WISCONSIN DEPARTMENT OF NATURAL RESOURCES

TECHNICAL STANDARD

EPISODIC ALUMINUM-BASED COAGULANT DOSING FOR MAINTENANCE OF STORM WATER WET DETENTION PONDS

1014

DEFINITION

Episodic *additive*[1] dosing of a *wet detention pond* is the practice of applying aluminum (Al)-based *coagulants* across the surface of an existing wet detention pond.

PURPOSE

The purpose of this practice is to maintain urban storm water wet detention ponds so that they continue to provide pollutant control needed to meet non-agricultural storm water performance standards and total maximum daily load (TMDL) wasteload allocations. The practice reduces release of pollutants from accumulated wet detention pond sediments. The technical standard also includes a method for estimating the total suspended solids (TSS) and total phosphorus (TP) removal from the water column during each application of Al-based coagulants.

CONDITIONS WHERE PRACTICE APPLIES

This standard applies to the maintenance of existing wet detention ponds serving urban runoff with extended periods of turbidity, high levels of floating plant cover, or other indicators of phosphorus export from settled sediments.

> Note: Existing wet detention ponds that have been accumulating sediment for 10 years or more are more likely to have phosphorus export from settled sediments.

The episodic dosing criteria in this standard applies to existing wet detention ponds that meet the following conditions:

- Provide at least 3.5 feet (1.1 meters) of depth from the permanent pool surface to the top of existing sediment at the time of dosing (this provides at least 6 inches (15 centimeters) of available sediment storage depth), and
- Have adequate access for sampling of the water in the permanent pool area.

This standard does not apply to:

- Lakes, natural ponds, landscape ponds, wildlife ponds, or other ponds not designed and maintained for the purpose of storm water treatment.
- Wet ponds within navigable waterbodies except where credit is allowed under s. NR 151.003, Wis. Adm. Code.
- Application of Al-based coagulants to storm water pond inlets. See WDNR Technical Standard 1013 Flow-Weighted Coagulant Dosing of Storm Water Facilities.
- Application of herbicides or pesticides for the purposes of aquatic plant management.
- Water-applied additives during land disturbing construction activities—see Technical Standard 1051.

[1] Words in the standard that are shown in italics are described in the Glossary section. The words are italicized the first time they are used in the text.

CRITERIA

General Criteria

Laws and Regulations. Comply with all federal, tribal, state, and local laws, rules, or regulations. This standard does not contain the text of federal, tribal, state, or local laws.

Permitting. Identify and obtain applicable permits prior to implementing this practice.

Location. Wet detention ponds that have been designed and maintained for the purpose of storm water quality treatment and have received all applicable permits.

Sampling Methods. Some of the steps below require acquiring samples of pond water and sediments. Detailed instructions are not included in this standard. See the references section for links to instructions and how-to videos unless otherwise specified.

Design Parameters.

Note on units: A mix of imperial and metric units are used intentionally in this standard based on the units the information is typically expressed. For instance, alkalinity is commonly measured in mg/L as $CaCO_3$ and therefore an imperial unit equivalent is not included.

Step 1: Gather information:

- Confirm that the storm water wet detention ponds have at least 3.5 feet (1.1 meters) from the top of sediment to the permanent pool surface. Measurements or survey information obtained within the previous 5 years may be used unless unusual loading, such as that from construction, has occurred. Sediment is typically removed instead of performing Al-based coagulant treatment when limited sediment storage remains.
- Determine the following information for each wet detention pond:
    - Pond name, number, or other identifier along with location.
    - Permanent pool area from as-built drawings, survey, or aerial photos.
    - Surface area at the top of the sediment (i.e., sediment surface area) where the Al-based coagulant will be applied. Where survey data is not available, this may be estimated based on average sediment depth information and the distance from the edge of the permanent pool to the point where that depth first occurs.
    - Permanent pool volume of water when the pond surface is at the lowest outlet or the anticipated volume at the time of dosing. Exclude volume occupied by existing sediment.
- Assess the extent and thickness of floating vegetation.

