Section 7 Vegetative Infiltration Basin Design

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Purpose

Vegetative infiltration basins (VIB) provide an optional treatment component that relies on soil properties for filtering nutrients and other contaminants from the runoff water. They have demonstrated the ability to significantly reduce concentration of nutrients and solids in runoff and substantially delay the release of runoff into a latter treatment stage. These benefits can make VIBs a useful component in a VTS. This section will summarize VIB performance and review critical VIB design issues.

VIB description

A VIB has many similarities to a VTA described in section 6. It is an area planted to perennial forages or grasses and relies upon the treatment capabilities of the plant material and the soil for removal of potential pollutants. However, the VIB also has several unique differences:

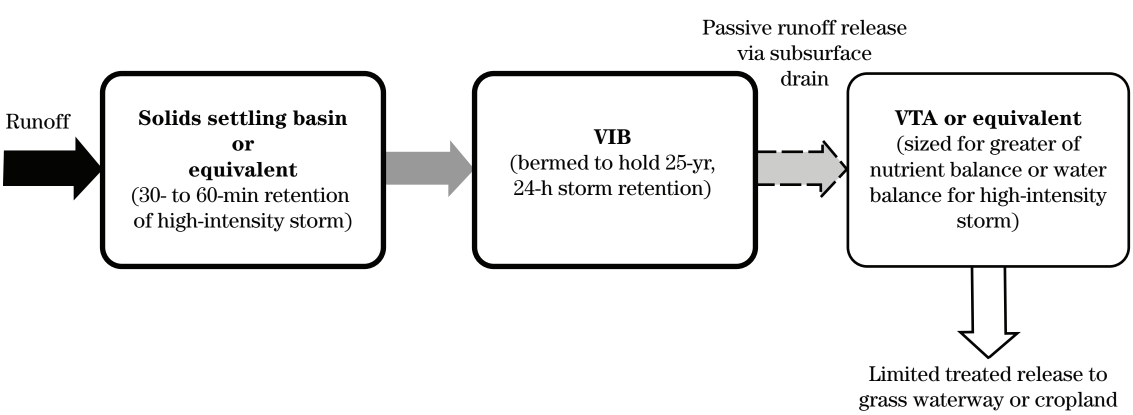
- A VIB is completely enclosed by a berm designed to handle the open lot runoff and precipitation for a design storm (25-yr, 24-h storm is recommended).
- All runoff and precipitation must infiltrate through a 4- to 6-foot soil layer. Surface water discharges are very unlikely with an VIB.
- A tile drain system collects the infiltration and delivers the treated sub-surface discharge to the next treatment component, commonly a VTA.

VIBs downstream of open feedlots are designed to be treatment areas using soil as a filter medium. Basin design is based on hydraulic loadings and soil properties that allow infiltration within a specified length of time based on plant tolerance to wet conditions. Nutrients will likely exceed agronomic nutrient loadings. Nutrient removal is significant, but not complete. The infiltrated water that passes through the system is collected in a subsurface tile drainage system and returned to the surface for further treatment. Unlike wetlands, VIBs should remain dry (aerobic) the vast majority of the time and only be saturated for short time periods immediately following runoff events.

For CAFOs, a VIB is typically considered to be one treatment component of a larger system. It is designed to compliment solids removal and VTA components and minimize the potential for a discharge from the VTA (fig. 7–1). It performs three critical functions when placed before the VTA and after the solids removal components:

- It provides significant additional reduction of potential pollutant concentration and mass prior to the runoff release into a VTA.
- It significantly delays the release of runoff and spreads the release over an extended period of time (fig. 7–2). This should substantially limit the release of treated effluent into a VTA that follows a VIB during most storm events and minimize the risk of a release from the VTA.
- For smaller non-CAFO open lots, a settling basin and VIB may satisfactorily treat runoff water without the VTA. VIB sub-surface discharge is **not** sufficiently treated for direct discharge to surface or ground water. However, the smaller volumes associated with small open lots may be released to crop or pasture land.

Figure 7–1 Infiltration basin is typically an additional treatment component between the solids settling basin and VTA designed to minimize the potential for a discharge from a VTA.



