Overview of Continuous Monitoring and Adaptive Control for Enhancing or Converting Approved Stormwater BMP Types 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: A vigorous verification process (record keeping and reporting) should be followed for anyone using the technology who is seeking pollution reduction credit toward Bay or local TMDL WLAs. Proof of contractual agreement between CMAC service provider and facility owner or entity responsible for the facility should be provided.

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 underdesigned 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 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%

This example provides guidance for how to use the retrofit removal adjustor curves to calculate the credit available in a wet pond retrofit with CMAC. Additional considerations for obtaining the credits from Chesapeake Bay state regulators may include providing pre-treatment, forebay, wet pool, and vegetation requirements. As with other BMPs, individual states must work with local jurisdictions to establish a credit approval process.

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 be deployed to exceed requirements without additional cost (Kerkez et al. 2016). This is one of the benefits of the approach.

The retrofit removal adjustor curves for ST practices are used to 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%

This example provides guidance for how to use the retrofit removal adjustor curves to calculate the credit available in a dry pond retrofit with CMAC. Additional considerations for obtaining the credits from Chesapeake Bay state regulators may include providing pre-treatment, forebay, wet pool, and vegetation requirements. CMAC provides an alternative approach for achieving one of the more cost-prohibitive and site constraint sensitive components of retrofitting dry ponds into water quality treatment BMPs - creating water quality and channel protection storage volumes. As with other BMPs, individual states must work with local jurisdictions to establish a credit approval process.

References

Bannerman, R. T., D. W. Owens, R. B. Dodds and N. J. Hornewer. Sources of pollutants in Wisconsin stormwater. Water Science Technology. 28(3-5):241-259. 1993.

Carpenter, Jason Faber, Bertrand Vallet, Genevieve Pelletier, Paul Lessard, and Peter A. Vanrolleghem. Pollutant removal efficiency of a retrofitted stormwater detention pond. Water Quality Research Journal of Canada. 49.2. 2014.

Chesapeake Bay Program (CBP) Sediment Workgroup and Sediment BMP Workshop of February 2003. Best Management Practices for Sediment Control and Water Clarity Enhancement. CBP/TRS-282-06. October 2009.

DeBusk, K. M. and W. F. Hunt. Impact of rainwater harvesting systems on nutrient and sediment concentrations in roof runoff. Water Science & Technology. 14(2): 220-229. 2014.

Gaborit, Etienne, D. Muschalla, B. Vallet, P.A. Vanrolleghem, and F. Anctil. Improving the performance of stormwater detention basins by real-time control using rainfall forecasts. Urban Water Journal, Vol. 10 No. 4, 230-246. 2013

Kerkez, Branko, Cyndee Gruden, Matthew Lewis, Luis Montestruque, Marcus Quigley, Brandon Wong, Alex Bedig, Ruben Kertesz, Tim Braun, Owen Cadwalader, Aaron Poresky, and Carrie Pak. Smarter Stormwater Systems. Environ. Sci. Technol., 2016, 50 (14), pp 7267–7273

Klenzendorf, Brandon, Michael Barrett, Marty Christman, Marcus Quigley. Water Quality and Conservation Benefits Achieved via Real-Time Control Retrofits of Stormwater Management Facilities near Austin, Texas, 2015.

Moran, Amy Christine. A North Carolina Field Study to Evaluate Greenroof Runoff Quantity, Runoff Quality, and Plant Growth. A thesis published by the Graduate School of North Carolina State University, under the direction of Dr. William F. Hunt, III, and Dr. Greg Jennings. 2004

Muschalla, Dirk, Bertrand Vallet, Francois Anctil, Paul Lessard, Genevieve Pelletier, Peter A. Vanrolleghem. Ecohydraulics-driven real-time control of stormwater basins. Journal of Hydrology. 511, 82-91. 2014.

OptiRTC, Inc. Report on Nationwide Continuous Simulation Modeling of Forecast-Based Control BMP Performance Using the EPA Stormwater Management Model (SWMM). 2015.

Debusk, Kathy. Unpublished White Paper. Achieving Stormwater Management with OptiRTC: A Case Study at United States Environmental Protection Agency Headquarters in Washington, D.C. 2015.

Schueler, Tom and Cecilia Lane, et al. Recommendations of the Expert Panel to Define Removal Rates for Urban Stormwater Retrofit Projects. Chesapeake Bay Program. 2012.

Water Environment Research Foundation (WERF). Transforming our Cities: High-Performance Green Infrastructure. WERF and IWA Publishing. 2014.