Coagulant Enhanced Stormwater Treatment for Use in the Chesapeake Bay Watershed

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List of Abbreviations

ACH	aluminum chlorohydrate
Al	aluminum
Alum	aluminum sulfate
ANSI	American National Standards Institute
BMAP	Best Management Action Plan
BMP	Best Management Practices
CAN	Control Area Network
CBP	Chesapeake Bay Program
CBPO	Chesapeake Bay Program Office
CET	Coagulation Enhanced Treatment
CWP	Center for Watershed Protection
cfs	cubic feet per second
DO	dissolved oxygen
DP	dissolved phosphorus
EPA	US Environmental Protection Agency
EPR	Expert Panel Report
FDEP	Florida Department of Environmental Protection
FRP	Fiberglass reinforced plastic
Ft	feet
gpm	gallons per minute
HDPE	High density polyethylene
ID	Idaho
IDEQ	Idaho Department of Environmental Quality
L	liter
mg/L	milligrams per liter
MG	million gallons
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
NPRD	National Pollutant Removal Performance Database
NSF	National Sanitation Foundation
NuRF/NURF	Nutrient Reduction Facility
O&M	Operation and Maintenance
PAC	polyaluminum chloride
PLC	Programmable Logic Controller
PPV	Permanent Pool Volume
PRF	Phosphorus Removal Facility
RR	Runoff Reduction
SCS	Soil Conservation Service
SR	Stormwater Retrofit
ST	Stormwater Treatment
s.u.	Standard units
SWMM	Stormwater Management Model
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	total phosphorus
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
VA	Virginia
VRRM	Virginia Runoff Reduction Method
WI	Wisconsin

Section 1

Key Definitions and Qualifying Conditions

1.1 Definition of the Coagulant Enhanced Treatment (CET) Retrofit Practice

Coagulant Enhanced Treatment (CET) is a stormwater/surface water treatment Best Management Practices (BMP) enhancement used to increase nutrient and pollutant removal efficiencies. CET is being classified as a BMP enhancement retrofit alternative by the Chesapeake Bay Urban Stormwater Workgroup. CET can be added to an existing wet pond or can be constructed as a new BMP. Implementation can be completed on existing wet ponds regardless of original design and water quality treatment volume. A wet pond (stormwater retention pond, wet extended detention pond) is a stormwater BMP with a permanent pool of water typically with an average depth of 3.5 to 8 feet. Wet ponds are designed to treat stormwater quality through physical, chemical, and biological processes.

CET includes adding a common flocculent to stormwater/surface water which forms precipitates which trap total phosphorus (TP), total nitrogen (TN), bacteria, total suspended solids (TSS), metals, and other pollutants. CET is different in that it is a flow through treatment system with a shorter design residence time. Settling pond residence time is based on the contributing watershed peak design water flow rate (peak treatment flow rate) for the design rainfall event/depth. CET treatment can be directly related to the existing Chesapeake Bay Retrofit Removal Rate Adjustor Curves by understanding the relationship between rainfall event depth and average annual runoff volume captured or treated.

With CET, stormwater or surface water is typically diverted from a storm sewer or channel into an off-line treatment system or treated in-line with a wet settling pond. Treated water is returned to the storm sewer or channel downstream of the inflow. Primary unit processes are flash/rapid mix (vigorously mixing water with the coagulant) and precipitate settling in a wet pond. Wet pond permanent pool volume is sized to allow sufficient detention time for the precipitates to settle to the bottom of the pond (prior to pond discharge) at the peak design water flow rate. Systems are designed to treat stormwater runoff from “common” rain events (typically 1 to 2-inches) and/or surface water to achieve the desired pollutant load reductions. Settling pond detention time is based on the results of jar testing using multiple samples of the actual water to be treated plus a safety factor. Coagulants containing aluminum are normally used due to their high pollutant removal efficiencies and precipitate stability in natural waterbodies. CET is selected due to:

- Higher pollutant removal efficiencies
- Substantially less land required
- Ability to treat large watershed areas with a single project
- Lower life cycle cost per mass TP, TN, and bacteria removed
- Improves surface water quality for habitat, aesthetics, and recreational use

- Accelerate and simplify National Pollutant Discharge Elimination System/ Municipal Separate Storm Sewer System/Total Maximum Daily Load (NPDES/MS4/TMDL) compliance

CET design and implementation must meet the following criteria:

- Treat up to the peak runoff/surface water discharge rate for the design storm event, 1 to 2-inches in depth. Note that this proposed peak design water flow rate determines the required settling pond Permanent Pool Volume (PPV) as a function of minimum residence time. More detail is provided in Section 3.
- Minimum settling pond PPV residence time for floc settling at peak design water flow rate shall be the time for floc settling observed during jar testing times a safety factor of two, 3 hours minimum. Settling pond PPV for floc storage is separate.
- Additional settling pond PPV shall be provided for consolidated floc storage. Consolidated floc storage must be provided for each year between floc removal events, one year minimum floc storage. One year of consolidated floc volume is the floc volume resulting from treating the design average annual runoff volume at the design coagulant dose. Consolidated floc volume as a percent of water volume treated shall be determined using floc consolidation from jar testing.
- Total minimum settling pond PPV shall be the minimum PPV for floc settling plus the design number of years of consolidated floc volume (one year minimum).
- Aluminum coagulants shall be used and must be produced by a reputable company with minimal impurities and be NSF/ANSI/CAN 60 certified for use in potable water treatment.

1.2 Additional Qualifying Conditions and Practice Limitations

<u>Watershed Area Treated:</u> Treating larger watershed areas is preferred due to the larger pollutant load reduction and cost effectiveness. Existing CET systems treat watershed areas of more than 60 square miles while it is also common to treat a 1,000-acre watershed. Few systems have been constructed that treat a watershed area less than 500 acres. Many coagulant treatment components are similarly sized regardless of watershed size (e.g., coagulant feed pump(s) and control system, water flow meter(s), equipment piping, equipment building or vault, electrical and water service. The primary difference is the size of the stormwater/surface water conveyance and the floc settling pond.

<u>Hydrology and Hydraulic Analyses:</u> An appropriate hydrologic and hydraulic model (e.g., PCSWMM, XPSWMM, ICPR) shall be used to model the watershed peak design water flow rate for the selected design storm event depth and design any inflow and outflow water conveyances. Per Bay guidance, a SCS Type II distribution (24 hrs.) should be used. Other watershed hydrologic and hydraulic parameters must also be developed for post condition modeling. Additionally, implementation of CET shall not increase the 100-year 24-hour peak stages or discharges at, upstream, or downstream of the project. Other local and state flood protection requirements must also be met.

In some cases, there may be a desire to treat runoff, and possibly dry weather baseflow, from a tributary with sufficient and accurate historic flow rate monitoring. In this case an acceptable alternative is to create a flow probability distribution that relates design water flow rate treated to average annual water volume treated. An example is shown in Table 1 for a 10,000-acre watershed tributary. All water flows up to 200 cfs are treated equating to approximately 82 percent of the watershed average annual water volume. Larger storm discharges (>200 cfs) bypass the treatment system. This is one example and each watershed will be unique depending on area, physical, hydrologic and hydraulic characteristics.

Table 1. Example Average Annual Water Inflow Probability Distribution

Daily Mean Water Flow Range (cfs)	Days Per Year	Daily Mean Flow Rate (cfs)	Annual Flow Range Volume (ac-ft)	Annual Cumulative Flow Volume (ac-ft)	Cumulative Percent of Total Annual Volume (%)
0-5	179	2	669	669	6
5-10	70	7	1,017	1,686	15
10-15	36	14	993	2,678	24
15-20	18	17	617	3,295	30
20-25	13	22	590	3,885	36
25-30	8	28	443	4,328	40
30-40	13	35	872	5,200	48
40-50	8	45	720	5,920	54,
50-60	6	55	624	6,544	60
60-70	3	64	410	6,954	64
70-80	2	74	297	7,250	66
80-90	1	85	217	7,468	68
90-100	1	94	161	7,629	70
100-150	4	118	851	8,480	78
150-200	1	173	442	8,922	82
200-300	0.5	248	246	9,168	84
300-500	1	376	477	9,645	88
500-1000	0.5	758	751	10,396	95
1000-1500	0.2	1,234	514	10,910	100
Total	365		10,910	10,910	

Laboratory Jar Testing: Laboratory jar testing shall be completed on the stormwater or surface water to be treated with CET for at least four wet weather events (>0.25-inches in depth and visible wet weather flow, 72-hour antecedent dry weather) separated by at least 21 days. If dry weather flow is also to be treated complete laboratory jar testing on at least three dry weather samples (<0.1-inches over 72-hours) separated by at least 21 days.

If the contributing watershed includes one or more large industrial dischargers with substantial seasonal variability, consider modifying the laboratory program to capture any seasonal variability in watershed discharge characteristics. Industrial dischargers, including power plants, will ramp up or down production depending on need thereby increasing or decreasing their discharges which could change wet and dry weather discharge characteristics.

Laboratory Jar Testing shall be used to determine:

- Preferred aluminum coagulant and coagulant dose: typically, between 4 and 7.5 mg Al/L water treated to achieve the desired pollutant removal efficiencies and a settleable floc, and acceptable treated water quality. In unique cases a coagulant dose > 7.5 mg Al/L may be required to achieve the desired floc formation and pollutant removal efficiencies.
- Time for complete floc settling (hours).
- Raw and treated water lab results for each coagulant and dose at time 0 and 24 hours for: pH, conductivity, alkalinity, TP, TN, TSS, Cl^-, total Al, dissolved Al, and sulfate if using aluminum sulfate (alum) or other coagulant containing sulfate. pH shall also be measured 5 minutes after coagulant addition, and at 1 hour and 3 hours. Can also analyze for bacteria

(e.g., fecal coliform), metals, and other pollutants, if a concern. All field/lab samples must meet the Standard Method holding time requirements. Method detection limits must be sufficiently low to accurately present treatment pollutant removal efficiencies. All samples must be analyzed and reported by a laboratory accredited by the state for all parameters.

- Treated water pH shall be in the range of 6 to 7.5 s.u. at 3 and 24 hours.
- Provide tables with percent change in concentration for each lab parameter for each raw and treated water sample (for each coagulant and dose). Provide a table of average percent change for each lab parameter for each coagulant and dose (combine results for all treated water samples with the same coagulant and dose from different events). The combined results should demonstrate consistent pollutant removal efficiencies equal to, or greater than, the CET design efficiencies: 85 percent for TP, 45 percent for TN, and 90 percent for TSS. See additional information in Section 3.3.
- Measure unconsolidated average floc volume (percent of water volume treated). Record for each treated water sample (each coagulant and dose) after 24 hours by removing water and pouring floc into a graduated cylinder. After 24 hours combine floc samples from like coagulants (e.g., combine all water treated with alum) in a graduated cylinder. Record initial floc volume, typically 0.2 to 0.4 percent of the treated water volume).
- Measure consolidated average floc volume (percent of water volume treated). Record after 90 days and longer, if possible, up to one year. Record for combined treated water samples with the same coagulant and dose, typically 0.05 to 0.1 percent of the treated water volume).
- If floc dewatering is proposed, pilot testing of the dewatering process shall be completed on at least three different consolidated wet floc samples. Lab analysis of floc moisture content over time shall be provided to demonstrate the ability to achieve the necessary dry solids within the available time frame until dewatered floc removal is required.
- Floc testing per state requirements (similar to stormwater sediments) along with coordination with the end users/receivers is recommended to confirm there are no obstacles to the desired floc reuse and/or disposal approach. Note that dewatered floc has beneficial uses that is discussed further in the report.

Additional Qualifying Conditions for CET are as follow:

- Settling pond PPV depth is typically 10 to 15 feet (8 ft minimum). Freeboard to top of pond bank varies and flood storage above the PPV can be provided if desired. Provide one-foot minimum pond freeboard at design storm peak stage.
- Settling pond side slopes, safety bench, vegetation, perimeter maintenance drive, fencing, and any other pond requirements should meet local jurisdiction wet detention pond requirements. If there is no local requirement, a minimum 12-ft. wide maintenance drive shall be provided around the pond perimeter. If allowed by local requirements pond side slopes near and to several feet below the normal water surface elevation can be planted. A minimum 15 ft. wide concrete boat ramp extending to an elevation 6-ft. below the pond normal water surface elevation shall be included for pond boat and dredge access.
- Coagulant feed pump selection and sizing shall be provided that can pump the necessary coagulant feed rate over the full range of water flow rates to be treated. Lower end treatment water flow rate is typically 1 -2 cfs. This may require two coagulant feed pumps to achieve accurate turndown in automatic operation and treat the full range of flow rates.

- Automatic operation of the coagulant treatment system to maintain the same design coagulant/aluminum dose over the full range of design water flow rates shall be provided by the equipment and a programmable logic controller (PLC). Supervisory Control and Data Acquisition (SCADA) system (or equal) shall be provided for automatic and remote operation of the coagulant treatment system.

  For all systems coagulant feed shall automatically stop when the measured water flow rate into the settling pond exceeds the peak design water flow rate. Coagulant feed shall be automatically reenabled when the water flow rate drops below the peak design water flow rate.

  The system shall incorporate other safeguards (alarms and automated shutoffs) based on set parameters and the coagulant characteristics. Considerations should include pump speed, incoming flow, tank levels, coagulant metering, discharge pH if using coagulants that affect water pH, system security, etc.
- Coagulant storage is typically provided for 5 to 10 days of treatment at the peak design water flow rate. This is somewhat dependent on the availability of the selected coagulant. If delivery of the selected coagulant takes longer, additional storage may be warranted. Coagulants should be used within their useful life per the manufacturer.
- Fiberglass reinforced plastic (FRP) tanks are recommended for coagulant storage. Secondary containment is highly recommended and required for some coagulants (meet state/federal requirements). This is typically accomplished by using a double wall FRP tank with interstitial wall monitoring. In some jurisdictions a single wall tank can be used in a concrete building with a depressed floor or concrete tank for containment with liquid monitoring. The tank(s) should be housed within a concrete building or enclosure for protection and include required local/state/federal tank and building signage.
- Liquid coagulant aluminum content should be between 4 and 13 percent by weight.
- Aluminum sulfate or other coagulant that consumes water alkalinity and reduces pH below acceptable levels should only be used if all laboratory jar testing raw water samples have sufficient alkalinity and finished water meets the water quality requirements without the addition of a buffering compound. Alternative aluminum coagulants, that do not reduce water pH, are available and should be used in the case described.
- pH monitoring and automatic system shutdown is required for CET systems using acidic or alkaline coagulants that can substantially reduce or increase water pH outside of the desired range. System operational controls need to be established during design with the acceptable range, and shut down value(s).
- Procedures for system operations or shut down during extremely cold weather should be provided.
- Provide approach to monitoring floc depth throughout the settling pond (manual or using equipment) and to estimate the total pond floc volume. This ties to deciding when dredging is needed, discussed below. Also provide the proposed method of floc removal and disposal.
- Consolidated floc shall be removed from the bottom of the settling pond prior to the total floc volume reaching the design floc volume. For example, if a settling pond is designed with 5 ac-ft of floc storage, in addition to the pond permanent pool water volume required for floc settling, floc needs to be removed prior to the total floc volume in the pond reaching 5 ac-ft. Due to additional floc consolidation, the frequency of floc removal may be less frequent than estimated during project design. Floc removal can be accomplished using a hydraulic dredge

and pumping the floc to an adjacent wastewater system, with utility company approval. Alternatively, floc can be hydraulically dredged, dewatered on-site, and trucked and reused, or disposed of.