  Note: Extensive floating vegetation may interfere with the application. This can be addressed by timing the application prior to vegetation growth or aquatic plant management. See Attachment 1 for additional information on pretreatment of vegetation.

Step 2: Obtain information on pond water chemistry:

- Test the pH and temperature via hand-held meters and probes. Collect one water sample from just below the surface at the center of the pond for lab analysis. Use a certified lab to test the sample for alkalinity, TSS, and TP concentrations.
- Additionally, test the pH of the pond at the lowest point of the pond above existing sediment – approximately 6 inches (15 centimeters) above the pond bottom. Typically pond pH is lower at the bottom.

  Note: This test is typically completed with a pH tester with the probe on a 10 foot (3 meter) cable.
- Record all test results for inclusion in pond maintenance records.

Step 3: Optional: Determine sediment TP *inactivation dose* based on the TP content of sampled pond sediments. See Attachment 2. If not completing sediment sampling, go to Step 4.

Step 4: Determine the mass of Al needed to address phosphorus in wet detention pond sediments based on one of the following methods:

- Determine sediment TP inactivation dose based on one of the following methods:
    - Use the sediment TP inactivation dose determined in Step 3 or
    - Assume an inactivation dose between 450 lbs/acre to 890 lbs/acre (50 g/m^2 to 100 g/m^2) as Al.
- Do not apply more than 890 lbs/acre (100 g/m^2) as Al in any 10-year period unless justified by one of the following:
    - sediment sampling results, or
    - measured accumulation of greater than 4 in (10 cm) of additional sediment since the most recent application of Al-based coagulants.
- Multiply the sediment TP inactivation dose by the sediment surface area established in Step 1 to get the total mass of Al required for inactivation.

Step 5: Determine the maximum coagulant concentration that can be applied at a time while maintaining pH between 6.0 and 8.5 via pond water bench testing.

- Select an NSF/ANSI/CAN 60 listed coagulant product consisting of one of the following compounds to use in the bench test. When selecting the compound to be used, consider the pond pH, alkalinity, and desired longevity. Additional discussion of coagulant selection is provided in the considerations section.
    - Aluminum sulfate (alum)
    - Aluminum chlorohydrate (ACH)
    - Polyaluminum chloride (PAC)
- Evaluate proposed dosing using bench testing of pond water following procedures in Attachment 1.
- Select the highest *treatment concentration* that will maintain pH between 6.0 and 8.5. This range maintains Al compounds in a solid and stable state.
- Determine the number of applications and the final application concentration needed to reach the mass of Al required for sediment TP inactivation. Multiple applications may be required to maintain pH and reach the phosphorus inactivation of sediments dose. Do not apply more coagulant than needed to inactivate total phosphorus in sediments.
- Develop specifications or a work plan as described in the Plans and Specifications section. Require the use of NSF/ANSI/CAN 60 listed Al-based coagulant products.

Step 6: Apply to pond

- Follow the work plan developed in Step 5 considering the following:
    - Schedule applications for periods of zero discharge from the wet detention pond if possible. Zero discharge may be accomplished by temporarily blocking the outlet if that can be done without causing flooding upstream.
    - If the outlet must remain open, apply the treatment far enough from the outlet so that no visible *floc* leaves the pond. A residence time of 5 hours is expected to be adequate for floc settling.

  - If the pond has a fountain or aerator, turn them off prior to treatment and leave off for at least 5 hours following the conclusion of treatment to allow the floc to settle.
  - Avoid dosing the pond during a rainfall event.
- Apply the coagulant to the surface or just below the surface of the permanent pool:
  - Confirm the pond water pH at the surface immediately prior to application. If a boat is available, test pH at the center of the pond. If no boat is available, measure the pH as far from shore as possible without stepping into the water.
  - Dilute the Al-based coagulant with pond water per manufacturer's recommendations to prevent alum from sinking to the bottom of the pond without mixing with pond water. A liquid-based Al coagulant is much denser than water, therefore dilution improves dispersal within the water column, and facilitates application. If application is by subsurface injection from a boat, pre-dilution may not be necessary to achieve adequate dispersal.
  - Apply the coagulant evenly across the water surface area.
  - Measure the pH at least 3 times throughout the application process and prior to discharging water. Measure pH at least 3 locations each time from either a boat or as far from shore as possible without stepping into the water. If pH is at or below 6.0 standard units, stop application. Test pH and alkalinity periodically until testing indicates pH and alkalinity have rebounded to allow dosing to resume. Either pH meters or test strips may be used for testing to determine if dosing may resume.