Performance

Three recent studies of VIBs have shown significant water quality improvements resulting from this technology. Lorimor et al. (2003) observed that a VIB associated with a 380 head beef feedlot produced an average of a 65 percent reduction in suspended solids, 80 percent reduction in total Kjeldal nitrogen, 81 percent reduction in ammonium nitrogen, and 77 percent reduction in total phosphorus over a 5-year period. Nitrate levels increase substantially as runoff moved through VIB. Typically, almost no nitrate exists in feedlot runoff. In an aerobic environment, nitrification of ammonia occurs. Any treatment component following a VIB will need to utilize or treat nitrate. Lorimor et al. (2003) reported that nitrate represents about 0.5 percent and 4 percent of the total nitrogen in the influent and effluent of the VIB, respectively.

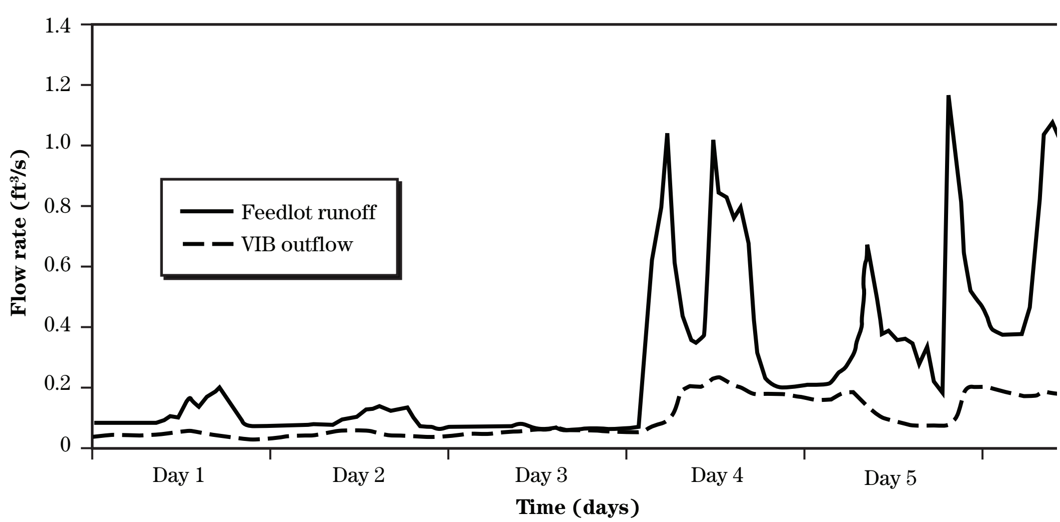
If a VIB precedes a VTA, removal of nutrients by the VIB should reduce the nitrogen based sizing requirements of the VTA by 70 to 80 percent. A water balance method for VTA sizing must also be checked. For the large storm events used to size a VTA based upon a water balance, it is appropriate to assume that the VIB **will not significantly reduce the volume of water** moving to the VTA. Thus, the water balance sizing method may become the limiting method for estimating VTA size when combined with a VIB. Additional information on VIB performance is summarized in section 9.

VIB performance under winter conditions is a common concern. Although current experience is limited, it is the professional judgment of the authors and their experience based upon 6 years of VIB operation at the Iowa State University feedlot that frozen soil conditions do not represent a problem.

Runoff volumes under winter conditions are generally small. High-intensity or large storm events are rare during the winter. The normal volume of runoff is also typically very small during this period. In most locations, the fraction of rainfall that exits a dirt lot as runoff is typically very small during the winter (for Ames, IA: 10%, <10%, and 15% of monthly rainfall exits as runoff in Jan., Feb., and Mar., respectively). Precipitation is also low during these months (for Ames, IA: 0.76, 0.74, and 2.06 in for Jan., Feb., and Mar., respectively). Frozen soil conditions in a VTA may present minimal environmental risk because of low total runoff from dirt lots during the same period (for Ames, IA: 0.08, 0.07, and 0.30 in of runoff in Jan., Feb., and Mar., respectively).