- Hydraulic dredging can be completed using a manually driven or remote-control dredge. The dredge may be purchased if also needed for other uses by the local utility, or a dredge contractor can be hired for the short duration needed.
- When pumping floc from a dredge to the sanitary sewer system for disposal, provide permanently installed underground piping and fittings for connection of the dredge floating hose near the pond top of bank to the sanitary sewer connection. Information needed includes expected pumping rate, duration, and frequency of dredging events (every couple of years or more). Obtain the wastewater utility's acceptance of the pumped floc discharge. They may request floc to analyze themselves or completed floc laboratory analyses.
- If floc dewatering will be performed on site, provide a design for floc dewatering and plan for trucking for reuse or disposal. Provide details on the dewatering approach and ability to achieve the necessary percent solids to successfully haul. Pilot testing is recommended. Provide the expected frequency, and quantity of dewatered floc, to be trucked, the disposal location, and end use(s). Common options for floc dewatering include drying areas and geotextile tubes. Polymers to aid in dewatering may be useful. For very large systems that produce substantial quantities of consolidated floc, mechanical dewatering with a centrifuge, or other dewatering equipment, may be needed to reduce the quantity of floc to be hauled and beneficially used or disposed of. Polymers may be required to enhance the dewatering process. Floc decant is returned to the treatment process.
- All treatment system equipment, piping, and materials shall be compatible with the selected coagulant (minimal abrasion/corrosion, etc.).
- At a minimum, concrete markers shall be placed at ground surface above all coagulant feed lines and flow meter signal conduits at 100 ft. spacing/at bends. The markers shall include "Buried Utility", "Do Not Dig", and the name of the entity responsible for system maintenance and a contact name and phone number. Metallic locating tape shall be placed 12-inches above the lines and conduits indicating the line type.
- All local, state, and federal health and safety requirements for all elements of the treatment system including coagulant storage and use must be met during construction, start-up, and operations and maintenance. Appropriate signage for the selected coagulant shall be posted on the building door(s) and a MSDS shall be posted in the building. Appropriate PPE shall be provided for use in the building in addition to eye wash/shower and potable water supply.
- Provide and comply with the project Operations and Maintenance Plan. See Section 2.6.
- Include pertinent CET project elements based on the project specific needs which typically include:
  - ✓ Inflow diversion (if off-line)
  - ✓ Inflow and outflow water quality monitoring
  - ✓ Treatment elements
    - Gross solids removal and sedimentation (can be upstream or part of the floc settling pond); floating boom is useful for capturing floatables for removal if substantial
    - Continuous inflow water flow rate measurement (cable to building or telemetry)

  - System automatic operations PLC with programmed system safeguards and SCADA remote monitoring and controls
  - Coagulant injection system and coagulant flow rate measurement
  - Coagulation flash or rapid mix
  - Wet floc settling pond
  - Coagulant storage and equipment enclosure
  - Floc dredging and pumping (250-500 gpm)
  - Dredged floc to wastewater collection system or to Floc dewatering and reuse/disposal
- ✓ Treated water discharge

1.3 Potential Benefits of the Retrofit Practice

CET would be highly beneficial to local governments, state government, and residents in Virginia and other Chesapeake Bay watershed states for the above stated reasons. Related reasons for approving and providing credit for coagulant treatment include:

- Substantial stormwater nutrient and suspended solids load reductions are needed to achieve the Chesapeake Bay, and other, TMDLs and improve surface water quality.
- Numerous wet stormwater ponds were constructed and many of those were only designed to address water quantity and provide limited water quality benefits.
- CET can be implemented in higher groundwater areas (e.g., coastal), relies on a permanent wet pool to function, and does not rely on infiltration.
- Aluminum coagulants are very effective for treating stormwater runoff/surface water and typically achieve pollutant removal efficiencies of 90 percent for TP (including dissolved phosphorus, DP), 35-70 percent for TN, >90 percent for TSS, and 99 percent for bacteria (Harper, 1994, 1997, 2007).
- Required treatment system total land area is 0.1 to 0.5 percent of the watershed area treated. If an existing wet detention pond can be used for coagulant treatment, the required land area is negligible. Implementing more traditional stormwater retrofit projects require substantially more land which is costly and disruptive, prohibits that land from being developed, and reduces economic value and long-term revenue.
- Implementing more traditional retrofits generally cost, over their life cycle, from 4 to 20 times more than coagulant treatment retrofits. CET retrofits using existing wet ponds are particularly cost effective.
- Entire watershed areas can be treated with a single coagulant project which substantially reduces the effort and total cost to operate and maintain.
- CET is not recognized as an approved technology and local governments are waiting on formal credit approval to implement retrofit projects.
- Dewatered floc produced by CET has multiple beneficial uses due to the ability to uptake additional TP and other pollutants.

1.4 Potential Scope of CET Retrofits in Bay Watershed

According to CBPO staff, approximately 346,000 acres are currently treated by wet ponds in the Chesapeake Bay watershed (or roughly 540 square miles). On average, wet pond surface area comprises about 3 percent of their contributing drainage area (Schueler, 1987), so that a maximum of about 10,000 surface acres of wet pond could potentially be retrofit in the watershed. Other state-wide BMP databases suggest that this a conservative estimate of wet pond surface acreage in the Chesapeake Bay watershed (Schueler et al, 2016).

As an example, consider a 1,500-acre urban watershed (50 percent impervious, 750 acres) with existing average annual stormwater loads of 1,500 lbs TP and 11,000 lbs TN. A single CET retrofit project on 5-acres of land would annually remove approximately 1,100 lbs TP and 4,500 lbs TN at a life cycle cost (construction + 20 years annual operation and maintenance) on the order of $3M to $6M, or $4,000 to $8,000 per impervious acre treated.

Capturing 1-inch of runoff from impervious areas would require approximately 63 ac-ft of detention. CET will provide greater nutrient load reduction with a wet settling pond PPV of approximately only 18-ac-ft. Multiple, to numerous, traditional stormwater retrofits projects would need to be implemented requiring substantially more land to achieve similar load reductions with an expected total life cycle cost on the order of $12,000 to $120,000 per impervious acre treated (King and Hagan, 2011 and BC projects), or a total of $12M to $90M. Savings for this one example watershed area is expected to be between $9M and $84M. Consider the potential savings if CET is used to remove just a portion of the estimated 1,800,000 pounds of TP load reduction required by the Chesapeake Bay TMDL in VA.

Section 2

Review of the Available Science

2.1 History of Coagulant Use and CET Project Examples

In the modern era, aluminum coagulants have been used for over 100 years to remove impurities from drinking water sources and wastewater. Every day throughout the world, a wide range of aluminum coagulants are used extensively in water treatment processes with the treated water consumed by people and discharged to lakes, rivers, and natural systems. There are dozens of approved aluminum coagulants commonly used including aluminum sulfate (alum), polyaluminum chloride, sodium aluminate, and aluminum chlorohydrate which range from acidic to neutral to alkaline.

In 1970, granular alum was mixed with lake water and applied to the surface of Horseshoe Lake in Wisconsin to reduce the concentration of phosphorus in the water column. This is the first recorded surface application of a coagulant to a lake in the United States. Due to the beneficial effects on water quality, aluminum coagulants are now routinely applied to the surface of lakes as a lake management tool. The surface application of coagulants removes phosphorus in the water column and bind available phosphorus in lake bottom sediments to improve surface water quality.

The first known use of a coagulant to treat a non-point source discharge was at Lake Ella in Tallahassee, FL. Stormwater runoff was the primary source of TP to this shallow, hypereutrophic lake. Coagulant treatment was selected because there was no space adjacent to the lake to construct traditional stormwater treatment BMPs such as wet detention ponds or dry retention basins. After extensive jar testing with alum and other coagulants, along with pre-construction testing of lake surface water quality, sediment quality, and benthic macroinvertebrates, a coagulant stormwater treatment system was designed and constructed in 1987. The system, which has now been in operation for over 35 years, includes a flow meter to measure runoff volume to the lake. Water flow rate information is transmitted to an equipment/operations building which houses coagulant feed pumps and a coagulant storage tank. Alum is added automatically on a flow proportionate basis to maintain the same coagulant dose regardless of water flow rate. Meters are used to record the amount of alum pumped at each location. The project resulted in immediate and substantial improvement in stormwater quality. As a condition of construction permit approval from the Florida Department of Environmental Protection (FDEP), extensive post construction testing was performed on lake surface water quality, sediment quality, and benthic macroinvertebrates (Harper, 1991). Improvements were observed in all areas evaluated.

Figure 1. Lake Ella before (left) and after (right) coagulant enhanced treatment

Since Lake Ella, numerous coagulant treatment systems have been constructed to reduce the concentration of TP and other pollutants in non-point source discharges and improve surface water quality. Early systems (1987-1996) are mostly in-line with the resulting floc settling in a natural receiving surface water/lake. Each of these systems was designed to have sufficient travel time in the storm sewer pipe upstream of the lake so that the coagulant reaction is complete before the treated water reaches the lake.

The use of off-line systems with floc settling ponds began in the mid-1990s with the Largo Regional Stormwater Treatment System. Current systems use off-line or on-line wet settling ponds and have evolved to include automated floc removal and dewatering systems. Coagulant treatment has also been combined with other treatment train components including sedimentation basins, and constructed wetlands where space allows, to decrease coagulant use and increase overall cost effectiveness.

Following coagulant jar testing, and system design and permitting, construction of the Largo Regional Stormwater Treatment System (Largo Central Park) was completed in 2002 as shown in Figure 2. A total land area of 4-acres (0.3 percent of watershed area treated) was needed to treat non-point source discharges from approximately 1,200 acres of urbanized watershed. This project utilizes an off-line configuration with a 3-acre wet floc settling pond (historic borrow pit). Water flow rates up to approximately 78 cfs are diverted via gravity 4-ft. x 8-ft. concrete box culvert into the off-line system for treatment. At a water flow rate of 78 cfs, the settling pond detention time is approximately 3 hours. The design alum feed rate is 7.5 milligrams aluminum per liter (mg Al/L). Floc accumulates on the bottom of the settling pond and is pumped into the wastewater collection system. The construction cost was approximately $1 million, and the annual operation and maintenance cost was approximately $50,000.

Project construction was funded by a FDEP/U.S. Environmental Protection Agency (USEPA) 319 grant and a required post construction monitoring effort was completed in 2003. Autosamplers with flow meters were installed on the inflow and discharge from the treatment facility and composite samples were collected from September 2002 to February 2003. The project Post Construction Water Quality Monitoring Final Report documents mass pollutant removal efficiencies of 85 percent for TP, 37 percent for TN, and 88 percent for TSS (Environmental Research and Design, 2003). These removal efficiencies include the pollutant loads from water flow rates that exceed 78 cfs, bypass the system, and are not treated.

Figure 2. Large Regional Stormwater Treatment System

In 2015, construction was completed on the Upper Lake Lafayette Nutrient Reduction Facility (NURF) in Tallahassee, FL, to reduce watershed pollutant loads and meet a downstream TMDL. Prior to the project, Weems Pond was an existing 15-acre wet detention pond which received non-point source discharges from a 10,175-acre urban/suburban watershed. The wet detention pond was very small in relation to the contributing watershed area (0.15 percent) and provided minimal pollutant load reduction. The existing wet pond was converted to an off-line coagulant treatment system including sedimentation basin, rapid mix structure, flocculation structure, 10-acre settling pond (0.1 percent of watershed area treated) and floc removal as shown on Figure 3.

The completed project treats non-point source discharges up to 200 cfs and at that flow rate the detention time in the floc settling pond is approximately 4 hours. Flows in excess of 200 cfs bypass the system through a constructed channel. Water flow rate is continuously monitored, and alum is injected on a flow proportionate basis into the rapid mix basin. The design alum feed rate is 5 mg Al/L. The off-line coagulant treatment system includes water flow meters, blowers for air mixing, alum flow meters, coagulant feed pumps, and two 15,000-gallon alum storage tanks stored in a brick building. The system is remotely operated through the use of advanced SCADA.

Project construction was partially funded by a FDEP/USEPA 319 grant, and a post construction monitoring effort was completed by the City. Performance monitoring demonstrated the facility treats approximately 82 percent of the annual watershed runoff volume (9,200 acre-feet/year), and achieves substantial annual mass removal efficiencies of approximately 74 percent for total phosphorus, 68 percent for total nitrogen, and 83 percent for fecal coliform, which are greater than what was predicted, and surpassing the 36 percent total phosphorus reduction requirement established by the Environmental Protection Agency (EPA) 2012 TMDL for Upper Lake Lafayette (City of Tallahassee, 2018). These removal efficiencies include the pollutant loads from water flow rates that exceed 200 cfs, bypass the system, and are not treated.

The construction cost was approximately $6 million, and the estimated annual operation and maintenance cost was $200,000. Life cycle cost effectiveness was approximately $210 per pound TP removed and $195 per pound TN removed. Cost effectiveness is based on construction cost plus 20 years of annual O&M cost divided by 20 years of TP and TN load reduction for this and other projects included.

Figure 3. Original Weems Pond (top) and Upper Lake Lafayette Nutrient Reduction Facility (bottom)

The largest non-point source coagulant treatment system was completed by the Lake County Water Authority (LCWA) in 2009 on the Apopka-Beauclair Canal downstream of Lake Apopka outside of Orlando, Florida. An aerial photograph of the system is shown on Figure 4. Lake Apopka is a 30,000-acre eutrophic lake which receives urban and agricultural discharges from its contributing watershed. Water from Lake Apopka discharges north through the Apopka-Beauclair Canal into Lake Beauclair which serves as the headwaters for the Harris Chain-of-Lakes. This gravity flow system was designed and constructed to provide TP removal in discharges from Lake Apopka to meet downstream TP TMDLs in the Harris Chain-of-Lakes. From 2009 through 2021 the system annually treated an average of approximately 20,000 acre-feet of water and removed 3,500 pounds of TP which achieves the TP reduction goals for four downstream lakes (Lake County Water Authority, 2023). At a construction cost of $7.4M and annual operation and maintenance cost of $1M, the life cycle cost effectiveness was $390 per pound of TP removed.