- Maintain the following records:
  - Water chemistry test results from step 2.
  - Sediment test results from step 4 and Attachment 2, if applicable.
  - pH measurements from steps 2, 5, and 6.
  - Dosing calculations.
  - Bench testing results and photos.
  - For each dosing event:
    - Product(s) and quantity used.
    - Personnel responsible for application.
    - Weather and flow conditions.
    - Approximate volume of pond during dosing.
  - Recommendations for subsequent dosing events.

Step 7: This step is applicable if water quality treatment credit will be taken for water column stripping. Estimate pounds of TP removed due to *water column* stripping for the year dosing is completed:

- *Approved models* are used to determine reductions for particulate P settled to the bottom of the wet detention pond. Duplicate credit is not given for inactivating the particulate P in the bottom sediments.
- Credit may be taken for the mass of TSS and TP removed from the water column during each dosing event in the year the dosing occurs. The amount of TP and TSS removed during water column stripping may be estimated using one of the following methods and be taken in addition to settling predicted by an approved model without coagulant application:
  - Approved model approach:

- Calculate the difference between the annual average TP concentration at the pond outlet (as predicted by an approved model) and 0.14 lbs/acre-ft (0.05 mg/L).
- Calculate the difference between the annual average TSS concentration at the outlet (as predicted by an approved model) and 16.3 lbs/acre-ft (6.0 mg/L).
- The resulting concentration is then multiplied by the volume of the permanent pool to determine the mass of TP and TSS removed.

- Optional measured approach: Measure the TSS and TP concentrations before coagulant application in the middle of the pond just below the surface. Repeat at least 5 hours after the coagulant dosing and before the next rain event. The mass of TSS and TP reduced can be calculated based on the difference between pollutant concentrations before and after treatment times the volume of the permanent pool. For this approach, measure water column TSS and TP concentration for each application for which TSS and TP reduction credit will be taken.

CONSIDERATIONS

The following considerations are intended to enhance the use of this practice, or to address special cases that may arise in the implementation of the practice.

- Prioritize ponds to be dosed based on the size of the watershed treated, TP impairments in the receiving water, extent of algae and floating plant cover, importance of aesthetics to adjacent landowners, and age of the wet detention pond.
- If sediment sampling is conducted and there is less than 3.5 feet (1.1 m) of water over the surface of the sediment, consider dredging pond sediment instead of Al-based coagulant dosing. If dredging is warranted collect samples needed for ch. NR 528, Wis. Adm. Code compliance instead of sampling for Al-based coagulant dosing.
- If feasible, conduct the sediment fractionation testing described in Attachment 2 after dividing the sediment sample in two 2-inch (5 cm) lifts rather than a single composite sample.
- The following information should be considered when selecting a coagulant and planning applications:
  - To optimize treatment longevity, apply alum in multiple applications, with each application at the smaller of 50 g/m^2 (450 lbs/acre) or the maximum concentration that will not lower pH below 6.0. Time multiple doses to allow pH and alkalinity to rebound between applications.
  - If pond pH is below 6.5 standard units or the alkalinity is less than 30 mg/L as $CaCO_3$ before coagulant application, either use an Al-based compound with a smaller pH impact or use alum with a buffering compound. Sodium aluminate may be applied simultaneously with alum as a buffer at a 2 parts alum to 3 parts sodium aluminate by weight of Al to reduce pH impacts. Contact the department for prior approval if other buffering compounds are proposed.
  - The higher cost of coagulants other than alum or the use of sodium aluminate to buffer alum may be offset by the cost savings of doing fewer applications. These options may not have optimum longevity due to aging of Al flocs.
  - If using a buffer, apply Al-based coagulant and buffer simultaneously.
  - Coagulants and other additives not listed in the Criteria section may be used with prior WDNR consultation and/or approval. Additives proposed should provide stable bonds with phosphorus under *anoxic* conditions within the pH ranges anticipated within the pond. Please contact WDNR storm water runoff staff prior to selecting an alternate

additive as water and sediment toxicity testing is required for additives that may be discharged to surface water.