A settling basin upstream of a VIB can provide a safety mechanism for protecting the VIB under winter conditions. The settling basin would need to include some storage capacity (runoff volume for 10-yr, 1-h storm or greater) and a valve on the settling basin outlet that can be closed for winter conditions. This would allow the settling basin to store winter runoff when VIB soils are frozen. Designing the settling basin to include such options in regions with higher snowfall should eliminate frozen VIB soil concerns, although the limited experience to date would suggest that this is not a concern.

Figure 7–2 Sample runoff flow rates into VIB and out of VIB for June 18–23, 2002 (Lorimor et al. 2003). VIB delays and reduces peak flow from feedlot into any treatment component following the VIB.



Site selection issues

Only soils with acceptable infiltration rates are usable for VIBs. Permeability, as shown in soil surveys, should be from 0.6 to 2.0 inches per hour. Soils with lower permeability generally will not drain quickly enough for vegetation maintenance unless a very large footprint and shallow impoundment depth is used. More permeable soils will not provide adequate treatment of contaminants as the liquids move through them too quickly. It is recommended that a site evaluation for a potential VIB location should include a site-specific measure of infiltration rates.

Sites with low slopes are preferable for VIB construction. VIBs should be built essentially flat to facilitate spreading of inflow across the entire bottom area. A slight slope (≤0.5% away from the inlet) may be built into the basin to encourage small events to spread out for more uniform loading. The top elevation of the berm should be approximately level, with a spillway for safely handing storm events exceeding the design storm.

Impervious subsurface soils, creating a perched water table (saturated conditions) below the VIB is important for the tile system to function properly, and to avoid water movement below the tile depth. Situations for which a VIB may not be suitable include:

- Sandy or gravelly subsoils due to increased potential for contamination of ground water.
- Fractured bedrock (including karst or incipient karst topography) is closer than 10 feet from the surface again due to potential for contamination of ground water.
- Loess soils. If the water table is deep, a VIB may be considered especially if subsurface drains will function. VIB application to loess soils should be reviewed with local NRCS or conservation district staff for risk to ground water and potential subsurface drain function.

Section 4 should be reviewed for additional site selection issues.

Sizing a VIB

VIBs for CAFOs should be designed to retain a 25-year, 24-hour storm, plus an additional 6 inches for freeboard. Designs based upon a smaller storm may be acceptable for non-CAFO facilities. A VIB should impound all collected runoff to no greater depth than will infiltrate into the soil within a predetermined time dependant on the vegetation's tolerance to flooding. Seventy-two hours is generally considered a maximum limit. Determine the VIB area by using the following steps.

Step 1 Calculate maximum depth of VIB (including freeboard) based upon steady-state soil infiltration rate (in/h) and maximum design time for drainage of VIB (h):

$$D_{MAX} = \left(I_{VIB} \times T\right) + F \tag{1}$$

where:
D_{MAX} = maximum basin depth (in)
I_{VIB} = steady-state infiltration rate (in/h)
T = infiltration time to empty VIB (h)
F = freeboard (in)

Step 2 Determine a practical VIB depth. A practical limit to a VIB liquid depth is approximately 24 inches (30 in with freeboard). This practical limit will often be less than the maximum depth calculated in step 1. If the maximum VIB depth is smaller than the practical depth, proceed to step 3. If the practical VIB depth is smaller than the maximum depth calculated in step 1, skip to step 4.

Step 3 Calculate VIB volume and area based upon a maximum allowable depth. The VIB volume can be estimated by two unique equations. Equation 2 is based upon runoff from feedlot and additional contributing area plus direct precipitation falling on the settling basin and VIB. Equation 3 is the depth of water that will infiltrate through the VIB in an allowable design time period.

$$V_{VIB} = R + \left[\left(A_{SB} + A_{VIB}\right) \times P\right] \tag{2}$$

$$V_{VIB} = A_{VIB} \times I_{VIB} \times T \tag{3}$$

Using equations 2 and 3, solve for area of the VIB and use the result of this calculation to then estimate VIB volume with either equations 2 or 3:

$$A_{VIB} = \frac{R + (A_{SB} \times P)}{(I_{VIB} \times T) - P} \tag{4}$$

where:
V_{VIB} = total volume of VIB, a-in
R = total runoff from feedlot and contributing area from appendix B, a-in
A_{SB} = area of the settling basin, a
A_{VIB} = area of VIB, a
P = design storm depth, in