Figure 4. Lake Apopka Nutrient Reduction Facility (NuRF) (Source LCWA)

Water is diverted off-line by gravity from the Apopka Beauclair Canal though a control structure and open channel to two parallel 9-acre wet settling ponds. Treated water returns to the canal and discharges downstream.

A remote-control dredge is used to pump accumulated wet floc to a storage/equalization tank and then to a centrifuge for dewatering. The dewatered floc is applied to an adjacent constructed wetland treatment system during routine wetland system maintenance to bind available phosphorus in the wetland system soils. Adding dewatered floc reduces the export of TP from the constructed wetland when it is reflooded after maintenance is complete. Some dewatered floc is also used to stabilize farm roads. Dewatered floc that dries becomes strong and durable and does not rewet. All treatment system elements combined including the dewatered floc storage area comprise approximately 46 acres (0.1 percent of watershed area treated). The NuRF has contributed to substantial improvements in the Harris Chain of Lakes as shown for Lake Beauclair in Figure 5.

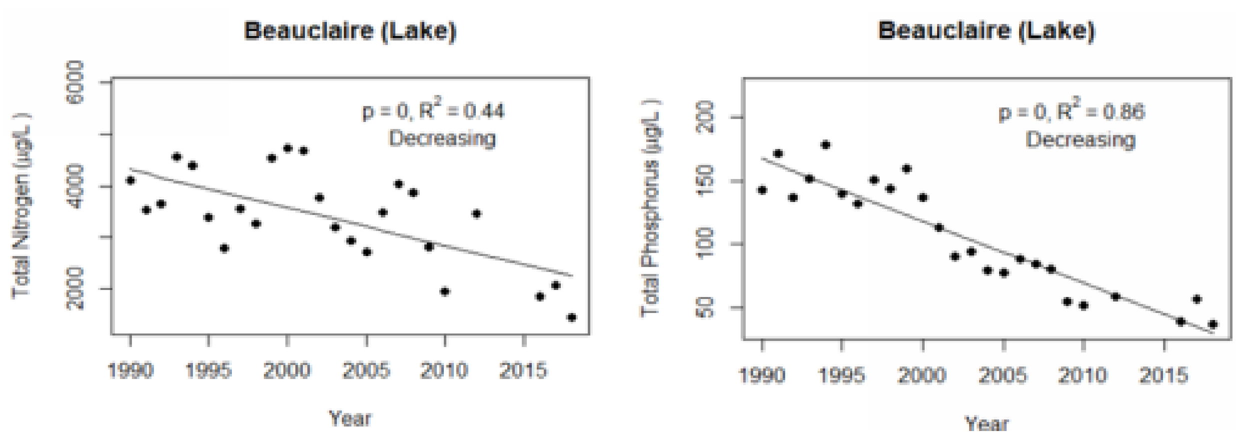

Figure 5. Trend plots of annual average TN and TP concentrations in Lake Beauclair (Lake County Water Authority (LakeWatch Report, 2021)

Boise, Idaho uses enhanced coagulant treatment to offset TP load reductions mandated at their wastewater treatment facilities by USEPA to meet the Snake River TP TMDL. Rather than spend substantially more public funds with minimal environmental benefit at their wastewater facilities they elected to build and operate the Dixie Drain Phosphorus Removal Facility (PRF) well outside the City of Boise and much closer to the Snake River. The PRF is a water treatment facility that removes nonpoint source TP from the Dixie Drain, an agricultural drain with a watershed area of approximately 40,000-acres. The source of water for the Dixie Drain PRF is unregulated ground and surface water flows from agricultural operations, which are estimated to contribute up to 40 percent of the TP load in the Boise and Snake Rivers.

Extensive jar and pilot testing was completed to prepare for system design with jar testing results shown on Figure 8. Evaluation of the wet floc, floc drying, and recovered supernatant were also completed by the City.

The facility was completed in 2016 and is located just upstream of the Dixie Drain confluence with the Boise River. Flow from Dixie Drain up to 200 cfs is pumped into the facility with treated water returning to the drain. Higher flows bypass the system. TP load reduction is achieved with chemical precipitation and gravity settling in the facility. The TP removal requirements are tied to a phosphorus removal offset written into the City's West Boise Water Renewal Facility USEPA Region 10 National Pollutant Discharge Elimination System (NPDES) permit. Figure 6 provides a process flow diagram and a project aerial with primary elements is shown on Figure 7.

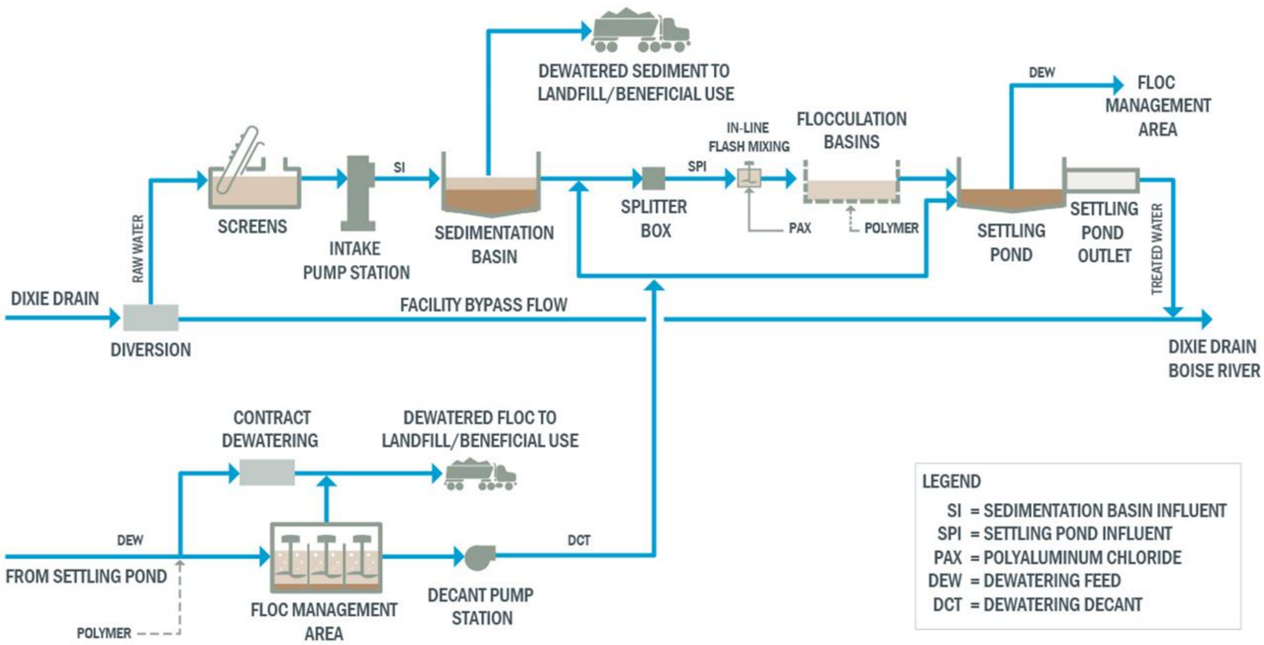

Figure 6. Dixie Drain PRF Process Flow Diagram (flocculation basins were not needed

Dixie Drain

REMOVING
140 lbs of phosphorus
PER DAY

1 **Inlet diversion and screening:** Located in the Dixie Drain channel, a set of gates control the water surface elevation in the channel and divert water into the screens, preventing vegetation from entering the process.

2 **Intake pump station:** The intake pump station controls the flow of water through the facility. Each of the four 150-horsepower pumps can convey 25 to 50 cubic feet per second (cfs) of water through the facility, for a maximum of 200 cfs.

3 **Sedimentation basin:** Up to 8,000 tons of sediment can settle out of the water in this 12-acre-foot basin.

4 **Operations building:** This structure houses storage for the water treatment chemical and serves as the control center for the facility.

5 **Flash mix facility:** Water is delivered to one of four pipe-mounted flash mixers where a water treatment chemical (polyaluminum chloride) is injected into the flow stream. This coagulation process removes dissolved phosphorus from the water, causing it to form a stable "floc" particle, making it easier to remove from the water.

6 **Settling pond:** The phosphorus-containing floc particles clump together and settle out in this low-velocity 97-acre-foot pond. Approximately 140 lbs of phosphorus per day is prevented from reaching the Boise River here.

7 **Outlet structure:** Treated water is returned to the Dixie Drain channel and subsequently the Boise River, removing 50 percent more phosphorus than would have been removed at a water renewal facility, and with significant solids reduction that would not have been otherwise realized.

8 **Floc management area:** Floc from the Settling Pond is dredged up and delivered to this basin to undergo a natural drying process.

Figure 7. Dixie Drain PRF Treatment Overview

An intake and screening structure was constructed in the Dixie Drain to divert water into the system. A 200 cfs pump station sends water into a sedimentation basin and then coagulant is added in four flash mixers. Treated water then enters the wet settling pond for floc settling. The treated water returns to the drain downstream of the intake. The system can treat up to 400 acre-feet of surface water a day and remove more than 140 pounds of TP per day. Seventy acres of land were purchased for the facility (less than 0.2 percent of the contributing watershed area). The NPDES permit includes inflow and outflow monitoring to demonstrate TP removal and compliance with the permit. Monitoring by the City has demonstrated the system exceeded the TP reduction requirement of the NPDES permit and the state Water Right. The construction cost was $14M and the life cycle cost effectiveness is approximately $300/lb TP removed.

2.2 Chemistry of Aluminum Coagulants

Aluminum coagulants are selected over ferric coagulants due to aluminum's high ionic charge and small crystalline radius. These create a level of reactivity greater than any other soluble metal. Another benefit is the quality of aluminum coagulants and their availability. Aluminum coagulants are manufactured using quality raw materials with minimal impurities, are approved for potable water treatment, and are used extensively throughout the world daily. Aluminum precipitates are also very stable with minimum aluminum solubility in the pH range of natural surface waters (6-8 s.u.) Ferric coagulants are often manufactured using lower quality materials that contain impurities and ferric precipitates have minimum solubilities at a water pH lower than typical for natural surface waters. Aluminum precipitates are also stable with changes in water reduction-oxidation potential (related to water dissolved oxygen (DO) concentration) whereas ferric precipitates can dissolve under reduced conditions (low DO).

The addition of aluminum-based coagulants to non-point source discharges creates precipitates which remove pollutants by two primary mechanisms. Removal of suspended solids, phosphorus, heavy metals, and bacteria occurs primarily by enmeshment and adsorption onto aluminum hydroxide precipitate per the following reaction:

$$Al^{+3} + 6H_2O \rightarrow Al(OH)_{3(s)} + 3H_3O^+$$

Aluminum hydroxide precipitate, Al $(OH)_3$, is a gelatinous floc which attracts and adsorbs colloidal particles onto the growing floc and purifying the water. The removal of additional dissolved phosphorus is achieved by the direct formation of aluminum phosphate according to the following reaction:

$$Al^{+3} + HnPO_4^{n-3} \rightarrow AlPO_{4(s)} + nH^+$$

These reactions occur very quickly and are generally complete in less than 30 seconds. After initial contact and flash/rapid mixing of coagulant and water, the coagulant no longer exists, and only the resulting aluminum hydroxide and aluminum phosphate are present in the treated water. For non-point source treatment projects, this reaction commonly occurs in an enclosed pipe or concrete flash mix/rapid mix structure and the coagulant does not enter the wet settling pond or the environment.

The solubility of dissolved aluminum in the treated water is primarily regulated by water pH. Various types of aluminum coagulants range from acidic to neutral to alkaline. The choice and dose of coagulant depends on the raw water pH and alkalinity. Treated water is in the neutral pH range and near minimum aluminum solubility. The dissolved aluminum concentration in treated water is often less than the non-point source raw water because of the attention on finished water pH in the neutral range.

Most of the coagulant enhanced stormwater treatment projects used liquid aluminum sulfate (alum, ~4.4 percent aluminum (Al) by weight). It is effective for capturing stormwater pollutants and is relatively inexpensive. Alum is acidic, consumes water alkalinity, and reduces water pH. If the raw water pH is somewhat alkaline it can help to lower water pH to near neutral which is desired. If, however the raw water has less alkalinity and a lower pH, addition of alum can lower the pH below acceptable levels and impact fish and aquatic organisms. To safeguard against depressing water pH too much, pH monitoring and control systems were used to automatically stop alum addition if the pH was below a preset level.

More recently aluminum chlorohydrate (ACH) or polyaluminum chloride (PAC) is the coagulant of choice for raw waters that have a near neutral pH. These have more aluminum per unit volume than alum and do not change water pH. Another advantage is that the required coagulant storage volume and pumping rate is about half or less of alum.

Select coagulants including ACH have much lower freezing points than alum and have performed effectively in cold weather. This has been demonstrated in Boise and during jar testing for a pending CET project in Madison WI on Starkweather Creek. Intentional cold weather jar testing was completed to verify effective TP removal efficiency. Heaters are recommended for use in the equipment/storage tank building and/or around the coagulant storage tank during cold weather.

Road salt is used during winter months in VA and a fraction of the salt is entrained in stormwater runoff. Previous jar testing in Madison (WI), and Boise (ID), and operations of the Dixie Drain project in Boise, have not shown changes in coagulant effectiveness during winter months.

Aluminum precipitates once formed are exceptionally stable and do not dissolve due to changes in pH or redox potential in natural waters. Therefore, pollutants such as TP trapped by the precipitates are not released into soils or groundwater. As the floc ages at the bottom of the settling pond, even more stable complexes form, eventually forming gibbsite (Livingston, Harper, and Herr, 1994).

Precipitates formed as a result of the coagulation process settle to the bottom of the wet settling pond and remain there until removed. Because TP and other pollutants contained in the floc are tightly bound, pollutants will not be released from the floc into the pond bottom soils or surrounding groundwater system. Floc continues to accumulate in the bottom of the settling pond and increases in depth above the bottom of the pond until removed. Periodically, likely once every 3-10 years depending on the design floc storage volume, the accumulated wet floc is hydraulically (vacuum) dredged and removed from the bottom of the settling pond. Although the dredging effort will slightly disturb the floc, the aged floc will not release bound pollutants. Instead, any disturbed floc will simply resettle to the pond bottom. Freshly formed floc is typically 98 to 99 percent water. As additional floc depth accumulates it will consolidate to some extent but will still be on the order of 95 to 98 percent water until dried.

Floc dewatering testing was done by the City of Boise on floc generated from the Dixie Drain pilot tests. The material dewatered quickly in a drying bed within a matter of days. Floc drying decant water was analyzed for TP concentration in October 2010 and the result was 0.10 mg/L. During floc dewatering, the water which drains from the floc should be very similar in characteristics to the treated water with no leaching of bound pollutants.

