive Control for Enhancing or Converting Approved Stormwater BMP Types in the Chesapeake Bay Watershed"
	Underground dry detention facility	Designed to moderate influence of peak flows and drains completely between storm events, using underground facilities for storage.	C	An underground dry detention facility can be retrofit into a water quality treatment facility by adding a semi-permanent pool to facilitate particle settling, without compromising peak flow mitigation.	
C: Dry Extended Detention - A stormwater design feature that provides gradual release of volume of water in order to increase settling of pollutants and protects downstream channels from frequent storm events.	Dry extended detention pond	Dry ponds with an outlet designed to retain a water quality volume for a minimum duration, but do not have a permanent pool.	A, C	A dry extended detention pond can be retrofit into a wet pond or similar Category A BMP, or enhanced, by increasing the water quality volume, adding a permanent pool, and/or increasing the retention time.	See Retrofit Example 2
	Extended detention basin	An impoundment that temporarily stores runoff for a specified period and is usually dry during non-rainfall periods.	A, C	An extended detention basin can be retrofit into a wet pond or similar Category A BMP, or enhanced, by increasing the water quality volume, adding a permanent pool, and/or increasing the retention time.	See Retrofit Example 2
	Enhanced extended detention basin	An extended detention basin enhanced with a shallow marsh in the bottom.	A, C	An enhanced extended detention basin can be retrofit into a wet pond or similar Category A BMP, or further enhanced, by increasing the water quality volume, adding a permanent pool, and/or increasing the retention time to facilitate improved water quality treatment conditions in the marsh.	

Presentation to the Chesapeake Bay Program USWG

Supporting Material for CMAC Urban BMP Decision Request

February 16, 2016

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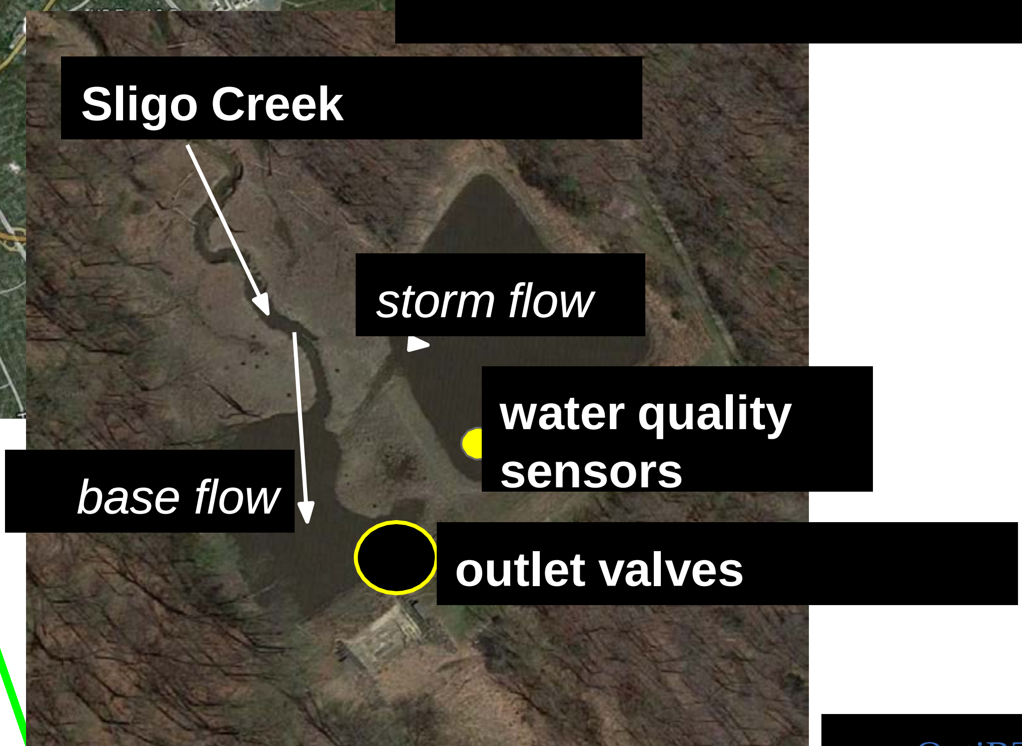
Retrofit Example 1: Enhance Existing Wet Pond