- Multiple applications may produce more efficient, longer-lasting sediment inactivation and may be necessitated by pH limitations. Multiple smaller applications reduce the risk of Al-Al binding which reduces the amount of alum-phosphorus binding, thus reducing efficiency.
- If algae, duckweed, or other plants form a continuous cover on the pond's surface, treat algae, duckweed or other floating plant cover through application of an appropriate herbicide under a WDNR aquatic plant management permit prior to dosing. By doing so, the phosphorus that is tied up in these plants will be released and the Al application will be more effective at inactivating phosphorus. If herbicide treatment is conducted, test the pond pH after herbicide treatment and before coagulant application.
- Water temperatures below 40˚ F (4˚ C) may impact the efficacy of treatments.
- If a pond receives high levels of chlorides in the winter, consider delaying dosing until summer to avoid peak chloride levels. The jar testing process should help account for the effect of chloride levels on the dosage.
- Field jar testing is recommended on the day of application to verify pH and other parameters.

PLANS AND SPECIFICATIONS

Prepare plans and specifications in accordance with the criteria of this standard.

Develop specifications of a work plan as outlined below:

- Project purpose and scope summary.
- Owner or responsible party contact information (if not the applicator).
- Name and contact information of the applicator.
- Name of the product to be applied, color, opacity.
- Area and volume of the pond permanent pool.
- Proposed dosage to include estimated application rate and anticipated frequency and duration of application. Include information on how the application rate and number of applications were derived for each product and the proposed treatment area.
- Description of the following elements:
    - Coagulant and equipment staging (set-up, storage, and removal) at the proposed treatment area.
    - Application method.
    - Anticipated schedule, including weather and seasonal constraints under which the Al-based coagulant will be applied, pH monitoring and visual inspection as required in Step 6 during application will be conducted. This covers both during application and prior to release to a navigable waterway.
    - Required reporting and recordkeeping described in Step 6. Include the location where records will be stored, and the employee's name or position that will perform any required reporting to the department.
    - Procedures that will be used in case of emergency, including how spills or compliance will be reported.
    - Personnel training on the procedures of the coagulant application.
    - Public notification, if applicable.

Attach information on the pond size and dimensions such as an as-built or other schematic of the pond showing inlet, outlet, and permanent pool boundaries to the work plan.

OPERATIONS AND MAINTENANCE

Adjust the operations and maintenance plans for affected wet detention ponds to reflect use of Al-based coagulants, the recommended interval between Al-based coagulant treatments, and the anticipated frequency of wet detention pond dredging.

REFERENCES

ASTM D2035-19 Standard Practice for Coagulation-Flocculation Jar Test of Water, March 1, 2019.

James, William F. and Bischoff, Joseph M., Relationships between redox-sensitive phosphorus concentrations in sediment and the aluminum: phosphorus binding ratio, Lake and Reservoir Management, 31:4, 339-346, October 2015.

Psenner, Roland & Puckso, R., Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch Hydrobiol. 30. 43-59, 1988.

Rydin, Emil and Welch, Eugene B., Dosing Alum to Wisconsin Lake Sediments Based on in vitro Formation of Aluminum Bound Phosphate, Lake and Reservoir Management, 15:4, 324-331, 1999.

WDNR, Additives webpage https://dnr.wisconsin.gov/topic/Wastewater/Additives.html.

WDNR, Citizen Lake Monitoring Network https://dnr.wisconsin.gov/topic/lakes/clmn has links to acceptable sampling protocols that may also be used in storm water ponds for the purpose of this technical standard.

WDNR, Management of Accumulated Sediment from Storm Water Structures, 2009.