Step 4 Calculate area of VIB based on practical depth. Equation 4 can be altered by substituting a practical basin depth (D_P) minus freeboard (F) in place of the estimate of depth based upon infiltration rate and design time to empty a VIB (I_{VIB} x T). The resulting equation for area of VIB is:

$$A_{VIB} = \frac{R + (A_{SB} \times P)}{(D_p - F) - P} \tag{5}$$

where:
D_p = practical VIB depth (in)

This result can be substituted into equation 2 to estimate VIB volume for a practical depth.

Warning: Do not use equation 3 to estimate VIB volume if area of VIB is based upon a practical depth.

Tile drain design

The VIB will be underlain by subsurface drain tiles (fig. 7–3). The drains shall be installed deeper than the seasonal high water table and not less than 4 feet deep (5–6 ft is recommended). In addition, drains shall be placed above the seasonal low water table to prevent year round water flow from the tile system into the next treatment stage. The time to drain the 25-year, 24-hour precipitation event including runoff from the feedlot area should be compatible with selected vegetations tolerance to flooding and generally not exceed 72 hours.

The spacing of tile drains shall be designed to efficiently remove excess water. Kirkham's method (Kirkham 1957) for flow to drains under ponded conditions is valid for the design of drain tile spacing for the VIB. The Web site, *http://msa.ars.usda.gov/ms/oxford/nsl/java/Kirkham_java.html*, provides a tool for using Kirkham's method. An example design using this procedure is illustrated in appendix E.

In addition to determining the required drain spacing, the tile size must be determined, and the grade of the installed tile lines must be specified. The capacity of the tile drains shall be computed using Manning's equation and the equation of continuity. An example calculation using the following two relationships is illustrated in appendix D.

$$Q = AV \tag{6}$$

$$V = \frac{C_v R^{\frac{2}{3}} s^{\frac{1}{2}}}{n} \tag{7}$$

where:
Q = discharge, ft^3/s
C_v = 1.49 for Q, ft^3/s
V = velocity, ft/s;
A = cross section of pipe flow, ft^2 (tile drain should not be less than 4-in diameter)
R = hydraulic radius of the pipe, ft
s = slope of the pipe, ft/ft
n = Manning's roughness coefficient

The minimum drain size required to provide adequate discharge capacity can be computed using these equations (ASAE 2003). The minimum grade to prevent siltation for installed tile lines shall be in accordance with table 7–1. The maximum velocities in tile drains to prevent erosion shall be designed to not exceed the values provided in table 7–2. An example design can be found in appendix D.

Installation of tile lines will disturb natural soil conditions. The potential exists for short-circuiting of runoff to tile lines in these disturbed areas. Consideration should be given to tile installation methods that minimize soil compaction during backfilling and restore the soil over the tiles lines to as natural a condition as possible. In addition, macro-pore flow may develop in the drained profile with time. It is critical to prevent tree and weed establishment that could create direct flow pathways due to root systems. It is also important to till an infiltration basin every few years with heavy tandem disk or chisel plow and reestablish vegetation to diminish macro-pore flow.

Figure 7–3 Tile line should be located at least 4 ft below the ground surface and between the low and high seasonal water tables.