440 Acre Drainage Area

160 Acre Impervious

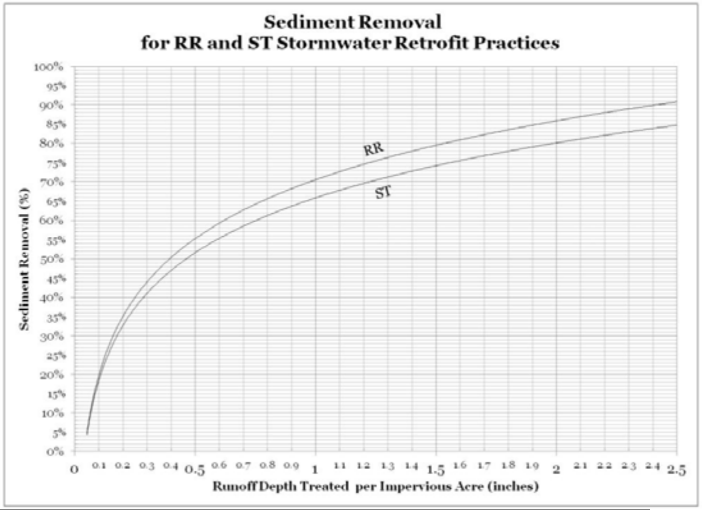
Storage in-line on Sligo Creek
Permanent pool approx. 3 ac-ft



