Coagulant Enhanced Stormwater Treatment for Use in the Chesapeake Bay Watershed

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Coagulant treatment involves adding a common flocculent to stormwater/surface water which forms precipitates which trap total phosphorus (TP), total nitrogen (TN), bacteria, total suspended solids (TSS), and other pollutants. 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 at the peak design water flow rate. Systems are designed to treat stormwater runoff from “common” rain events (up to 1-1.5-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 (typically 2+). Coagulants containing aluminum are typically used due to their high pollutant removal efficiencies and precipitate stability. Coagulant Enhanced Stormwater Treatment is selected due to:

- Higher pollutant removal efficiencies
- Substantially less land required
- Ability to treat large watershed areas with a single project
- Typically lowest life cycle cost per mass TP, TN, and bacteria removed
- Improves surface water quality for habitat, aesthetics, and recreational use
- Accelerate and simplify NPDES MS4/TMDL requirements

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), 35-65 percent for TN, >90 percent for TSS, and 99 percent for bacteria (Harper, 1994, 1997, 2007). Typical life cycle costs (construction + 20 years annual operation and maintenance) range from $200 to $600 per pound TP removed and from $100 to $400 per pound TN removed. 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.

Why Should Coagulant Treatment be Approved in Virginia?

Coagulant Enhanced Stormwater Treatment 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.
- Many of the wet stormwater ponds were constructed only to address water quantity and provide limited water quality benefits.
- 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 50 times more than coagulant treatment retrofits.
- Entire watershed areas can be treated with a single coagulant project which substantially reduces the effort and cost to operate and maintain.
- Coagulant Enhanced Stormwater Treatment is not recognized as an approved technology and local governments are reluctant to implement due to the lack of credit.

As an example, consider a 1,500-acre urban watershed with existing average annual stormwater loads of 1,500 lbs TP and 11,000 lbs TN. A single coagulant retrofit project on 5-acres of land would annually remove approximately 1,100 lbs TP and 3,500 lbs TN at a life cycle cost (construction + 20 years annual operation and maintenance) on the order of $3M to $6M. Multiple to numerous traditional 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 $12M to $90M. Savings for this one watershed area is expected to be between $9M and $84M. Consider the potential savings if coagulant treatment 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.

History of Coagulant Use

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.

In 1970, granular aluminum sulfate 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, alum and other 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 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 best management practices (BMPs) such as wet detention ponds or dry retention basins. After extensive jar testing with aluminum sulfate 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 flow meters to continuously measure the flow of water through multiple stormwater outfalls. Water flow rate information is transmitted to a treatment equipment 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 lake water 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 stormwater 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 stormsewer pipe upstream of the lake so that the coagulant reaction is complete before the 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 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/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 in 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. A manually driven hydraulic dredge is used to pump consolidated floc into the adjacent wastewater collection system every few years. System monitoring and operation can be performed with an iPad.

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 is greater than what was predicted, and surpassing the 36 percent total phosphorus reduction requirement established by the 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 $5.4 million and the estimated annual operation and maintenance cost was $300,000. Life cycle cost effectiveness is approximately $200 per pound TP removed and $166 per pound TN removed.


Figure 3. Original Weems Pond (left) and Upper Lake Lafayette Nutrient Reduction Facility (right)

The largest non-point source coagulant treatment system was completed in 2009 on the Apopka-Beauclair Canal downstream of Lake Apopka outside of Orlando, Florida. An aerial photograph of the system is shown in 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 is $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.