2.3 Summary of Monitoring Results

2.3.1 Pollutant Removal Efficiencies

Laboratory jar testing and constructed project influent and effluent monitoring has been completed for dozens of known CET projects completed to date. Aluminum coagulants at doses of 5 to 10 mg Al/L have proven to be very effective for treating stormwater runoff/surface water and typically achieve CET treated pollutant removal efficiencies (Harper, 1994, 1997, 2007) as shown in Table 2.

Table 2. Summary of CET Average Pollutant Removal Efficiencies (percent)

Pollutant	Removal Efficiency (percent)
Total Phosphorus (TP)	>90
Total Nitrogen (TN)	35-70
Total Suspended Solids (TSS)	>90
Bacteria	99

Removal efficiencies for TP and TSS are consistent and predictable. TN removal efficiencies are dependent upon the nitrogen species present, with higher removal efficiencies associated with runoff containing more particulate and organic nitrogen, and lower removal efficiencies for runoff which contains primarily inorganic nitrogen species. Pollutant removal efficiencies generally increase slightly with increasing aluminum dose. Selection of the "optimum" dose often involves an economic evaluation of treatment costs vs. desired removal efficiencies.

As discussed with project examples in Section 2.1, up to the peak runoff flow rate from a 1 to 2-inch storm event is typically diverted and treated. Higher peak discharge rates are not treated resulting in CET of approximately 80 to 95 percent of the average annual runoff volume. For this reason, average annual mass load reductions as summarized in Table 3, are commonly reported for completed projects, and are lower than the CET pollutant removal efficiencies listed above. This is due to typically treating less than 100 percent of the average annual runoff volume.

As an example, for Upper Lake Lafayette NURF, 82 percent of the average annual runoff volume is treated with coagulant, and for the portion of the annual runoff volume treated, 90 percent of the TP concentration is removed. The resulting average annual mass TP load reduction is 0.82 * 0.9 = 0.74 or 74 percent. For Largo Park, approximately 94 percent of the average annual runoff volume is treated, resulting in an average annual TP load reduction of 0.94 * 0.9 = 0.846 or 85 percent.

Table 3. Summary of CET Average Annual Mass Load Reductions[1] (percent)

Project	TP Mass Removal	TN Mass Removal	TSS Mass Removal
Largo Park with CET	85	37	88
Largo Park w/out CET	*46*	*8*	*91*
Upper Lake Lafayette NURF	74	68	na
Dixie Drain PRF	77	na	na
Range of Values for CET Examples	74 - 85	37 - 68	88 - 91

[1] Annual mass removal is a function of annual water volume treated and pollutant removal efficiencies from Table 2.

2.3.2 Resulting Precipitate and Disposal

Since the first project, Lake Ella, the physical and chemical characteristics of the resulting precipitates (floc), and disposal options have been evaluated extensively. The resulting wet floc and dewatered floc has been found to be stable, does not release bound pollutants, has beneficial uses, and can be sent to the sanitary sewer system or can be beneficially used/land applied.

Early CET systems using alum provided for floc settling directly in receiving waterbodies (natural lakes). Extensive laboratory testing was conducted by Harper (1991) to evaluate the long-term stability of phosphorus and heavy metals contained in alum floc generated as a result of stormwater treatment. These evaluations were conducted by collecting accumulated alum floc from the bottom of various receiving waterbodies and using an incubation apparatus to evaluate the influence of pH and redox potential on the stability of alum treated sediments. These experiments indicated that phosphorus and heavy metals combined into alum floc are extremely stable under a wide range of pH conditions and redox potentials ranging from highly oxidized to highly reduced. The stability of heavy metals within the sediments under post-treatment conditions was found to be substantially greater than the observed under pre-development conditions.

As alum floc ages, the freshly precipitated $Al(OH)^3$ forms into a series of ringed structures which are extremely stable and which tightly bind phosphorus and heavy metals in a crystalline lattice network. These phosphorus and metal associations are inert to changes in pH and redox potential normally observed in a normal lake or pond system. Introduction of alum floc into polluted sediments has been shown to reduce poor water concentrations for phosphorus and all evaluated heavy metals (Harper, 2007).

Sludge drying and leachate investigations were conducted at Lake Ella to evaluate potential disposal methods which could be used for ultimate disposal of the alum sludge. Composite sludge samples were placed onto a drying bed and the characteristics of the leachate were monitored continuously at the filter underdrain. Alum sludge leachate was found to be approximately neutral in pH with low levels of both total nitrogen and total phosphorus. Concentrations of aluminum within the leachate were low with a mean dissolved aluminum concentration of 23 ug/L. Low levels of all heavy metals were also found in the leachate flow with concentrations substantially less than surface water standards for Class III waters. Dried alum sludge was found relatively low values of nitrogen, phosphorus and heavy metals. Based upon this analysis, dried alum sludge could potentially be disposed of on sod farms, pasturelands, forests, highway shoulders, nurseries and land reclamation projects (Harper, 1991). Alum sludge does not make a good agricultural soil nutrient amendment due to the fact that phosphorus is tightly bound to aluminum and is largely unavailable for uptake by plant species. This characteristic makes it ideal to bind phosphorus in soils and reduce stormwater runoff phosphorus concentrations.

With the advent of dedicated floc settling ponds monitoring has been completed on both consolidated wet floc and dewatered floc. These relate to the two primary means of floc disposal, discharge to the sanitary sewer system, and dewatering and material beneficial use or disposal. Extensive laboratory testing was performed on wet floc associated with the Largo Regional Treatment System including EPA 601, 602, 603, 608, 625, 200.7 (Metals), Inorganics, and Microbiology. The positive results enabled the floc to be pumped to the City's sanitary sewer system. Similar testing was performed for other systems which provided similar results and the ability to discharge accumulated floc to the wastewater system. The CET system operated for 18 years by the Ramsey-Washington Metro Watershed District in MN uses alum and following acceptable testing results, routinely pumps floc from the bottom of their settling pond to their sanitary sewer system for disposal.

Several existing alum treatment systems utilize on-site floc dewatering. These drying beds are constructed similar to a wastewater sludge drying bed, with an underdrain system constructed beneath a permeable sand layer. The alum floc is deposited onto the drying area, and the leachate is returned to the settling pond. Drying characteristics for alum sludge are similar to a drinking water treatment plant sludge. A drying time of approximately 30 days is sufficient to dewater and dry the sludge, with a corresponding volume reduction of 80-90 percent.

Chemical characteristics of the dried alum residual from the LCWA NuRF was evaluated through pilot studies. The alum sludge was generated by chemical coagulation of thousands of gallons of water collected from the project raw water supply, the Apopka-Beauclair Canal. Generated floc was captured, placed onto a drying bed, and allowed to dewater. A photograph of the alum sludge during the dewatering process is given in Figure 8. After the sludge dried, chemical characteristics of the sludge were evaluated and compared with State of Florida Clean Soil Criteria, outlined in Chapter 62-777 FAC, to assist in identifying disposal options. Measured chemical characteristics from the alum residual were substantially less than the applicable Clean Soil Criteria, based upon direct residential exposure which is the most restrictive soil criteria. Based upon this analysis, the dried alum residual easily meets the criteria for use as fill material, land application, and daily landfill cover (Harper, 2007).

CET systems completed to date have been able to discharge consolidated floc from the bottom of the settling pond to the public wastewater treatment system. Floc testing was performed to confirm the acceptability of discharge with no adverse impacts. The rate of floc discharge, typically 300-500 gpm, and pollutant loading rates are small relative to the wastewater flows and loads. See examples in Section 2.5.

CET systems completed to date have also successfully dewatered consolidated floc and used the material for beneficial uses. See examples in Section 2.5. Dewatered floc has beneficial uses due to its ability to uptake additional TP and other pollutants. The dewatered floc can be applied to a constructed wetland treatment system during routine maintenance to bind available phosphorus in the wetland system soils. Adding dewatered floc reduces the export of TP from the constructed wetland when it is reflooded after maintenance is complete. Dewatered floc can also be applied to former agricultural land or other land with high soil phosphorus content that is being reclaimed to reduce phosphorus release in stormwater runoff. Dewatered water treatment facility floc is valuable as it is increasingly being used to develop custom bioretention soil medias and other types of flow-through stormwater treatment systems for the enhanced removal of TP and other pollutants. Dewatered floc is also be used to stabilize farm and maintenance drives due to its physical characteristics. Once it dries it does not rewet.

Figure 8. LCWA NuRF Alum Floc Drying Process

University of Florida, IFAS Extension published a paper originally in July 2009 that concluded the combined studies clearly demonstrate that aluminum-based water treatment residuals (Al-WTR) should have no negative impacts on the environment and biological systems when appropriate rates (based on the chemical characteristics of WTR) are land applied. Thus, Al-WTR is a safe soil amendment to control off-site phosphorus losses to sensitive water bodies (Agyin-Birikorang, O'Connor, and Obreza, 2009). Surface waters commonly treated with aluminum coagulants typically have substantially higher concentrations of nutrients, total organic carbon, and other pollutants which will be captured in the resulting Al-WTR.

Related to the acceptability of applying aluminum based residuals onto land or water, the North American Lake Management Society (NALMS) issued a position paper on the use of alum for lake management (NALMS, 2004). This paper states "Alum is a safe and effective method to mitigate excess phosphorus in lakes and reservoirs". As soon as alum is added to lake water, precipitates form which settle to the bottom of the lake and remain there. These precipitates help to bind phosphorus, metals, and other pollutants and improve surface water quality.

None of the completed projects have known issues with consolidated wet floc or dewatered floc that limited the ability to dispose of in the sanitary sewer system or general land application. It's important to note that dewatered floc has value and should be used for beneficial uses if possible. Private companies are buying aluminum water treatment residuals for the preparation of enhanced medias for stormwater BMP flow-through treatment systems for the removal of TP and other pollutants.

2.4 Project Initial Testing and Evaluation

Laboratory testing must be performed to verify the effectiveness of CET and to establish process design parameters. Coagulant treatment for a particular runoff or surface water source is typically evaluated in a series of laboratory jar tests conducted on representative runoff or surface water samples collected from the project watershed area. Water samples are collected over time during different conditions. For stormwater this may include dry and wet weather if dry weather baseflow is present. Extensive jar testing completed for many projects over the years has indicated minimal change in coagulant treatment effectiveness regardless of the variable conditions.

Laboratory testing is an essential part of the evaluation process and provides design, maintenance, and operational parameters such as the optimum coagulant and dose required to achieve the desired water quality goals, required settling pond residence time, chemical pumping rates and pump size, post-treatment water quality characteristics and pollutant removal efficiencies, floc formation and settling characteristics, floc accumulation volume and consolidation, annual coagulant volume, costs and storage requirements, and maintenance procedures.

Every treatment project completed to date has used a coagulant dose between 4 and 10 mg Al/L. Jar testing generally includes two to three doses of coagulant within this range. One or more coagulants may be tested depending on raw water characteristics which is normally analyzed to help select them. The collected field sample is split into raw and coagulant dose lab samples as shown in Figure 9.

Selected coagulant doses are added to separate clean beakers containing raw water (1-2 L depending on lab parameters) and rapid mixed for one minute using a jar testing apparatus. Lab samples are normally collected before the coagulant is added and 24-hours after coagulant addition from each beaker. pH may be measured more frequently. Lab samples are analyzed for selected parameters depending on the raw water and pollutants of concern and may include: pH, temperature, conductivity, turbidity, alkalinity, TP, DP, TN, alkalinity, sulfate, chloride, total suspended solids, fecal coliform, dissolved aluminum, and total aluminum.

Floc is collected at 24 hours and placed in a graduated cylinder to measure initial volume. Floc depth/volume readings are continued for up to one year to examine floc consolidation. Initial unconsolidated floc volume typically ranges from 0.2 to 0.4 percent of the treated water volume depending on raw water and aluminum dose. Photos are taken throughout the procedure. Floc samples may be analyzed for a variety of water and sediment lab parameters depending on the selected method of floc disposal and what is requested by the entity receiving the floc. Jar and lab testing procedures including minimum detection limits are provided to the certified laboratory performing the work. For some larger projects, like Dixie Drain PRF, flow through pilot testing of the planned treatment process may also be completed using the actual water to be treated. Example results from comprehensive coagulant jar testing at Dixie Drain PRF is shown on Figure 10. Note that multiple coagulants were able to achieve a 90 percent TP removal efficiency at a coagulant dose of 5 mg Al/L.