GLOSSARY

Additive – Any substance, typically a commercial product, which is added to water to remove or trap a pollutant and has the potential to be directly or indirectly discharged to surface water and may cause toxicity to fish and aquatic organisms.

Anoxic – A condition of total depletion in the level of dissolved oxygen.

*Approved mode*l – A computer model that is used to predict pollutant loads from urban lands and has been approved by the applicable regulatory authorities. WinSLAMM and P8 are examples of models that may be used to verify that a wet detention pond design meets the desired pollutant reduction.

Coagulant – Additive used to neutralize charged particles to promote bonding substances into settleable solids and/or larger settleable solids.

Inactivation Dose – The total mass of aluminum per area required to inactivate phosphorus in pond sediments.

Floc – A loosely clumped mass of fine particles.

Flow-weighted coagulant dosing – Automated injection of coagulant into a wet detention pond inlet proportional to the flow rate (see DNR Technical Standard 1013 - Flow-weighted dosing of storm water wet detention ponds).

Labile – Describes a molecule that is easily transformed through chemical or biological activity. Labile P is easily released into the water column and may also be readily absorbed by algae.

Treatment Concentration–The mass of aluminum per volume of wet detention pond water applied in an individual treatment.

Wet detention pond – A permanent pool of water with designed dimensions, inlets, outlets, and storage capacity, constructed to collect, detain, treat and release storm water runoff.

Attachment 1: Field Guide for Episodic Dosing

Introduction

The purpose of this field guide is to assist practitioners in applying aluminum-based additives that will strip phosphorus and total suspended solids from the water column and inactivate sediment phosphorus. Other information needed for this procedure includes pond size, pond volume, and pond water total phosphorus (TP). This guide covers the following steps:

1. Pre-application bench testing
2. Pre-treatment of floating vegetation
3. Application
4. Monitoring

Note: Most laboratory testing and reporting for the constituents below are reported in metric units and is not reported in dual units in this Attachment. Concentrations are also primarily reported in metric units.

Bench Testing Protocol

Perform bench testing to determine the amount of aluminum (Al) that can be safely applied to meet the objectives of stripping phosphorus from the water column and to inactivate sediment phosphorus.

Assemble supplies:

1. 3-4, 1-liter beakers
2. pH meter
3. Alkalinity meter
4. A device or pen and paper to record test results
5. Additive(s) to be tested

Measure pond water pH and alkalinity.

Collect a minimum of 3-4 liters of pond water. Obtain at least 1 liter of water from the pond for each dosage concentration to be evaluated plus 1 liter for a control. Use the design Al dose for one of the tests.

Place collected water into individual 1-liter beakers.

Prepare a dosage testing record similar to the example shown in Table A1-1. The example was prepared assuming alum. Doses may be higher for coagulants with a smaller impact on pH.

Table A1-1 Example Dosage Testing Record

Aluminum Dose	**pH at** 5-minute	**pH at** 20-minute	**pH at** 1 hour	**Alkalinity** 1 hour
4 mg/L as Al	*7.6*	*7.2*	*7.2*	*102 mg/L*
6 mg/L as Al	*7.3*	*7.1*	*7.1*	*95 mg/L*
8 mg/L as Al	*7.1*	*6.9*	*6.9*	*89 mg/L*
10 mg/L as Al	*6.7*	*6.1*	*6.0*	*76 mg/L*

Determine the mass of product needed per liter of water as follows:

Mass of Product = Target Concentration/Al Content * 1 liter

Where:

Mass of product is in mg.

Target concentration is in mg/L as Al. The target concentrations for bench testing are generally between 1 mg/L as Al and the concentration of Al needed to inactivate the sediments.

Al content is the grams of Al per gram of product. It is often expressed as a percent. For example, if an alum product is supplied with 9% Al, then the Al content is 0.09 in the equation above.

Since Al is supplied compounded with other molecules, a calculation is needed to go from mg/L as Al to mg/L as supplied. The percent Al should be shown on the packaging. For alum, dosages between 4 and 10 mg/L as Al are typically tested. The higher the alkalinity of the pond water the higher the dose of alum that can be added. Higher doses of aluminum chlorohydrate (ACH) and polyaluminum chloride (PAC) are typically used in bench testing because they have a lower effect on pH.