Retrofit Example 1: Enhance Existing Wet Pond

Retrofit Example 1: Enhance Existing Wet Pond

Credit Calculations

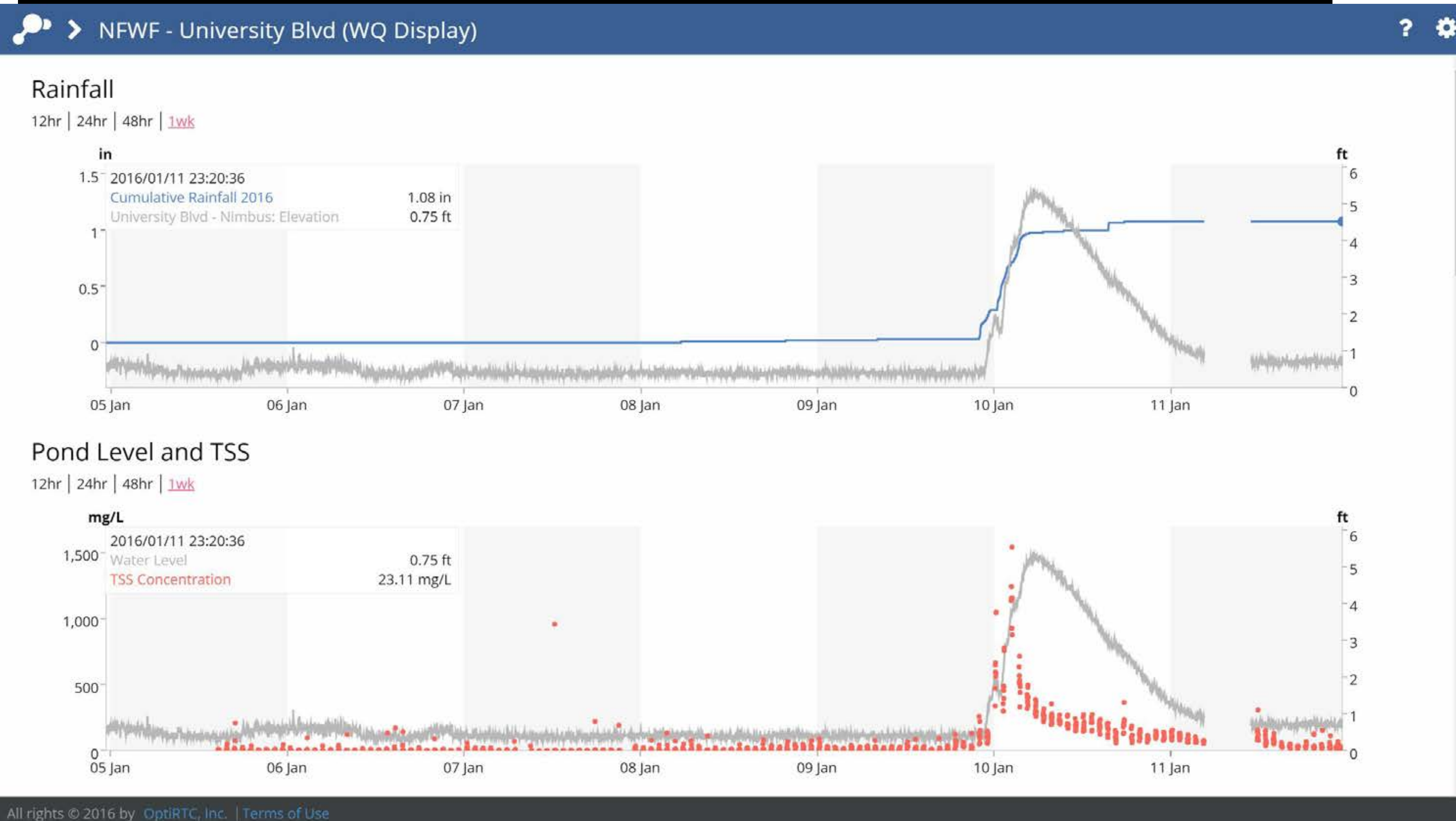


Retrofit Example 1: Enhance Existing Wet Pond

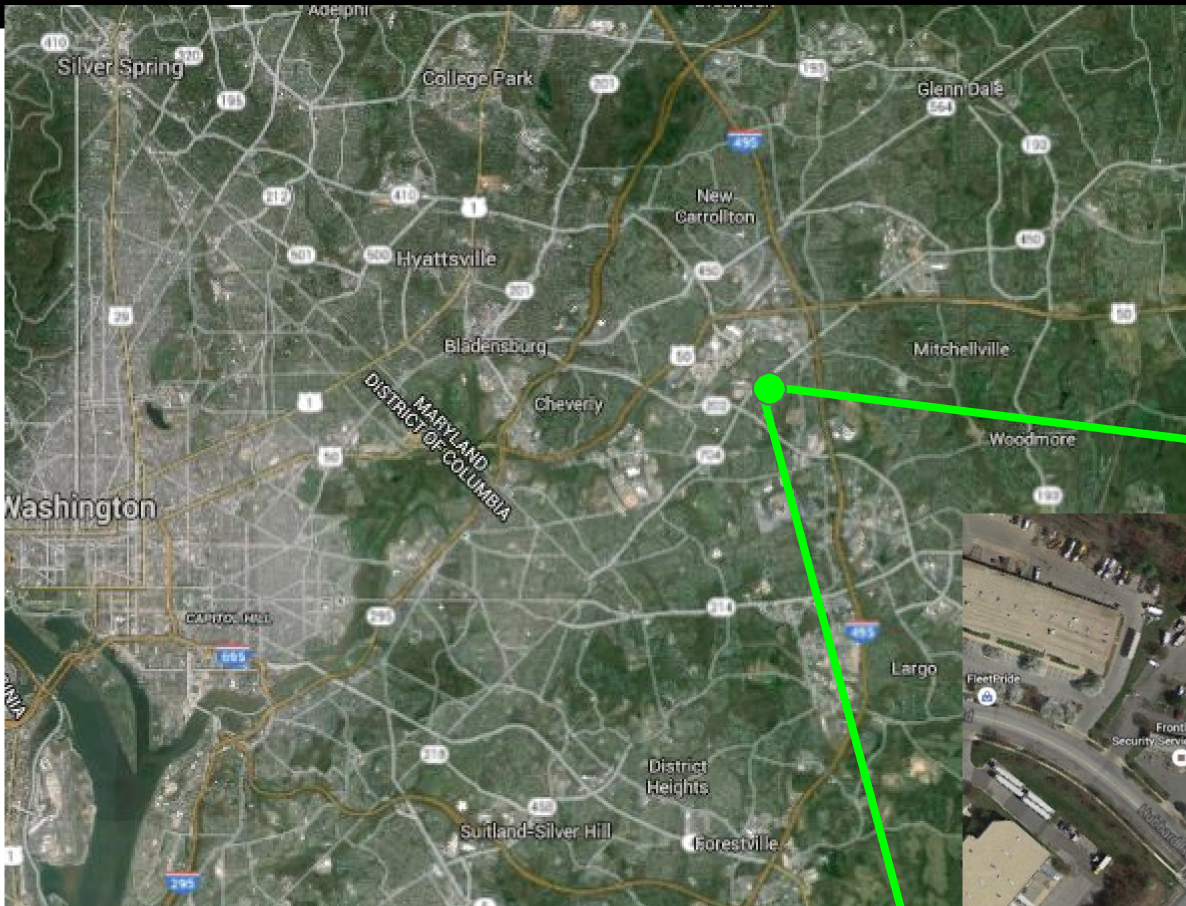
Data for Verification

Retrofit Example 1: Enhance Existing Wet Pond

Data for Verification (sensor integration)