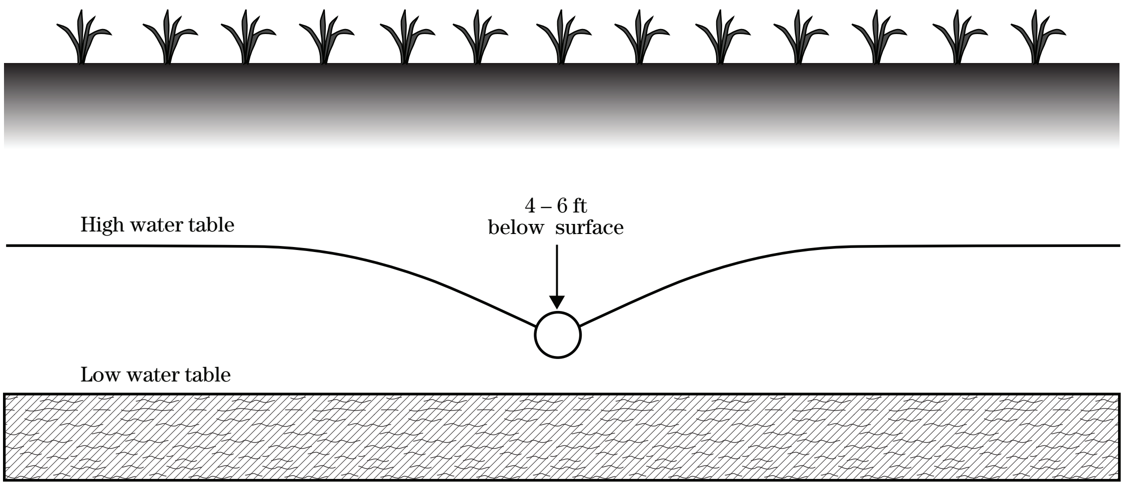


Table 7–1 Minimum grade, % (ASAE 2003)

Inside pipe diameter mm (in)	Corrugated plastic pipe *not* subjected to fine sand or silt [1]	Corrugated plastic pipe subjected to fine sand or silt [2, 3]
75 (3)	0.10	0.81
100 (4)	0.07	0.55
125 (5)	0.05	0.41
150 (6)	0.04	0.32

1 Grades provide a minimum cleaning velocity of 0.15 m/s (0.5 ft/s)
2 Grades provide a minimum cleaning velocity of 0.42 m/s (1.4 ft/s)
3 If a sock is installed, use values listed for corrugated plastic pipe not subject to fine sand or silt

Table 7–2 Maximum velocity without protective measures (ASAE 2003)

Soil texture	m/s	(ft/s)
Sand and sandy loam	1.1	(3.5)
Silt and silt loam	1.5	(5.0)
Silty clay loam	1.8	(6.0)
Clay and clay loam	2.1	(7.0)
Coarse sand and gravel	2.7	(9.0)

Design example for VIB depth and volume

Design a VIB for a 2,000 head dirt feedlot located in central Iowa. The feedlot is 11.5 acres in area with an additional 8 acres of roads, drainage ditches, feed storage and preparation areas, and compost site that drains into the settling basin. The VIB will be located in a soil with an infiltration rate of 0.6 to 2 inches per hour (found in county soil survey). It is desirable that the basin drain in 72 hours for a 25-year, 24-hour storm. Refer to examples in appendices B and C for additional information.

From appendices B and C, a 25-year, 24-hour storm (P) is 5.5 inches, feedlot runoff for this size storm (R) is 93 acre-inches, and area of settling basin (A_{SB}) is 123,000 ft^2 or 2.8 acres.

Step 1 Calculate maximum depth of VIB including freeboard (assume 6 in) and lower permeability value listed in county soil survey for this soil:

$$D_{MAX} = \left(I_{VIB} \times T\right) + F$$

$$D_{MAX} = \left(0.6 \text{ in/h} \times 72 \text{ h}\right) + 6 \text{ in} = 49 \text{ in}$$

Step 2 Estimate a practical VIB depth to be 30 inches including 24 inches for runoff storage and 6 inches for freeboard. Since the practical VIB depth is less than the Maximum VIB depth, use equation 5 in step 4 to calculate VIB area.