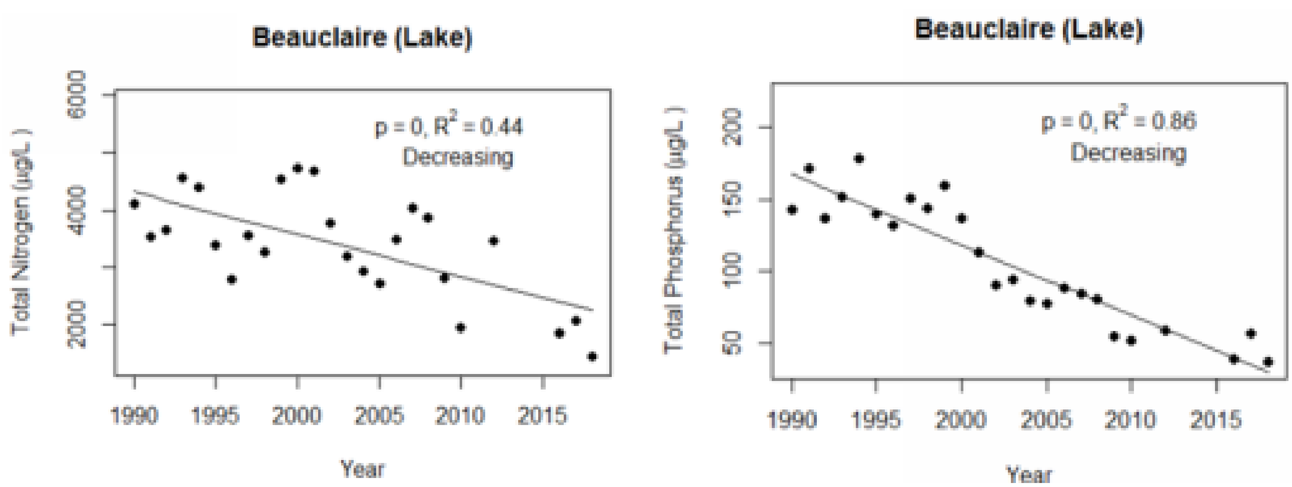

Figure 5. Trend plots of annual average TN and TP concentrations in Lake Beauclair (Lake County Water Authority (LakeWatch Report, 2021)

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 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.

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.

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. An aerial with process elements is shown on Figure 6. 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 requires 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.

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 6. Dixie Drain Phosphorus Removal Facility Treatment Overview

Chemistry of Aluminum Coagulants

Aluminum coagulants are commonly selected over ferric coagulants due to aluminum's high ionic charge and small crystalline radius. These combine to 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 to 45 seconds. After 45 seconds of contact between 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 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 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 of alum.

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 per year 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. Previous testing on dewatered floc, including leaching analyses, indicate it does not release bound pollutants and is safe for use in the environment. Typical beneficial uses are provided in a later section.

Project Initial Testing and Evaluation

Laboratory testing must be performed to verify the feasibility of coagulant treatment and to establish process design parameters. The feasibility of coagulant treatment for a particular water stream is typically evaluated in a series of laboratory jar tests conducted on representative runoff or surface water samples collected from the project watershed area. Typically on the order of six water samples are collected over time during different conditions. For stormwater this may include dry and wet weather if dry weather baseflow is present and will also be treated and during cold and wet weather. Extensive jar testing completed of 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, 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 7.5 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 a raw and coagulant dose lab samples as shown in Figure 7.

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. 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 by BC to the certified laboratory. 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 testing at Dixie Drain PRF is shown on Figure 8.