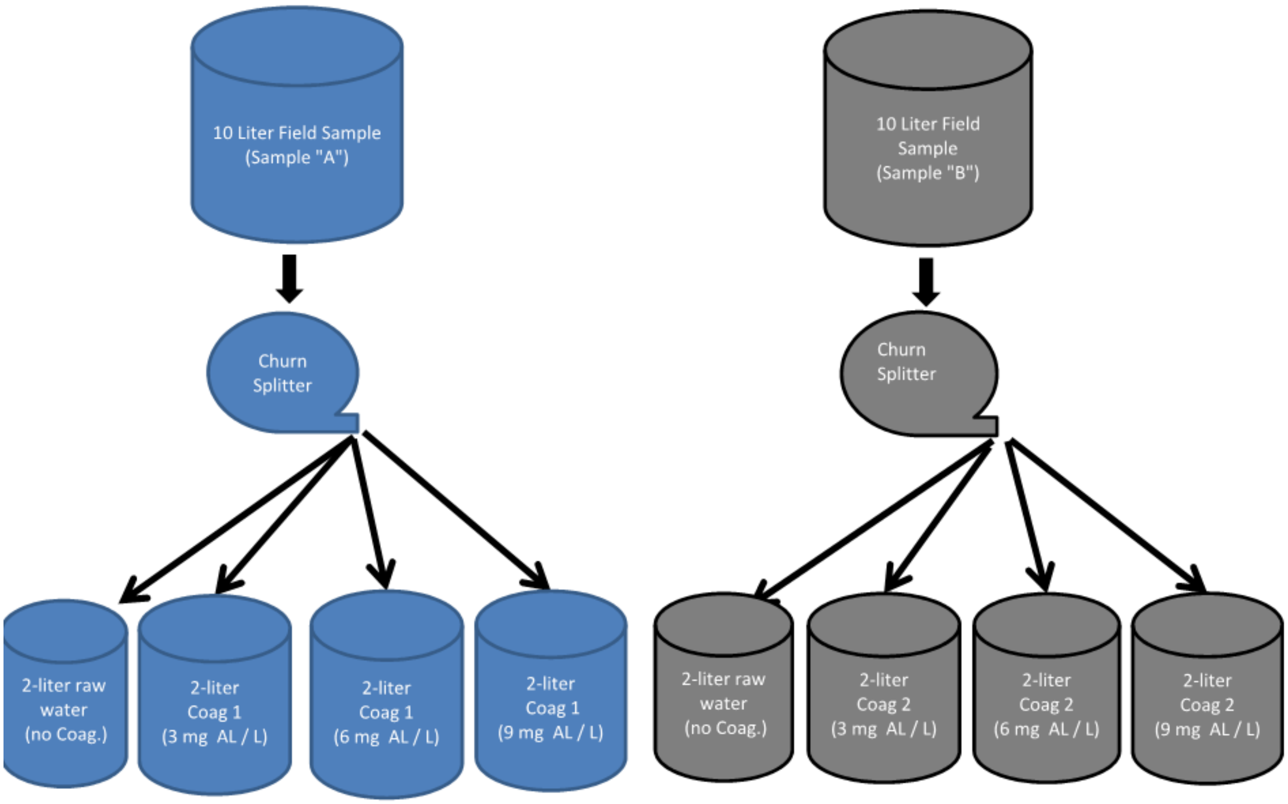

Figure 9. Schematic of Coagulant Jar Testing Lab Procedure

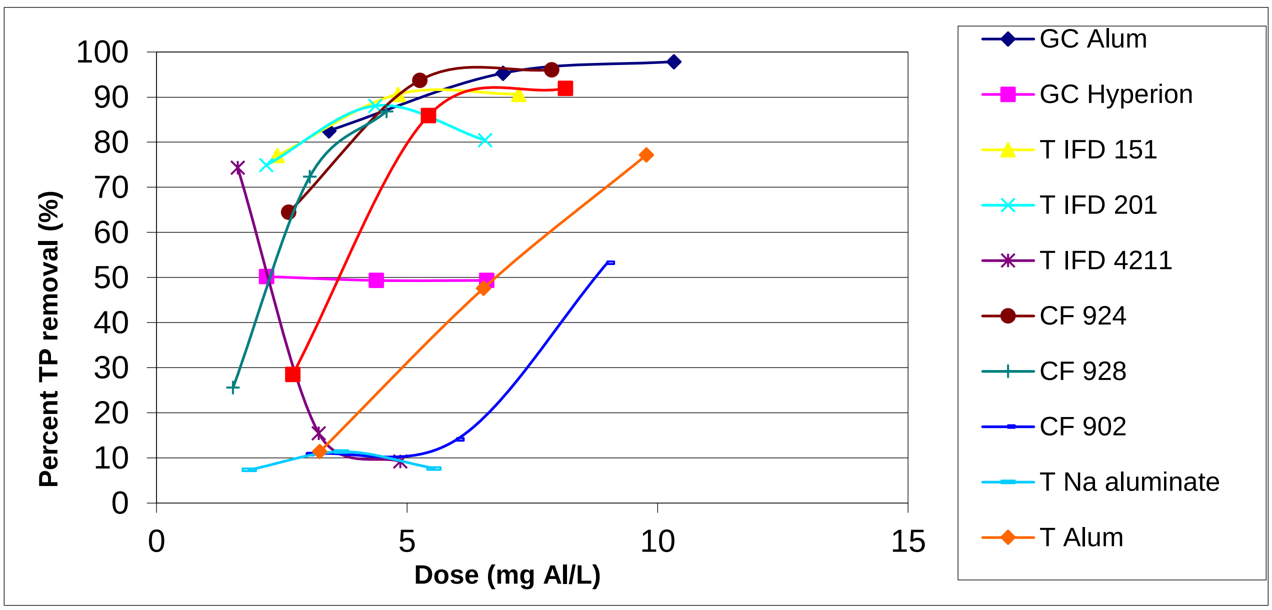

Figure 10. Jar Testing Results for Dixie Drain Water, Percent TP Removal vs. Coagulant Dose (City of Boise, May 2011)

Hydrologic and pollutant loading analyses for the project contributing watershed must also be completed to prepare for design. For stormwater treatment projects, hydrologic modeling must be done to understand the runoff peak discharge rate and volume for common rain events up to 1 to 2-inches, and to estimate the average annual runoff volume that is treated. For surface water treatment projects, a similar hydrologic modeling approach can be used, or if historic flow rate data is available, a flow probability distribution can be developed which relates peak discharge rate treated to average annual water volume treated. This approach was used on the Lake Lafayette and Dixie Drain projects.

CET pollutant removal efficiencies are confirmed based on the jar testing average removal efficiencies for the design coagulant and dose. Average annual pollutant load reductions are estimated based on the percent of average annual runoff volume treated and the design average pollutant removal efficiencies. For example, if the watershed average annual raw TP load is 2000 pounds per year (lbs/yr), 90 percent of the average annual runoff volume is treated, and the TP removal efficiency is 85 percent, the average annual TP load reduction is 2000 lbs/yr x 0.9 x 0.85 = 1,530 lbs/yr. See Section 3.3 for more detailed pollutant load crediting approach.

2.5 System Configuration and Components

In a CET system, coagulant is injected into the water on a flow-proportioned basis to maintain the same coagulant dose regardless of water discharge rate. A variable speed coagulant metering pump, typical of water and wastewater treatment applications, is used to accurately add coagulant to the flash/rapid mix structure. A high energy flash mixer is commonly used to provide effective mixing in a matter of seconds. Operation of each injection pump and the mixer is regulated by a programmable logic controller (PLC) that is receiving the water flow meter signal. In newer systems, monitoring and operation can be done using an iPad connected to a central SCADA system. The water flow meter signal may be wired or wireless depending on the distance between the point of injection and the building and owner preference. Since coagulant addition is regulated by the measured water flow rate, the treatment system can also treat dry weather baseflow, if desired. Coagulant injection is programmed to turn on and off at specific flow rates, for example 1 to 25 cfs. If the range of flows is large (e.g., 1 to 100 cfs) it may be necessary to have two coagulant feed pumps to cover the full range of flows to be treated.

Following coagulant addition and mixing, the water enters the wet settling pond which is usually sized to provide 3 to 6 hours of residence time at the peak design water flow rate. Note that with the recently used coagulants, floc settling is often complete in less than 1 hour. Additional time provides a safety factor and ensures complete floc settling. Additional storage volume is provided in the wet pond for floc storage depending on the expected floc accumulation rate and desired cleaning frequency (typically 3-5 years). There is no urgency in removing collected floc which will continue to consolidate with time.

Depending on the sediment/gross solids and/or channel bed load, a sedimentation basin may be beneficial to capture gross solids upstream of the coagulant treatment system. Initial discharge points in the wet settling pond can also be designed to capture gross solids and reduce sediment/floc mixing. Sediment particles are much heavier than floc and will settle much faster and close to the outfall points. Booms or other features to capture trash are commonly used. These features are sized depending on the estimated quality of gross solids to be collected and the desired cleaning frequency.

Mechanical components for the coagulant treatment system, including coagulant metering pump, piping and valves, coagulant flow meter, coagulant storage tank monitor, water flow meter and electronic controls, are typically housed in a central facility which can be constructed as an above-ground or below-ground structure. One or more double wall fiberglass storage tanks with interstitial space monitoring are typically used for coagulant storage. Some owners have the building include a small office and storage area with heating and air conditioning. Water service, safety shower, eye wash, fire extinguisher, and other essential and desired amenities and health and safety resources must be provided based on the coagulant used. The facility structure can be as simple or attractive as desired depending on location and owner preference. Photos from the Lake Lafayette facility are provided in Figure 11.

Figure 11. Photos from the Upper Lake Lafayette Nutrient Reduction Facility

A quick coupling fitting is provided inside the building for the semi-tractor trailer coagulant delivery truck (~4,500 gallons) to pump the coagulant into the coagulant storage tank. Coagulant storage tanks are sized based on the expected peak coagulant use and desired frequency of deliveries. The materials for piping, valves, and other features within the building are selected depending on the selected coagulant and compatible materials to reduce wear and corrosion.

An underground coagulant feed line (typically 1-inch PVC of HDPE) is installed from the central facility to the point of coagulant addition. Coagulant injection points can be located as far as 1,000 ft or more from the central facility. Concrete markers at ground surface and metallic locating tape on the pipe are used to note the location.

Wet floc is typically hydraulically dredged periodically using manned or remote-control equipment. Both have been used on the example projects. The pumping rate is low at 300 to 500 gallons per minute. Consolidated wet floc is typically pumped to the municipal wastewater collection system, if available, or to an on-site dewatering system with end product reuse or disposal. The flow rate and volume are normally very small compared to the total wastewater flow in the system, dredged floc is typically 98-99 percent water, the solids are light and flocculent, and there have been no observed impacts. The municipality commonly asks for an analysis of the wet floc or samples for their own analyses prior to approval to dispose of the floc.

In areas with no central wastewater systems, like the Dixie Drain, wet floc must be dewatered on site. This can be accomplished using drying lagoons, drying areas, and/or geotubes. For very large systems that produce substantial quantities of consolidated wet floc, like the Lake Apopka NuRF, mechanical dewatering with a centrifuge or other dewatering equipment may be needed to reduce the quantity of floc to be hauled and beneficially used or disposed of. Polymers may be required to enhance the dewatering process. Floc decant is returned to the treatment process. Normally at least 1 year is available for floc dewatering due to the minimum 1 year of consolidated floc storage available in the wet settling pod, which should provide more than enough time for dewatering.

2.6 System Operation and Maintenance

An operation and maintenance (O&M) manual will be prepared for the facility along with electronic fill-in-the-blank observation forms to be completed during each visit by operations staff. Training will be provided during start-up for personnel operating the system. With the treatment system SCADA system, continuous water flow meter, coagulant flow meter, PLC, telemetry, and digital interface, all real time and historic primary system data are readily available.

Routine monitoring of the system is done remotely using a computer or tablet with Wi-Fi including equipment status and operation, and coagulant volume remaining. Cameras at the facility can also be provided. Although the coagulant treatment system operates automatically and is monitored remotely, site visits should be performed at least once each week. Simple system testing should be performed to check the operable system components and building, and personnel should record key system information, and the need for any additional maintenance or repairs. This typically takes about one hour at the site. Much of this can also be done remotely. Operators will need to order additional coagulant when the storage volume reaches a pre-determined level to maintain sufficient coagulant storage at the site until the next delivery.

pH monitoring and automatic system shutdown is required for CET systems using acidic or alkaline coagulants that can reduce or increase water pH. System operational controls need to be established during design with the acceptable range, and shut down value(s). If water quality monitoring equipment is used (e.g., pH), sensors require routine cleaning and calibration, and periodic replacement. Replacement probes should be kept on hand. Water sampling equipment if used also requires routine cleaning and maintenance.

Periodic servicing of the coagulant feed pumps is required along with occasional system repairs. Common required spare parts are kept on site. Depending on the design floc storage volume in the wet pond, floc accumulation should be periodically checked, and scheduled for removal when the volume is approaching the predetermined maximum storage depth. If the wet floc is dewatered on site, the dewatered floc will need to be stockpiled and hauled from the site to the end user.

Remote monitoring and control of the system is proposed to allow operations staff to observe the condition and operation of the system. Remote monitoring reduces unnecessary trips to the site, enables operational adjustments, and alerts offsite personnel if a coagulant delivery needs to be scheduled. Typical remote monitoring includes:

- System power on/off
- Building access, cameras (if included)
- Coagulant storage tank(s) volume
- Flow meter water depth, velocity, and flow rate, as applicable to the type of water flow meter

- Totalized water flow
- Coagulant feed pump run
- Coagulant feed rate
- Totalized coagulant pumped
- Coagulant feed pump diaphragm alarm, if applicable
- Flash mixer run
- System water levels
- Water quality parameters
- Auto system shutdown (i.e. pH), if applicable

Like any wet detention pond, grassed and any landscaped areas need to be routinely maintained. Depending on the watershed and system configuration trash and sediment within the wet pond will likely need periodic removal, trash more frequent than sediment. The equipment building is generally low maintenance but will require interior and exterior cleaning and periodic maintenance.

2.7 Unintended Consequences

Coagulant enhanced stormwater treatment systems have been in use since the late 1980s. Even the early systems with floc settling in natural lakes exhibited only positive benefits and no adverse impacts based on extensive post construction testing on lake surface water quality, sediment quality, and benthic macroinvertebrates (Harper, 1991).

General System Performance: Technical rigor is needed during the planning and design of coagulant treatment systems. Jar testing and floc monitoring are essential as described earlier in this document to select the appropriate coagulant and dose based on the raw water characteristics and desired pollutant load reductions. Supervisory Control and Data Acquisition (SCADA) system (or equal) are needed for automatic and remote monitoring and operation of the CET.

Key System Components: Two key treatment system components, the water flow rate meter and the coagulant feed pump and controller, must be consistently operable over the full range of design water flow rates for treatment to be effective. These components should be robust and carefully selected from reputable manufacturers for their proven accuracy and reliability. Less expensive and/or unproven substitutes should not be accepted. Improper design or installation will also reduce effectiveness. For example, depending on the type of coagulant feed pump used, and the range of water flow rates to be treated, two different size pumps may be needed to accurately feed the desired coagulant dose. Careful attention to these and other operable system components should continue from design through bidding, construction, start-up, and demonstration and operation.

Automatic System Safeguards: System safeguards refined over the years are designed and constructed into the CET facilities. Coagulant can only be added when water flow is present, and the same dose is maintained throughout the design water flow rate range. The coagulant feed line to the point of addition to the water source includes a PVC backpressure valve so that coagulant can only be added when the coagulant pump is operating.

For all systems coagulant feed automatically stops when the measured water flow rate exceeds the peak design water flow rate. Coagulant feed is automatically reenabled when the water flow rate drops below the peak design water flow rate.

The CET incorporates other safeguards (alarms and automated shutoffs) based on set parameters and the coagulant characteristics. Considerations include pump speed, incoming flow rate, coagulant tank levels, coagulant metering, discharge pH if using coagulants that affect water pH, system security, etc.

Controlling Water pH and Precipitate Stability: Systems that use acidic or alkaline coagulants that can affect water pH (i.e. alum) include pH monitoring and automatic coagulant addition shutoff if the treated water pH drops below a preset level (typically 6.2 su) or rises above (typically 7.5 su). Other similar and equally effective aluminum coagulants are available that do not affect water pH.

Aluminum precipitates are stable in sediments and do not re-dissolve due to changes in redox potential or pH under conditions normally found in surface waterbodies. Over time, the freshly precipitated floc ages into more stable complexes. The solubility of dissolved aluminum in the treated water is regulated primarily by water pH. Minimum solubility for dissolved aluminum occurs in the pH range of 5.5-7.5 s.u. and overall preferred water pH in the settling pond is in the range of 6 and 7.5 su. Qualifying conditions in Section 1 require the treated water pH to be within 6 and 7.5 s.u. at 24 hours. In many instances, the concentration of dissolved aluminum in the treated runoff or surface water will be less than the concentration in the raw untreated water due to adjustment of pH into the range of minimum solubility (Harper, 2007).