Add different concentrations of Al to each beaker.

Stir beakers for two minutes and observe floc formation and other signs a reaction is taking place.

Measure pH at 5 minutes, 20 minutes and 1 hour following the conclusion of the two minutes of stirring.

Measure alkalinity after 1 hour.

In the example in Table 1, a safe initial dose to maintain pH above 6 would be 8 mg/L as Al.

If the goal is to obtain a dose of 50 g as Al per square meter over the pond's bottom sediments (which, given pond dimensions could translate to 36 mg/L), multiple separate applications of alum would be needed to maintain pH within the required range. Typically, the pond alkalinity will recover in a few days to a week, which would then allow for another application. Alternately, ACH and PAC may be used in one or more doses as they have a smaller effect on pH.

Pre-Treatment of Floating Vegetation

If the pond has a thick layer of floating plants, then treatment under a WDNR aquatic plant management permit may be needed prior to dosing with an Al-based additive.

Given that much of the phosphorus in ponds with extensive floating plant growths is tied up in the vegetation, pretreatment is beneficial. Alum can still be applied but much of the phosphorus in the system will not be initially tied up by the first application. Natural senescence of these plants will release bound phosphorus and the alum in the system will eventually capture the phosphorus from these plants. However, it will take longer to achieve visible control.

To capture more phosphorus with the initial alum treatments, application of an appropriate herbicide (e.g., sodium carbonate peroxyhydrate (SCP) for floating algae) prior to dosing has been shown to be beneficial. Schedule application of coagulant once visual inspection shows that floating vegetation has died, which may take a few days. If an herbicide treatment is used, pH should be measured following the herbicide treatment and prior to Al-based coagulant dosing.

Application

Confirm the pond water pH at the surface immediately prior to application. If a boat is available, test pH at the center of the pond. If no boat is available, measure the pH as far from shore as possible without stepping into the water.

Pre-Application Dilution for surface application

When using dry alum, it must first be dissolved to apply. Place dry alum into a water tank (i.e., 250-300 gallons) and then pump pond water into the tank. Agitate or mix tank contents to ensure the alum is dissolved before applying. Typically, 80 to 100 gallons of water is enough to dissolve a 50lb. bag of alum.

Commonly, the liquid products will also need to be diluted with pond water to properly spread across the surface of the pond similar to the dry product. Follow manufacturer's recommendations for dilution with pond water prior to application.

Small Pond Application

For low technology applications, a water container, e.g. 250 or 300 gallons (946 or 1135 L), mounted on a vehicle or trailer along with a pump and spray nozzle is needed. Typically, a 5 hp motor is usually sufficient to spray alum out across smaller ponds. Equipment used to spray trees have also been effectively used.

Since alum is an acid, a stainless-steel pump is recommended. Whether or not the pump and connection fittings are stainless, flush out immediately following use with tap water to prevent corrosion.

Large Pond Application

For larger ponds, boats may be used to apply diluted alum to the surface as described above. Alternatively, alum may be injected just below the surface behind the boat. For either operation, buoys may be used to mark areas that will receive a specific volume of Al-based coagulant prior to application.

Monitoring

Measure the pH prior to application, at least 3 times throughout the application process as noted in Step 6 of Technical Standard 1014, and prior to discharging water. If pH is at or below 6.0 standard units, stop application. Continue application when pH and alkalinity have rebounded to allow additional Al-based coagulant application.

If water discharges from the pond while treatment is occurring, monitor visually and stop application if floc appears to be leaving the pond.

If applying multiple doses, monitor alkalinity to determine when the next dose can be applied. Typically, this will occur within a few days, weeks, or a month.

Attachment 2: Sediment Testing for Site-Specific Dosage Calculation

The purpose of this Attachment is to provide information on one of the options for determining how much Al is needed to inactivate redox-sensitive phosphorus in storm water wet detention pond sediments.

Note: Units are in metric-only except where pond dimensions are used to match typical units in laboratory reports.