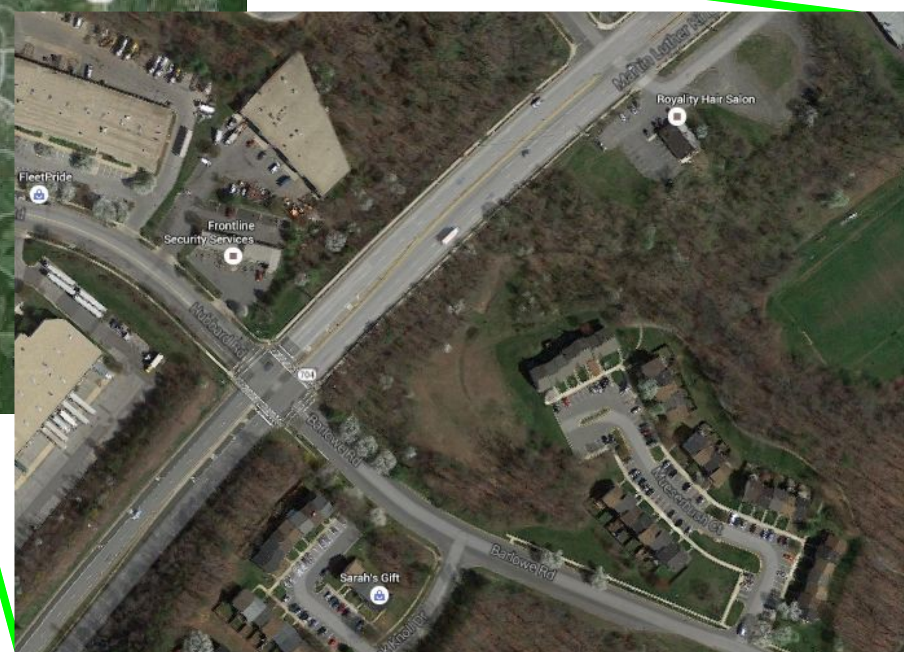
Retrofit Example 2: Dry Pond Conversion



60.3 Acre Drainage Area

19.2 Acre Impervious

Approx. 0.5 ac Dry Pond built in 1988



Retrofit Example 2: Dry Pond Conversion

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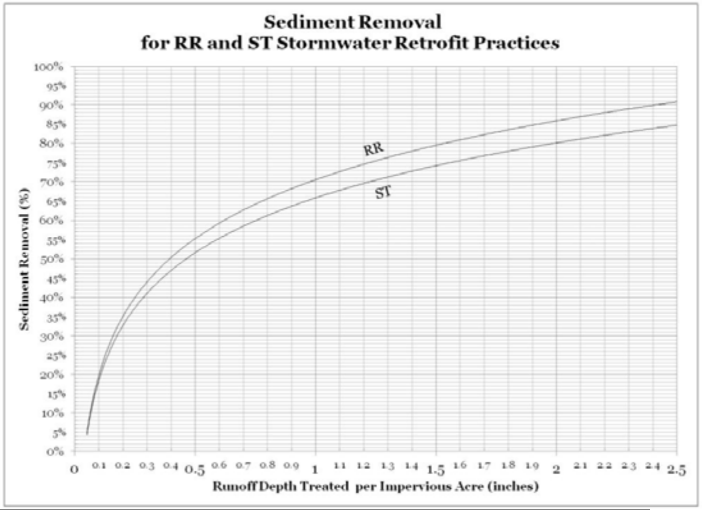
Credit Calculations



Retrofit Example 2: Dry Pond Conversion

Data for Verification