Downstream Water Chemistry: The CET system should be evaluated to determine if a particular chemical could have an unintended consequence in downstream waters. For example, the Boise River (Dixie Drain project) flows into the Snake River Hells Canyon complex (series of reservoirs along the Snake River). Research has indicated that the system has inordinately high rates of mercury methylation in the reservoirs. Additional research has indicated that sulfur could be contributing to that high rate. Alum contains sulfate. As described in Section 1, laboratory jar testing includes analyzing raw and treated water pH, conductivity, alkalinity, TP, TN, TSS, Cl^-, total Al, dissolved Al, and sulfate if using aluminum sulfate (alum) or other coagulant containing sulfate. CET will reduce additional pollutants which should be included in laboratory jar testing if of interest or a concern: bacteria (e.g., fecal coliform), metals, and others.

Floc Existing the Settling Pond: Accumulated wet floc in the settling pond does not have the ability to exit the settling pond unless pumped by a dredge for floc disposal. Sufficient permanent pool depth and volume is provided and if floc is disturbed it quickly resettles. For all systems, coagulant feed automatically stops when the water flow rate is approaching the peak design water flow rate. Not that the settling pond permanent pool volume provides two+ times the required settling time at the peak design water flow rate.

Dewatering System Recycle: If onsite floc dewatering is required, decant water from the dewatering process should be collected and returned to the treatment system upstream of coagulant addition. Although previous floc decant water and wet floc leaching testing did not indicate elevated concentrations of pollutants, recycle may improve treatment cost effectiveness.

Floc Disposal: Aluminum precipitates which settle to the bottom of the floc settling pond need to be periodically dredged and sent to the wastewater treatment system or dewatered on site with reuse and/or disposal of the dewatered material. Floc testing per state requirements (similar to stormwater sediments) along with coordination with the receivers/end users is recommended to confirm there are no obstacles to the desired floc disposal approach. Extensive testing of potential contaminants (metals, organics, etc.) has been completed with previous projects since 1991 are the results have not restricted either approach.

System Longevity and Controlling Spills: All piping, valves, meters, and materials in the building and throughout the project are compatible with the selected coagulant. Systems include continuous monitoring and provide wireless remote access for operator monitoring and operational adjustment. Above ground double wall coagulant storage tanks are used with interstitial wall monitoring. The coagulant feed line includes concrete markers at ground level and continuous metallic locating tape above the pipe for easy detection. Double wall piping can be used if desired. O&M manual is provided and staff training is completed during start-up with at least weekly maintenance visits at the project site.

Site Security and Safety: Equipment building including doors and windows shall meet local building code and requirements and be secure and capable of protecting equipment and storage tanks from vandalism. Cameras with remote monitoring are recommended as an added level of security.

As with any wet detention pond that accumulates stormwater pollutants, swimming, and consumption of fish from the settling pond is not recommended and access to the site is controlled and/or “No Swimming or Fishing” signs are posted around the pond. Floc settling ponds are used for catch and release fishing including planned community events at some facilities.

Suddenly Stopping Coagulant Addition: If a system is constructed and operated for some period of time with coagulant, there are no expected adverse impacts from stopping coagulant addition under conditions found in normal waterbodies. Floc within the wet settling pond should retain the pollutants until removal. The downside is that the water will not receive coagulant treatment and the pollutant removal efficiencies will be substantially lower.

Section 3

Removal Credits for Pond CET Retrofits

3.1 CET Removal Credits Derived in Other States

Previous coagulant enhanced stormwater and surface water treatment projects have been designed, permitted, and constructed in USEPA Regions 4 and 10 and credited for pollutant load reduction and NPDES/TMDL compliance.

Numerous Stormwater/Environmental Resource Permits for construction and operation of coagulant treatment projects have been issued by the FDEP since 1987. Coagulant treatment is also approved by FDEP for meeting NPDES MS4/TMDL pollutant load reduction requirements. Coagulant stormwater treatment is included in the FDEP Statewide BMP Efficiencies for Crediting Projects in Basin Management Action Plans (BMAPs) and Alternative Restoration Plans Draft, September 2021. Multiple projects received 319h and TMDL funding for implementation from USEPA/FDEP.

USEPA issued a NPDES permit for the Dixie Drain project TP load reduction to comply with TMDL requirements. The Dixie Drain project phosphorus removal offset is written into the City's West Boise Water Renewal Facility NPDES permit. Idaho Department of Environmental Quality (IDEQ) was involved with, and supported, the Dixie Drain project throughout implementation. IDEQ recently took on NPDES permitting from USEPA.

Pollutant removal efficiencies are generally specified (e.g., 90 percent TP removal efficiency) or developed by the project proponent and approved by the regulatory agency based on observed laboratory jar testing pollutant removal efficiencies and modeled percent of average annual runoff volume treated.

Multiple references are provided in the following section, including peer reviewed publications. No recent publications are provided because this is no longer a newer technology.

3.2 Protocol to Define the Existing BMP Baseline Removal Rate

Various methods have been used to define removal rates for wet ponds in the Chesapeake Bay watershed. A conservative estimate for wet pond removal rates was adopted by the Chesapeake Bay Program (CBP) in 2003. The estimates were about 7 to 13 percent lower than the median removal rates derived from an analysis of forty-five wet pond research studies by the Center for Watershed Protection (CWP, 2007). The CBP acknowledges that it discounted the removal rates to reflect concerns about wet pond maintenance over time.

The removal rates for wet ponds and other stormwater treatment practices were revisited by a new CBP expert panel in 2013. By that time, each Bay state had increased their water quality sizing requirements and strengthened their design specifications.

A series of curves were developed by the new expert panel to estimate average annual removal rates for total phosphorus, total nitrogen and total suspended solids based on the depth of impervious surface runoff captured for volume reduction (RR) or treatment (ST) as shown on Figures 12, 13 & 14.

Pollutant removal efficiencies for TP, TN, and TSS for existing wet ponds can be estimated from the adjustor curves. The corresponding removal rates for wet ponds designed to these sizing criteria are shown in Table 4 (Schueler et al, 2016).

Table 4. Wet Pond Pollutant Removal Rates Over Time

Pollutant	CBP (2003) [1]	CWP (2007)[2]	EPR (2013) [3]	75% NPRD [4]
TSS	60	73	50 - 70	88
TP	45	52	40 - 52	75
TN	20	31	25 - 35	40

[1] First CBP estimate of wet pond removal rates

[2] National Pollutant Removal Database, 3rd edition (CWP, 2007)

[3] Expert Panel Report for Stormwater Treatment Practices, 0.5-to-1.0-inch sizing assumed (SSPS EP, 2013)

[4] 75th percentile removal rate from NPRD (CWP, 2007)

Local governments may elect to construct CET retrofit projects in watersheds that contain existing wet ponds with varying impervious surface runoff depth capture. CET projects may also be proposed in watershed areas with no functioning wet ponds or other BMPs. Regardless of the level of treatment, the existing BMP(s) average annual pollutant removal percents can be estimated using the adjustor curves.

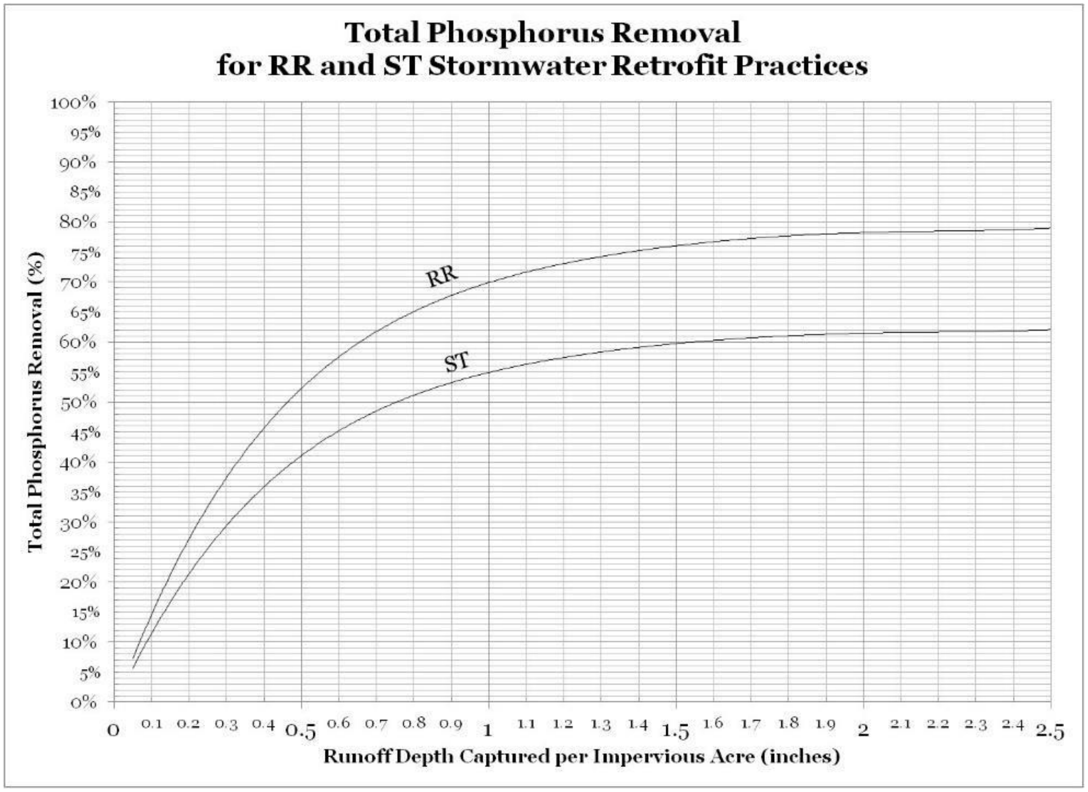

Figure 12. Retrofit Removal Rate Adjustor Curve for Total Phosphorus

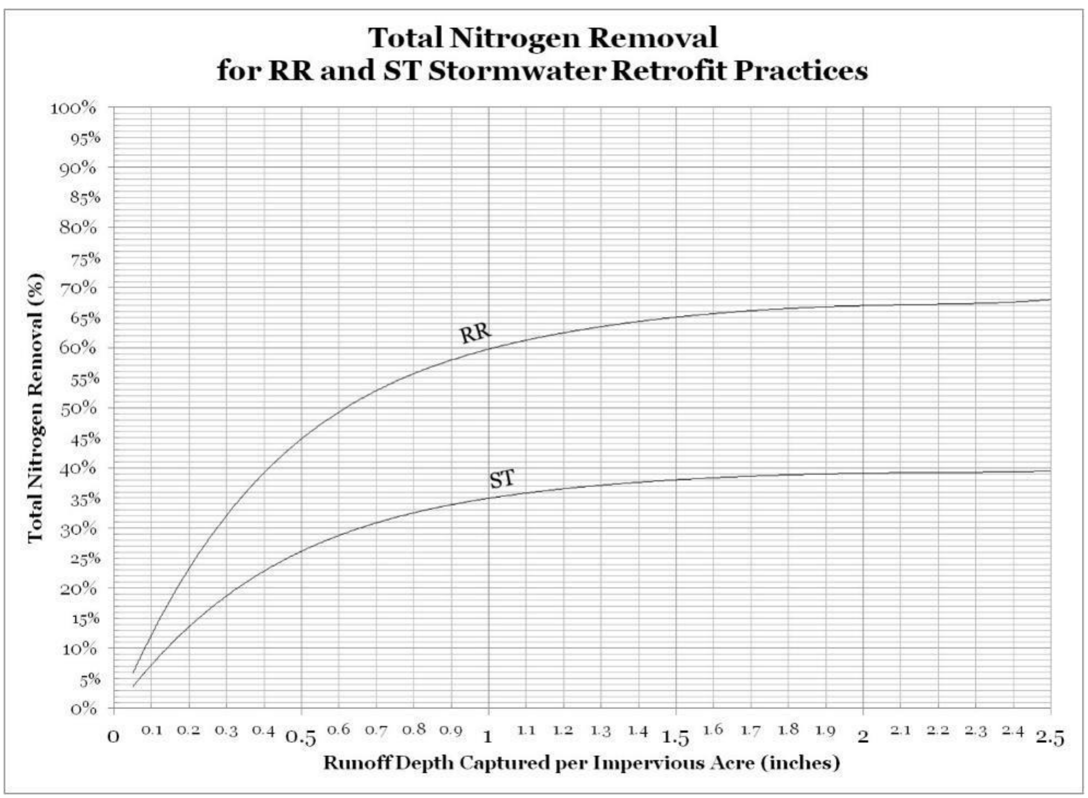

Figure 13. Retrofit Removal Rate Adjustor Curve for Total Nitrogen

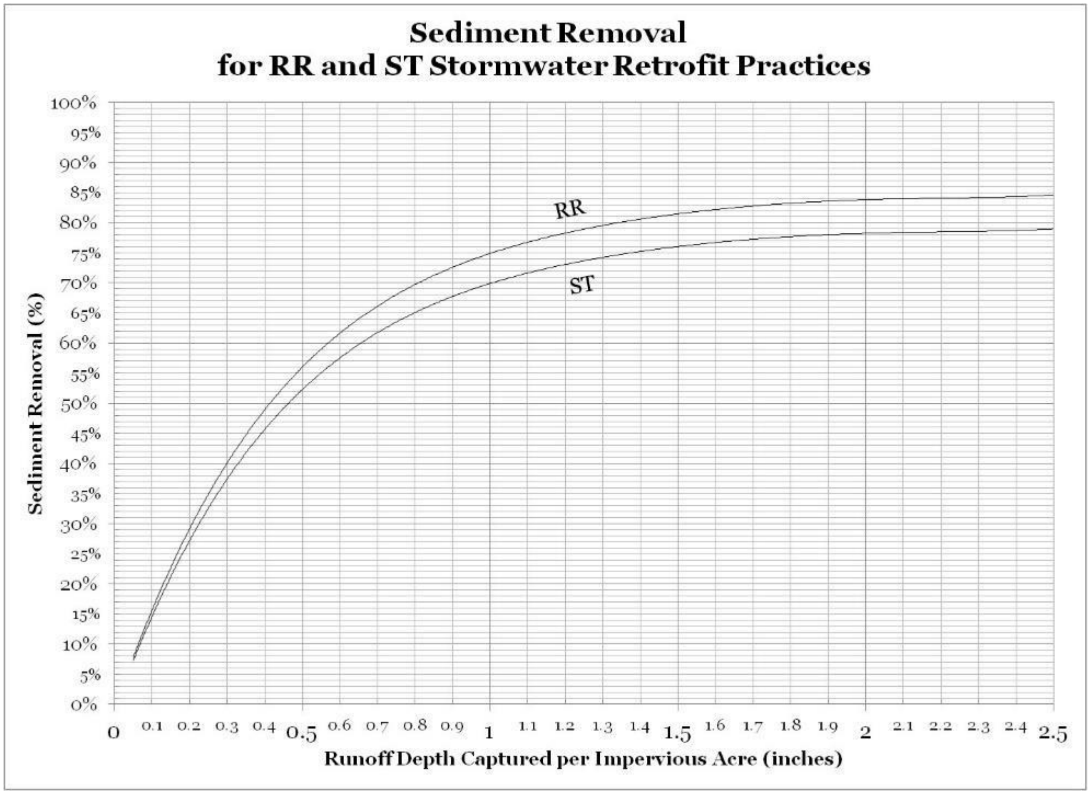

Figure 14. Retrofit Removal Rate Adjustor Curve for Total Suspended Solids

3.3 Protocol to Define CET Incremental Removal Rate

A simple approach is needed to calculate the CET average annual pollutant removal percents that matches the existing BMP approach using the adjustor curves. For impervious watershed areas, initial abstraction is near 0-inches and rainfall depth is approximately equal to runoff depth. From the adjustor curves, capturing or treating 2.5-inches of runoff from watershed impervious areas accomplishes capturing or treating approximately 100 percent of the average annual runoff volume. Capturing or treating 2-inches, 1.5-inches, 1.25-inches, or 1-inch of runoff accomplishes capturing or treating the average annual runoff volume percents in Table 5. Providing CET treatment for up to the peak discharge for the 1-inch rain event will result in treatment of approximately 88 percent of the watershed average annual runoff volume.