Sediment Sample Acquisition:

- Identify the minimum number of samples based on the size of the pond from Table A2-1.
- Using a core sample, take samples from the upper 2-4 inches (5-10 cm) of the sediment in the deepest part of the pond or subsection of the pond. A minimum of 3 grams of dry material is required for analysis. Depending on the water content of sediment at the site, 5-10 cubic inches of material is generally needed for analysis of each sample.
- The deepest part of the original pond is assumed to be the area with the greatest percentage of fines in the sediment. If not known, use the point midway between the inlet and outlet or the deepest water depth.
- The sample may consist of multiple sediment samples composited together if additional volume is needed.
- The minimum number of samples is listed in Table A2-1. The samples should be taken such that each sample represents a portion of the pond.

Table A2-1: Sediment Sampling by Wet Detention Pond Size

Permanent Pool Area (acres)	Minimum Number of Sediment Samples Recommended
≦1.50	1
1.51-2.50	2
2.51-3.50	3
>3.51	4

Step 3.1: Obtain sediment test results:

- Send sediment samples to a laboratory capable of completing phosphorus fractionation[2].
    - Test the collected sediment samples for the following:
        - Water content (%)
        - Bulk density (g/cm^3)
        - Loss on ignition (% organic matter)

[2] A procedure to determine the concentration of each species of phosphorus through sequential addition of extractants. The procedure is described in Psenner and Puckso (1988). At the time of technical standard development, this testing was available at the Center for Limnological Research and Rehabilitation Laboratory at University of Wisconsin - Stout.

- Phosphorus fractionation:
  - *Labile* P
  - Iron (Fe) bound P
  - Biologically labile P

Step 3.2: Determine the amount of aluminum (Al) required for phosphorus inactivation of sediments per area of sediment.

- Calculate the dry sediment mass per area using the following equation:

  Sediment Dry Mass = [10,000 (cm^2/m^2)] x ρ x (1-w) x h

  Where:

  Sediment Dry Mass = Mass of dry sediment per unit area, in g/m^2

  ρ = Sediment (wet) bulk density, in g/cm^3

  w = Water content as a decimal, dimensionless

  h = Sediment thickness (in cm) to be treated[3]

- Calculate the phosphorus-inactivation-of-sediments dose by completing the following steps or using the below-linked spreadsheet from WDNR's post-construction standards web page (https://dnr.wi.gov/topic/stormwater/standards/postconst_standards.html) to reduce calculation time and potential errors. Most labs will provide results in metric units, so the equations below are in metric units.
  - Calculate the redox sensitive P concentration for the upper 2-4 inches of sediment:

    Redox P = labile P + Fe bound P.

    - Calculate the mass of redox sensitive P in the upper 2-4 inches of sediment per unit area of the pond using the thickness, density, and water content of the sediment:

      Redox P Mass = Redox P_c x Sediment Dry Mass

      Where:

      Redox P Mass = Mass of Redox P per unit area (g/m^2)

      Redox P_c = Conc. of Redox P per mass of dry sediment, in mg/g

      Sediment Dry Mass = Mass of dry sediment per unit area, in g/m^2

  - Calculate the Al:P ratio for the sediment using the following table equation: Al:P = 30.2065 * (redox sensitive P)$^{-0.6446}$ (James and Bischoff, 2015). Where Redox sensitive P is in mg/g. Where the calculated Al:P is greater than 100, a value of 100 may be used.
  - Calculate the areal dosage in grams as Al per square meter dose by multiplying the Redox P Mass by the Al:P ratio. Where multiple sediment samples are taken, determine the average dosage in grams as Al per square meter.

[3] The maximum thickness to be treated is generally 4 inches, however this can be increased as appropriate where bottom feeding fish such as carp disturb the bottom sediments.

- Calculate the concentration of Al needed within the pond. Convert grams of Al per square meter needed for phosphorus inactivation of sediments to a concentration, in mg/L, based on the average depth of the permanent pool using the following equation:

  Concentration of Al = Areal Dosage/Area at Sediment Surface*Permanent Pool Volume

  Where:

  Concentration of Al is the target Al concentration for the pond in mg/L. This can be used with the Al content of a specific product to determine the amount of that product needed.