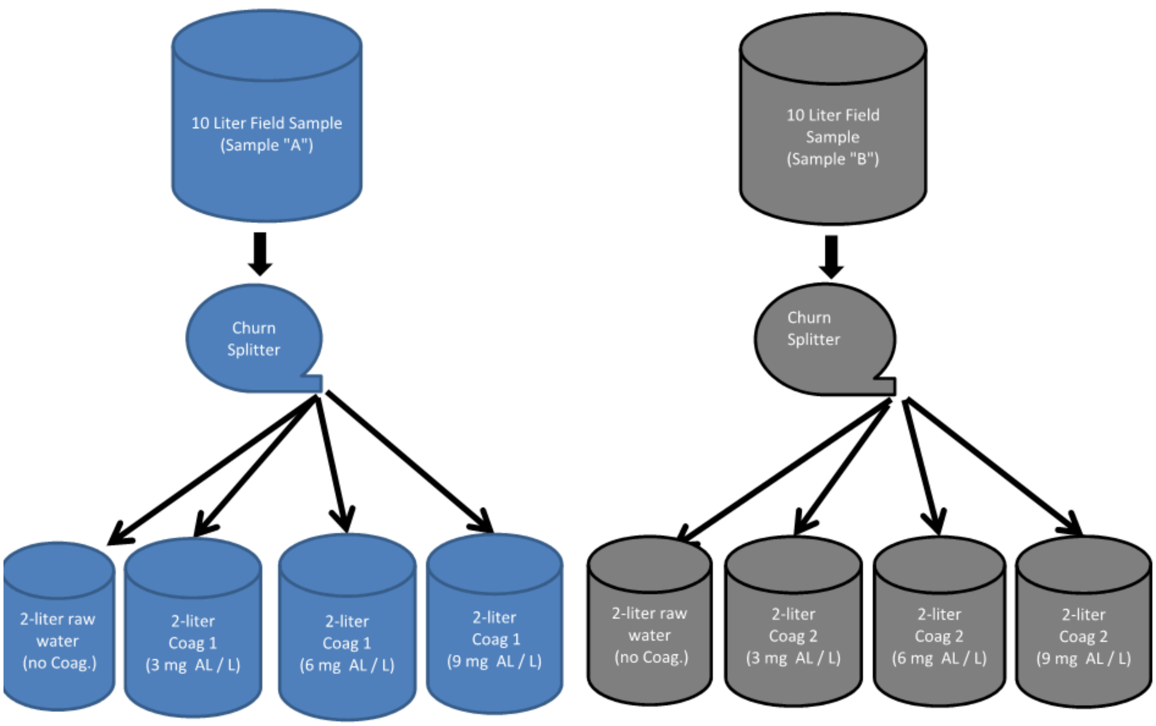

Figure 7. Schematic of Coagulant Jar testing Lab Procedure

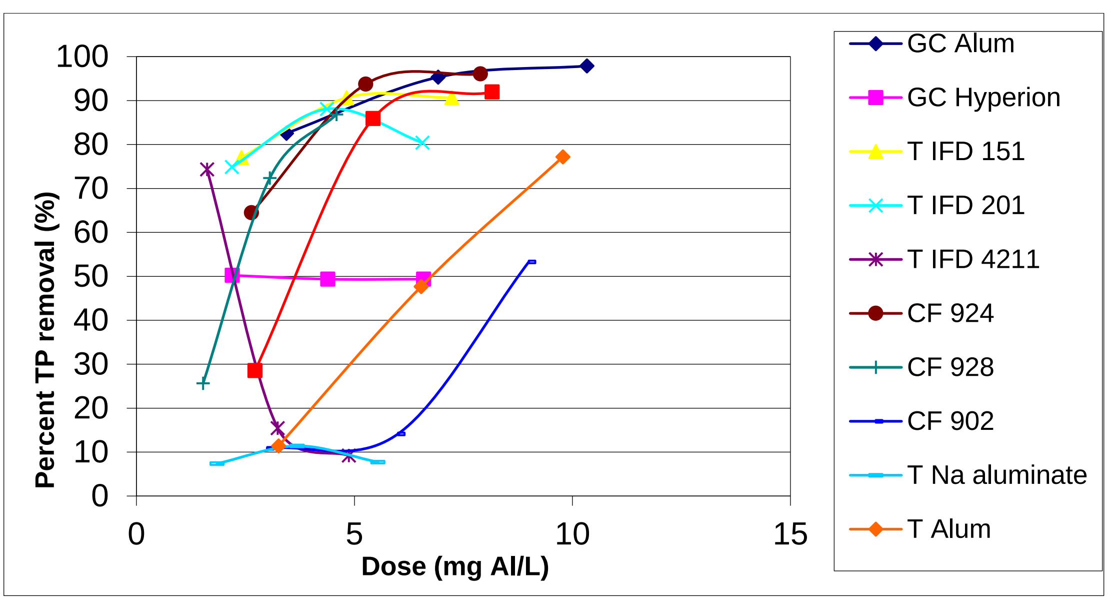

Figure 8. Jar Testing Results for Dixie Drain Water, Percent TP Removal vs. Coagulant Dose (City of Boise, May 2011)