Table 5. Rain Event Depth Relationship to Percent of Average Annual Runoff Volume Treated

Design Rain Event Depth (Inches)	Average Annual Runoff Volume Treated (%)
1.0	88
1.25	93
1.5	95
2.0	98
2.5	100

For the portion of the average annual runoff volume treated, CET is expected to achieve the pollutant removal efficiencies listed in Table 2, 90 percent for TP, 35-70 percent for TN, and >90 percent for

TSS. To be conservative, pollutant removal efficiencies used for calculating average annual removals included 85 percent for TP, 45 percent for TN, and 90 percent for TSS.

Table 5 provides the Average Annual Pollutant Removal (percent) to be used for CET that match the adjustor curves approach. Combining the percent average annual runoff volume treated from Table 4 with the CET removal efficiencies for TP, TN, and TSS, provides CET Average Annual Pollutant Removal (percent) based on design rain event depth in Table 6.

For example, if treating up to a 1-inch rain event, the average annual TP removal (percent) = 0.88 (annual volume) * 0.85 (TP efficiency) = 0.75 or 75 percent. If treating a 2.5-inch event, average annual TP removal percent = 1.0 (annual volume) * 0.85 (TP efficiency) = 0.85 or 85 percent. This range of 75 – 85 percent average annual TP removal matches the range from completed projects shown in Table 3.

Table 6. Summary of CET Average Annual Pollutant Removal Based on Rain Event Depth Treated

Design Rain Event Depth (inches)	TP Removal (%)	TN Removal (%)	TSS Removal (%)
1.0	75	40	79
1.25	79	42	84
1.5	81	43	86
2.0	83	44	88
2.5	85	45	90

[1]CET pollutant removal efficiencies (for portion of runoff volume treated) = 85 percent for TP, 45 percent for TN, and 90 percent for TSS

Subtracting the existing BMP annual pollutant removal percent (estimated using the adjustor curves) from the proposed CET annual pollutant removal percent (estimated using the percentages in Table 6), provides the CET net pollutant removal increase. Project laboratory jar testing with the selected coagulant and design dose is used to confirm the assumed CET pollutant removal efficiencies (85 percent for TP, 45 percent for TN, and 90 percent for TSS) are achieved.

The watershed average annual pollutant loads without BMPs can be calculated using the Virginia Runoff Reduction Method (VRRM) spreadsheet or equivalent in other states. The existing BMP and CET annual pollutant load reductions can be calculated using their annual pollutant removal percent.

3.4 CET Retrofit Design Examples

Example 1: Consider a 1,500-acre urban watershed with existing average annual stormwater loads of 1,500 lbs TP, 11,000 lbs TN, and 110,000 lbs. TSS.

There is an existing wet pond that provides treatment for 0.25-inches of runoff depth captured per impervious acre. From the adjustor curves for ST, annual TP removal is 26 percent, TN removal is 17 percent, and TSS removal is 33 percent. The associated existing BMP average annual removals are 390 lbs. TP, 1,870 lbs. TN, and 36,300 lbs. TSS.

A CET retrofit is proposed on the wet pond. Approximately 25 ac-ft of wet pond PPV is available which allows for treatment of the peak discharge rate for the 1-inch storm event and 2 years of consolidated floc storage. PCSWMM was used to model the watershed hydrology and hydraulics and determine the peak discharge for the 1-inch storm (78 cfs).

Laboratory jar testing was performed on the runoff to be treated and consistently met or exceeded the stated CET treatment removal efficiencies of 85 percent for TP, 45 percent for TN, and 90 percent for TSS.

Using the CET average annual removals in Table 6 for a 1-inch design storm event, the CET will remove 75 percent TP, 40 percent TN, and 79 percent TSS.

The additional average annual removals from the CET are 49 percent TP (75-26 percent), 23 percent TN (40 -17 percent), and 46 percent TSS (79-33 percent) or 735 lbs. TP (0.49*1,500 lbs.), 2,530 lbs. TN, and 50,600 lbs. TSS.

Example 2: Same as Example 1 but there is no existing wet pond or other BMPs providing treatment. Using the CET average annual removals in Table 6, CET will remove 75 percent TP, 40 percent TN, and 79 percent TSS. The average annual removals are 1,125 lbs. TP (0.75*1,500 lbs.), 4,400 lbs. TN, and 86,900 lbs. TSS.

Example 3: Consider a 1,500-acre urban watershed with existing average annual stormwater loads of 1,500 lbs TP, 11,000 lbs TN, and 110,000 lbs. TSS.

There are ten existing bioretention areas distributed throughout the watershed that retain and infiltrate runoff. An analysis of these BMPs indicates they provide a total of 0.15-inches of watershed runoff depth capture per impervious acre. From the adjustor curves for RR, TP removal is 22 percent, TN removal is 18 percent, and TSS removal is 25 percent. The associated existing BMP average annual removals are 330 lbs. TP, 1,380 lbs. TN, and 27,500 lbs. TSS.

A CET retrofit is proposed to treat the entire watershed and an existing borrow pit will be converted to a wet settling pond. Approximately 30 ac-ft of wet pond PPV is available which allows for treatment of the peak discharge rate for the 1.5-inch storm event and 1 year of consolidated floc storage. PC SWMM was used to model the watershed hydrology and hydraulics and determine the peak discharge for the 1.5-inch storm (92 cfs).

Using the CET average annual removals in Table 6 for a 1.5-inch design storm, the CET will remove 81 percent TP, 43 percent TN, and 86 percent TSS. The additional average annual removals from the CET are 59 percent TP (81 – 22 percent), 25 percent TN (43-18 percent, and 61 percent TSS (86-25 percent) or 885 lbs. TP (0.59*1,500 lbs.), 2,750 lbs. TN, and 67,100 lbs. TSS.

Section 4

Accountability Mechanisms for the Practice

4.1 General Issues on Practice Reporting and Verification

The accountability procedures established for CET are defined in Section 6 of the stormwater retrofit expert panel report (Expert Panel, 2013). The procedures outlined include:

- Initial construction and performance verification by the CET designer or local inspector
- No double counting removal credits
- Reporting BMP data to the state stormwater agency
- Detailed recordkeeping of BMP plans, surveys, inspections reports, and maintenance agreements

The typical duration for CET removal credit will be 5 years. The removal credit can be extended if a field inspection verifies the BMP is still functioning as designed (Expert Panel, 2013). Localities will need to verify that urban BMPs are installed properly, meet or exceed the design standards for its BMP classification, and are functioning as designed prior to submitting the BMP for load reduction credit.

4.2 Overall Estimate of CET Longevity

CET systems have been installed and operating effectively for more than 30 years. Longevity is directly related to proper design, construction, and regular operation and maintenance. Because of the importance of operation and maintenance, the duration of CET credit is 5 years. The credit can be renewed for the next 5-year period with a field inspection demonstrating that the CET is in good condition and is functioning as designed. Every 5 years CET credits need to be renewed.

4.3 Unique CET Operation and Maintenance Criteria

Weekly operation and maintenance are essential to maintain the performance of CET retrofits over time. Specific maintenance tasks for CET retrofits depend on the design, project components, and operations. System operation and maintenance requirements are detailed in Section 2.6.

4.4 Reporting, Tracking and Verifying the Practice

Reporting CET Retrofits

CET retrofits fall within an existing category of stormwater retrofits -- Enhancements to Existing BMPs - so communities should report the following data as outlined by the retrofit expert panel (Expert Panel, 2013) or otherwise required by your state stormwater agency:

- Retrofit type (i.e., enhancement of existing wet pond or new CET system)
- Latitude and longitude coordinates of the BMP
- Installation date and when the credit requires renewal

- 12-digit watershed of the BMP
- Total drainage area and impervious cover area treated
- Design storm event depth and runoff volume treated
- Removal credits for phosphorus, nitrogen, and total suspended solids

Tracking CET Retrofits Over Time

Given the shorter credit duration for CET retrofits, localities should develop a local tracking system. Localities should maintain a digital project file for each CET project. The project files should include a locator map, record construction drawings and/or as-built survey, digital photos, maintenance agreements, inspection and operation and maintenance records, and ongoing operational data. Locality should maintain and update the CET project files annually for the lifetime of the BMP.

Localities can renew the credit for an additional five years if they can report to the state that the retrofit has passed the field inspection and is being properly operated and maintained. Otherwise, the credit is automatically terminated by the state when the initial credit duration expires.

Verification for CET Pond Retrofits

Initially the design engineer shall certify the CET system has been constructed in accordance with the design and is operating properly after initial system start-up and testing is complete. Ongoing verification of proper operation is conducted by the locality maintenance entity by following the Operation and Maintenance Plan and conducting weekly field visits, see Section 2.6 for more information.

At least three months prior to the credit end date, the locality shall perform an inspection and assessment of system operation and maintenance. Verification that the system continues to function as designed, and is being properly operated and maintained, shall be submitted to the state with a request to extend the credit duration an additional five years. Additional criteria may be added by the state stormwater agency.

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Appendix A.

Compiled Comments and Responses from Expert Review Team

In May, 2023, the Chesapeake Bay Program's Urban Stormwater Workgroup (USWG) reached a consensus decision to pursue the review of Coagulant-Enhanced Stormwater ponds for nutrient and sediment reductions under the Chesapeake Bay TMDL, using the USWG's BMP Interpretation Policy (USWG, 2016). Under this policy, the USWG Coordinator convened a small panel of practitioners and experts with experience using and researching the practice, to review and provide detailed comments on the technology and proposed white paper. The review team was convened over two virtual meetings (one meeting with the Minnesota reviewers, and one with the rest of the review team) and given a 30-day period to review and provide feedback. The experts consulted are listed in Table A-1. Each set of comments and the proposal team's responses are then captured below.

Table A-1. Review Team	
Name	Affiliation (role)
Kate Harris	City of Boise, ID
Mark Heidecker	City of Tallahassee, FL
David Vlasin	Ramsey Washington Metro Watershed District, MN
Eric Korte	Ramsey Washington Metro Watershed District, MN
Andy Erickson	University of Minnesota
KC Filippino	Hampton Roads Planning District Commission (USWG Representative)
Norm Goulet	Northern Virginia Regional Commission (USWG Chair)
David Wood	Chesapeake Stormwater Network (USWG Coordinator)

Appendix A.

PUBLIC WORKS DEPARTMENT

MAYOR: Lauren McLean | DIRECTOR: Stephan Burgos

August 25, 2023

David Wood
Executive Director
Chesapeake Bay Stormwater Network
Wood.CSN@outlook.com

Comments submitted electronically

Mr. Wood,

Overall recommendations or comments on the proposal?
Thank you for the opportunity to provide comments on this proposal. Stormwater treatment is an important component of pollution reduction and the City appreciates the effort to increase the pollutant removal capability of wet ponds.
The document is well written and provides a good history on protocols used to determine BMP baseline removal rates. In addition, the review of available science (section 2) was well done and the City appreciated the variety of systems described. For example, the City of Boise's Phosphorus Removal Facility (PRF) on the Dixie Drain is a fully lined operation which initially made me question proposed total phosphorus removal rates in unlined facilities. However, the review also included unlined water bodies and the nutrient reductions achieved (Lake Beauclair, Largo Park, Upper Lake Lafayette).

Are the recommended pollutant load reductions reasonable and in-line with your professional experiences?
The City has the most experience with total phosphorus and total sediment removal rates. The proposed 85% removal rate for total phosphorus seems high, for reasons detailed below. The City recommends 80% which is closer to the average of the available science example results and likely more indicative of field efficiency vs. results from jar testing. The City of Boise's PRF NPDES total phosphorus removal requirement includes a 1.5 offset for varying environmental conditions, sampling variability and other factors that influence total phosphorus removal. The City of Boise supports the total nitrogen and total suspended solids removal rates.

Response: Table 6 in the report indicates CET average annual TP removals (percent) ranging from 75% to 85%, with 80% as the midpoint. 75% TP removal requires treating almost 90% of the average annual runoff volume and 85% TP removal requires treating 100% of the average annual runoff volume. These removal efficiencies are in line with actual removal efficiencies from completed and monitored projects.

In addition, the Boise system was designed to achieve only a 70% TP removal efficiency (water rights requirement) compared to the normal 90%. A lower coagulant does was used to achieve this lower TP removal efficiency requirement. The TP removal efficiency at Boise could likely be higher with a higher coagulant dose, but it is not required and would be less cost effective. Another factor in Boise is that surface water, not stormwater, is being treated and practically all of the TP is in the form of dissolved P. Stormwater contains a higher percentage of particulate P which typically requires less coagulant to form a good floc and remove.

The 1.5 offset requirement was due to the project being an offset to required TP reductions in the wastewater treatment facility effluent, and not the use of CET treatment.

Are there any specific design/maintenance requirements you would consider essential, or pitfalls that we should make folks aware of if we are going to recommend this practice for TMDL reductions? (that have not been mentioned or properly emphasized)

Operation

This has been mentioned in the paper, however it is important to stress the flow management aspect of treatment. Flow rates that induce sediment flushing from the wet ponds should be determined and avoided (bypassed) to prevent nutrients from entering the receiving water.

Response: Resuspension of floc and sediment flushing has not been observed in previous projects. Settling basins are designed with at least a 2x safety factor for PPV and residence time. In other words, sufficient residence time is provided for two times the peak design water flow rate. Coagulant addition automatically stops when the actual stormwater flow rate reaches the peak design water flow rate.

Settling basins are also designed with a typical depth of 10-15 ft., 8 ft. minimum, to the PPV normal water level. Floc is retained on the bottom of the pond, and the pond discharge is from the top of the pond. Off-line settling ponds which limit the flow entering the settling pond are used if possible. Sometimes on-line settling ponds need to be used.