  Inactivation Dosage is the amount of Al needed to deactivate the target thickness of sediment in grams as Al/m^2.

  Area at Sediment Surface is the area of the pond at the existing top of sediment in m^2. Area may be converted from acres to m^2 by multiplying acreage by 4,047 m^2/acre.

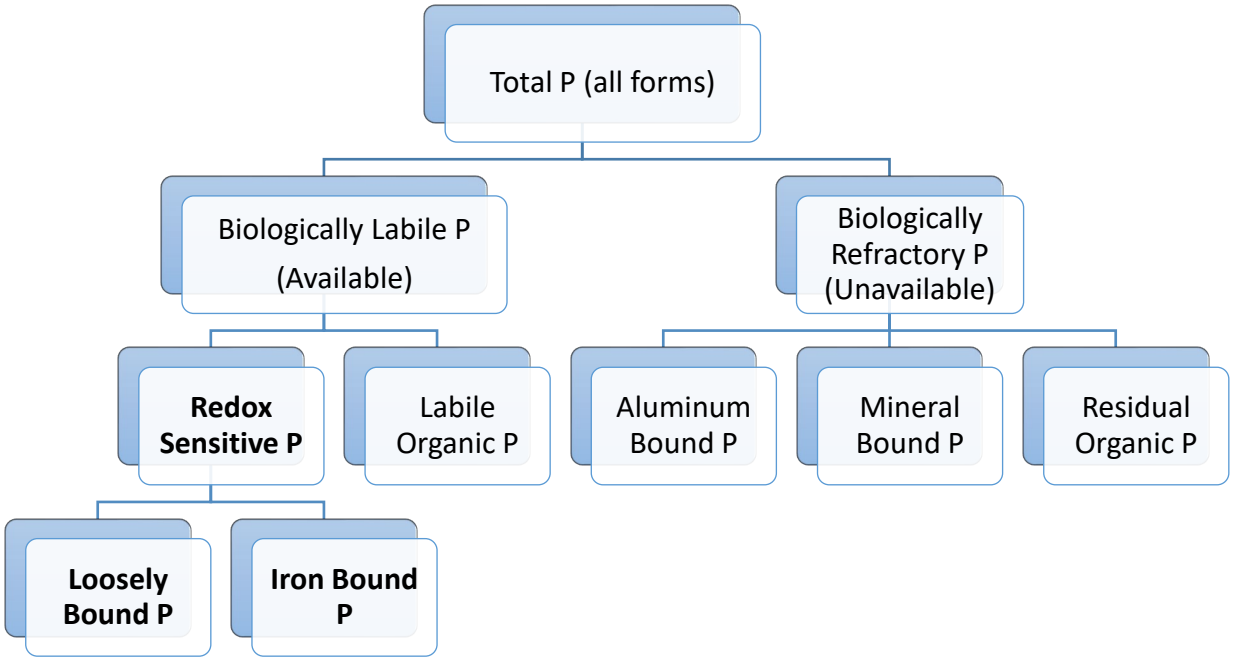
  Permanent Pool Volume is the volume of water within the pond at the time of dosing in m^3. This is usually the volume below the lowest outlet. Volume may be converted from acre-feet to m^3 by multiplying acreage by 1,233.48 m^3/acre-ft.

Attachment 3: Phosphorus Terminology

Introduction

Phosphorus takes many different forms in storm water pond water and sediments. The nomenclature for the forms is based on either what element the phosphorus is bound to (i.e., iron-bound P) or how easily the molecule can be broken down or 'used' in the environment (i.e., labile P). The adjective labile is used for phosphorus compounds that are easily transformed through chemical reactions or biological activity. Biologically labile P is used for forms of P that are easily used by bacteria, algae, and other living organisms. Biologically refractory P is generally unavailable for use by living organisms. Sediment testing focuses on the biologically labile P fractions **bolded** below.

Attachment 3 Figure: Hierarchy of Total Phosphorus Speciation Terms



William F. James, at the University of Wisconsin Stout provided the idea for the diagram above in response to a request from the technical standards team.