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 1-1.5-inches, and to estimate the average annual runoff volume that is treated based on treating flows up to the selected design storm event peak discharge rate. For example, if all watershed runoff up to the peak discharge rate for a 1-inch storm event is treated, approximately 80 percent of the average annual runoff volume will be 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.

Existing condition average annual pollutant loads can be estimated using the modeled flow volumes and literature and/or measured stormwater pollutant concentrations. The VRRM spreadsheet can also be used to estimate existing condition average annual pollutant loads. Pollutant removal efficiencies are estimated 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 average annual raw TP load is 2000 pounds per year (lbs/yr), 80 percent of the average annual runoff volume is being treated, and the average jar testing TP removal efficiency was 85 percent, the average annual TP load reduction is 2000 lbs/yr x 0.8 x 0.85 = 1,360 lbs/yr.

System Configuration and Components

In a coagulant enhanced stormwater treatment 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 flow meter signal. In newer systems, monitoring and operation can be done using an iPad. The 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 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 1-3 years). There is no urgency in removing collected floc which will continue to consolidate with time.

Depending on the gross solids and/or channel bed load, a sedimentation basin may be used to capture gross solids upstream of the primary treatment system. Booms or other features to capture trash are commonly used. The basin or other feature is 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 are provided. The facility structure can be as simple or as architectural depending on location and owner preference. Photos from the Lake Lafayette facility are provided in Figure 9.

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.

Figure 9. Photos from the Upper Lake Lafayette Nutrient Reduction Facility

Wet floc is typically hydraulically dredged using manned or remote control equipment. Both have been used on the example projects. The rate is usually low at 300 to 500 gallons per minute. Wet floc in areas with central wastewater collection systems is pumped directly to the municipal system. The flow rate and volume are normally small compared to the total wastewater flow in the system, dredged floc is typically 98-99 percent water and the solids are very 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. Polymers may be required to enhance the dewatering process. Normally at least 1 year is available for floc dewatering due to the storage available in the wet settling pod, which provides well more than enough time for dewatering.

Dewatered floc has beneficial uses due to its ability to still uptake some 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 is being used increasingly to develop custom medias in bioretention and other types of flow-through stormwater treatment systems for the removal of TP and other pollutants. Some dewatered floc is also used to stabilize farm roads.

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.

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 less than one hour at the site. 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.

Periodic servicing of the coagulant feed pumps is required along with occasional system repairs. Common required spare parts will be 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
- 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
- Chemical feed pump diaphragm alarm
- Flash mixer run
- System water levels

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).

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 reduction. System safeguards are designed and constructed into the facilities. Coagulant can only be added when water flow is present and the same dose is maintained throughout the design water flow rate range. Systems that use aluminum sulfate (alum) include pH monitoring and automatic alum addition shutoff if the water pH drops below a preset level. Alum is no longer typically used unless the raw water has adequate alkalinity and the finished water pH benefits from alum addition. 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.

All materials used in the building are compatible with the selected coagulant. Systems include continuous monitoring and provide 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.

If a system is constructed and operated for some period of time with coagulant, there are no adverse impacts from stopping coagulant addition. Floc will 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.

Permitting and Approvals 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 Florida Department of Environmental Protection (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 Best Management Practice (BMP) Efficiencies for Crediting Projects in Basin Management Action Plans (BMAPs) and Alternative Restoration Plans Draft, September 2021* provided. 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.

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.

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