Jar testing results

The City is concerned that jar tests may overestimate pollutant removal efficiency compared to field results. For example – while alum demonstrated the best results in the jar testing for the City of Boise, it did not perform as well in the field.

Response: We have observed only minor differences between jar testing removal efficiencies and completed projects monitored results. Coagulant dose can be slightly modified during operation if needed to achieve the target removal efficiencies. Regardless, this has been addressed by reducing the removal efficiencies used to develop the final pollutant removal percents shown in Table 6.

Type of phosphorus

The City of Boise's PRF results are included as one of the research study sites. The City's source water (Dixie Drain) phosphorus is primarily dissolved phosphorus (typically 90%), which is why chemical precipitation is the best approach for treatment in that system. In addition, as mentioned above, the particulate phosphorus that does enter the system settles out in the inlet flow channel or sedimentation basin prior to chemical addition increasing the efficiency of the chemical dosing step of the treatment train. It is important to determine the dissolved phosphorus fraction of the incoming stormwater to best estimate removal rates. The paper includes the equations for the creation of aluminum hydroxide and aluminum phosphate, but it is unclear of the efficiency of each portion. For example, if the phosphorus is 90% dissolved, the removal rate is 80%, but if the phosphorus is typically particulate, is the removal rate lower?

Response: Most projects completed to date have included laboratory testing of both particulate and dissolved P during jar testing and in post monitoring. Coagulants can remove particulate and dissolved P equally. In some cases a slightly higher coagulant dose may be required to remove higher concentrations of dissolved P due to forming a floc that settles efficiently.

Extensive jar testing is required for CET systems using the actual water to be treated. Whether the stormwater contains more dissolved or particulate P, the coagulant and dose needed to consistently achieve at least 90% TP removal efficiency will be determined. Actual TP reduction credit will be based on a lower TP removal efficiency.

Have you experienced (or are aware of) any unintended consequences from these systems that are not mentioned?

The white paper mentions it briefly, but the system should be evaluated to determine if a particular chemical has an unintended consequence in downstream waters. For example, the Boise River flows into the Snake River Hells Canyon complex (series of reservoirs along the Snake River). Research has indicated that the system has inordinately high rates of mercury methylation in the reservoirs. Additional research has indicated that sulfur could be contributing to that high rate. That was another reason why aluminum sulfate (alum) was not selected for use in the final project design.
The City of Boise also conducted jar tests to determine the impact of chemical dosing on water chemistry beyond just pH and alkalinity. The white paper mentions that the chemical doses for the example projects ranged from 4 -10 mg Al/L. During jar tests, the City of Boise evaluated a large suite of metals to determine the point past diminishing returns. For example, at chemical doses in the ascending limb of the dose response curve, more aluminum is present in the inflow water compared to the outflow water. At the top of the curve, however, the aluminum concentrations are increasing in the outflow water compared to the inflow. It is important to understand the implications/unintended consequences of chemical overdosing.

On page 2-10, the paper describes how previous testing on dewatered floc, including leaching analytes, indicate it does not release bound pollutants and is safe for use in the environment. It is not clear which study the paper is referring to. For the City of Boise, the source water to the Phosphorus Removal Facility is consistent in its chemical composition as most of the water (as mentioned in the paper) is from groundwater and agricultural return water. The City is concerned that stormwater from impervious areas does not have the same consistency and may contain harmful chemicals which may decrease the beneficial re(use) of the floc. The City of Boise recommends evaluation of the floc before it is said to be "safe for the environment".

Response: Text related to potential concerns with using coagulants containing sulfate have been added to the report. This issue has come up on FL CET systems and is why sulfate was always analyzed during jar testing to evaluate the potential for increasing the concentration. In the end, no alum system completed to date has had an issue with increasing mercury methylation in the reservoirs. Similarly, if jar testing using a coagulant containing chlorides, that parameter is included in the laboratory analyses.

Substantial additional content was added to the report related to completed projects and wet floc and dewatered floc and testing. None of the completed projects have known issues with consolidated wet floc or dewatered floc that limited the ability to dispose of in the sanitary sewer system or general land application. We've also added a qualifying condition for floc testing per state requirements (similar to stormwater sediments) along with coordination with the end users/receivers is recommended to confirm there are no obstacles to the desired floc reuse and/or disposal approach. Note that dewatered floc has beneficial uses that is discussed further in the report.

Controlling the dissolved Al concentration in treated effluent is also included in the unintended consequences, Controlling Water pH and Precipitate Stability.

Thank you again for the opportunity to participate in the review process. If you have questions or concerns about my comments, please don't hesitate to reach out.

Sincerely,

Kate Harris
Water Quality Programs Manager
City of Boise

Appendix A.

Coagulant-Enhanced Stormwater Ponds Review

Comments Submitted by: Mark Heidecker, City of Tallahassee

Page 1-3, paragraph <u>"Laboratory Jar Testing"</u>

Comment: If the basin includes industrial dischargers it may be prudent to also include a seasonal element here. Industrial discharger, including power plants, will ramp up or down production depending on need thereby increasing or decreasing their discharges which could change wet and dry weather discharge characteristics.

Response: Stormwater characteristics are variable and we've seen this variability with the proposed wet and dry weather sampling. Added a statement about considering this as a need although I would not expect it to impact the design or operations.

Page 1-4 bullet on Automated operation

Comment: Proposed text change to include the statement: "The system should incorporate alarms and automated shutoffs based on set parameters. Considerations should include pump speed, incoming flow, tank levels, coagulant metering, discharge pH, system security, etc".

Response: The proposed change was accepted.

Page 1-5 bullet 3 (water alkalinity)

Comment: Proposed text change to add the statement "The addition of a buffering compound will be necessary if appropriate alkalinity and pH can't be achieved."

Response: We did not include this revision. If the raw water does not have adequate alkalinity to use alum and maintain an acceptable finished water pH, then an alternative coagulant that does reduce water pH should be used. These are available and are effective. Adding a buffering compound increases the complexity of water treatment, monitoring, and system operations, and is not needed.

Page 1-5 bullet 6 (consolidated floc removal)

Comment: Proposed text change to add the statement, "at such time where the necessary residence time can't be achieved or appropriate settling of floc can no longer occur."

Response: We accepted the removal of the dredging info here and modified the language when sediment removal is warranted.

Page 1-5, paragraph 9 "When pumping floc"

Comment: Disagree with pumping to the sanitary system. In our experience, the floc doesn't settle within its own discreet layer but is rather mixed with other sediments and is likely to be inappropriate for disposal with the sanitary sewer system.

Response: I removed the statement about being preferred but still believe this to be the easier approach. With Mark's system they likely have a higher sediment load than most urban watersheds. We have seen the floc get mixed in with the pond bottom sediment and accumulate slower than predicted. We've not had a utility not accept the floc. We know there is also additional consolidation as the floc depth increases. Either approach works and floc depth and volume will need to be monitored to determine when dredging is needed. Lessened the recommendation for sending floc to sanitary sewer and importance of understanding watershed sediment load and capturing.

Page 1-5, paragraph 9 “every one or more years”

Comment: Our experience has been that floc accumulation estimates are overestimated during the jar testing process. It's likely that dredging will need to occur more in line with a typical swmf (20-25 years) rather than every 3-5 years as jar tests typically estimate.

Response: Initial floc volume can be estimated accurately using the jar testing floc volume results in conjunction with the annual water volume to be treated. We also know that floc consolidates over time on the bottom of the pond and increases with increasing floc depth. We also know that there is some mixing of floc with the original pond bottom sediments at that interface. We take all that into consideration when estimating longer term floc volume, pond floc storage, and the frequency of required dredging. We modified some of our text related to estimating longer term floc volume that accumulates in the pond.

Page 2-8, Section 2.2 “Chemistry of Aluminum Coagulants”

Comment: I understand new aluminum coagulants outside of alum exist. However, the projects referenced I believe are all Aluminum Sulfate (Alum). It's my opinion that this or a document outside of this should give a deeper dive into these other products to further review their efficacy.

Response: The other common aluminum coagulants are not new, have been used for many years, and treat stormwater just like alum, forming the same precipitates. Dixie Drain does not use alum. Aluminum is the reactive compound and all are approved for drinking water treatment. These coagulants are used extensively throughout the globe for water treatment every day and do not have an effect on water pH.

Page 2-14, paragraph 3 “Wet floc”

Comment: I have concerns with this. I believe operators should be prepared to dredge in an alternate manner than want is described.

Response: Their view is limited to one project that apparently receives a substantial sediment load from the contributing watershed. They also have no dedicated upstream sediment capture before the coagulant treatment. Consolidated floc is typically still 98-99% water and is a very small flow rate compared to the wastewater flow. If on-site dewatering is needed, it can be completed and could be less expensive if wastewater disposal fees have to be paid for sanitary sewer discharge. Additional text provided in the section.

Page 2-17, paragraph 1 “Coagulant enhanced stormwater”

Comment: Again, I believe the majority of studies have been related to systems utilizing aluminum sulfate.

Response: The aluminum based coagulants used are the same and are used extensively throughout the world for water treatment.

Appendix A.

Coagulant-Enhanced Stormwater Ponds Review Discussion: Meeting Notes

Attendees: Andy Erickson (UMN), David Vlasin and Eric Korte (Ramsey-Washington Metro Watershed District), David Wood (CSN)

Format of Review: David posed a series of questions about the proposal to the review team, in an interview-style format. Review team provided responses.

Discussion:

Question: Have you experienced any concerns regarding the disposal of the spent flocculent? For example, if flocculant has a large concentration of heavy metals or other containments of concern (PFAS, Pharmaceuticals, etc.) should it be disposed of in a special manner? Do you require testing of spent floc prior to disposal?

> Response: We haven't monitored for this ourselves. We have a permit with the treatment plant, so they monitor for that. We pay a cost per gallon of floc and give the treatment plant samples. For a normal pond, we do coring of the material to get lab results and determine where they go - mostly they go to landfills. In this system we liquify to pump it more easily.
>
> Proposal Team Response: Since the first project, Lake Ella, resulting precipitates (floc), physical and chemical characteristics, and disposal options have been evaluated extensively. The resulting floc has been found to be stable, does not release bound pollutants, has beneficial uses, and can be sent to the sanitary sewer system or land applied. Additional information has been added to the end of Section 2.3. Testing of CET project floc physical and chemical characteristics before the initial floc removal maintenance event is recommended to verify acceptable end uses in accordance with state requirements.

Question: Have you experienced any seasonality factors that would affect pollutant removal performance? With pH an important factor, and with winter road salt inputs, are there any considerations that you've had to take in winter months?

> Response: We don't run the system in the winter. We start in April through Novovember. It is not as efficient in really cold weather., so we turn it off. That said, we haven't broken down removal rates month by month. One maintenance consideration is that they system has to stay somewhat warm in the winter because the floc can really thicken in cold months.
>
> Proposal Team Response: Winter temperatures in MN are much colder than in the Chesapeake Bay states. Coagulants with a low freezing point, like ACH, are available and effective for treating cold water. This has been proven with jar testing in Madison, WI for Starkweather Creek, and accomplished in Boise at the Dixie Drain project. CET systems include heated buildings, and coagulant storage tanks can also be heated, if desired.

Question: Our proposal requires jar testing to establish the design parameters like dosing, etc. Was that part of your process? Is this re-conducted at different intervals to assess possible changes in the runoff due to landscape changes?

> Response: 8.2mg Aluminum per liter of stormwater was our ultimate goal. We did bench testing at the outset, but that pre-dated this team. We have not seen much change over time – watershed is very urban and hasn't changed much. Jar testing is a standard requirement

for these systems. It is good to redo it if the removal performance has changed, or if the landscape is rapidly developing.

Question: How about long term maintenance activities? What should operators be looking at and collecting over time?

Response: Changing the pH probe is the biggest one. Samplers need to be maintained, but most are minor, routine. It's a very reliable and bullet-proof as a system. Maintenance and monitoring are critical. We would estimate it takes us 6 person hrs per/week on the system checking probes and collecting samples. It is very hands-on.

Proposal Team Response: While we do provide for on-site observation, the use of a SCADA system or equivalent increases the reliability and effectiveness of the system through remote monitoring, testing, and operations.

Question: The proposal recommends a percentage bump in TN and TP removal efficiency over traditional ponds. Two studies sent to us showed 37% and 68% TN reductions, and 74 and 85% TP reductions. Is this in line with what you've observed?

Response: We are not monitoring for TN, but the TP efficiency is very close. We are seeing a 70% TP removal efficiency.

Proposal Team Response: Annual mass pollutant load reductions are directly correlated to the percent of annual water volume treated, and the effectiveness of treatment, which is a function of the coagulant and aluminum dose. Alum has a higher freezing temperature than some other coagulants and is not as effective for treating colder water. They also indicated a desire to lower the alum dose which may reduce the TP removal efficiency.

Question: Are there any specific design requirements you would consider essential, or pitfalls to avoid?

Response: The pH above 6 is the most important factor. Have a system in place to shut it down if it drops is the big thing. Diverting the water successfully is important, and having a way to avoid new inputs to the system if we need to. That way, if something negative were to happen, stormwater doesn't have to go through the system via diversions. We did have 1 board member who was very opposed due to the stigma of adding chemicals to the system. So there may be a public messaging and communication need from the outset.

Proposal Team Response: This is addressed in the document. Our preference is to use a coagulant that does not depress pH. Systems that use a coagulant that depresses water pH will have automated shut-off and the sensor will need to be checked routinely and replaced if needed.

Question: Are there any other general comments you would like to make about the practice or proposal?

Responses:

- Dollar for dollar, pound for pound, this is the best BMP we have in the watershed district.
- Every 5-7 years we physically pump out the floc and discharge it to the sanitary sewer. We are charged a fee based on the amount of gallons. Clean-out occurs when 50-60% full of the floc.

Appendix A.

- We sample inlet and outlet every week, at least 3x per month – storms or grabs. pH is the most critical (cant go below 6, system shuts off automatically at 6.2).
- A little more on the TP removal efficiency. We are showing a 70% reduction in P based on 20 years of monitoring, and this has been really consistent. Pre- enhancement concentrations were at 60 micrograms per liter, post-enhancement was 27 micrograms per liter.
- Maintenance has evolved. First cleanout used fly-ash to thicken up floc so it wouldn't resuspend in order to pump it out, but it was a mess and very expensive. Now we use a duckboat motor, and some trash pumps. It requires constant mixing to keep the floc liquid enough to pump it out. It takes about 7-10 days to pump it down w/ 12+ hours per day. Do this every 3-7 years based on rainfall.
- We would estimate a 35 year lifespan for the system.
- Our cost efficiency is around $1,300 per pound TP removed, including all costs (construction, maintenance, permitting, chemical usage and staff time)