Step 3 Skip[1]

Step 4 Select a practical VIB depth of 30 inches (including 6 in of freeboard) and estimate VIB area:

$$A_{VIB} = \frac{R + \left(A_{SB} \times P\right)}{\left(D_p - F\right) - P}$$

$$A_{VIB} = \frac{93 \text{ a-in} + \left(2.8 \text{ a} \times 5.5 \text{ in}\right)}{\left(30 \text{ in} - 6 \text{ in}\right) - 5.5 \text{ in}} = 5.9 \text{ a}$$

Substitute the results of equation 5 into equation 2 to calculate VIB volume:

$$V_{VIB} = R + \left[\left(A_{SB} + A_{VIB}\right) \times P\right]$$

$$V_{VIB} = 93 \text{ a-in} + \left(2.8 \text{ a} + 5.9 \text{ a}\right) \times 5.5 \text{ in} = 141 \text{ a-in}$$

1 Do not use equation 3 to estimate VIB volume if area of VIB is based upon a practical depth.

Plant materials

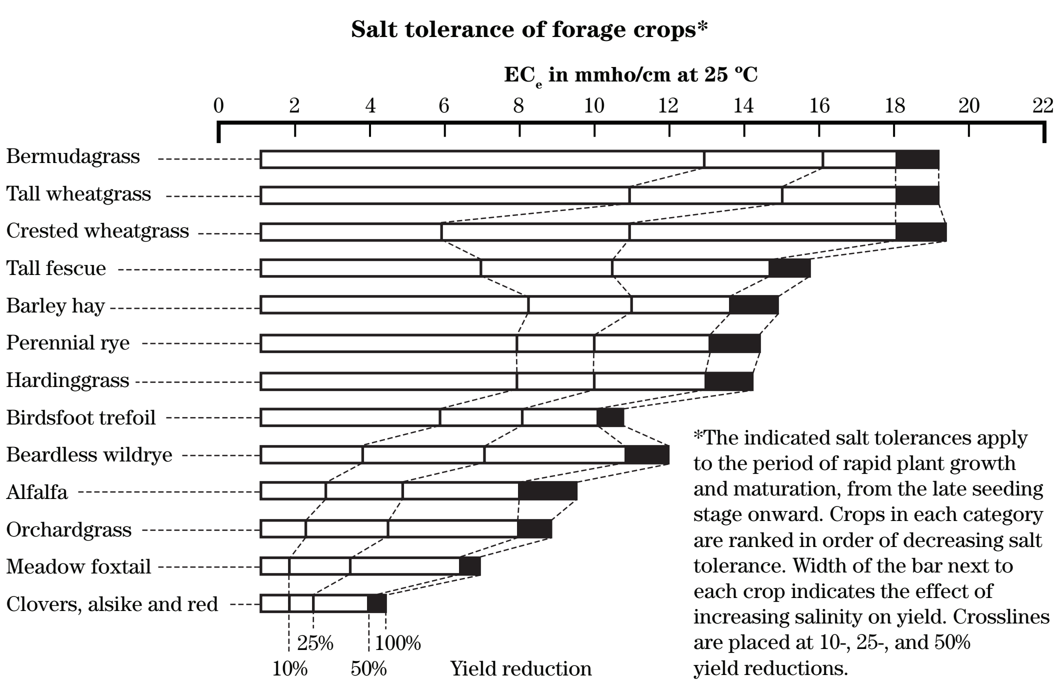
Forages or other crops selected for VIBs should be selected based on their ability to tolerate a variety of conditions. Appendix E provides summaries of plant characteristics that will assist in selecting appropriate species for VIBs. Additional information on plant materials selection can be found in:

- Comparative characteristics of forage species in Montana:
  http://www.animalrangeextension.montana.edu/Articles/Forage/Comparative/Comparative-char.htm
- USDA Conservation Plants Pocket Guide
  http://plant-materials.nrcs.usda.gov/pubs/mopmcpuidguide.pdf
- USDA VegSpec Web site
  http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm
- USDA Crop Nutrient Tool
  http://npk.nrcs.usda.gov/

Some of the more critical plant characteristics to consider include:

- *Tolerance of local climate*—Tolerance to temperature extremes, rainfall, and drought conditions specific to location should be a first consideration.
- *Tolerance to flooding and saturated soil conditions* for extended periods—VIBs will be designed to collect the runoff from the open lot and possibly contributing drainage from cropland and associated feedlot facilities plus the precipitation falling directly on the VIB. Typical infiltration design will require up to 72 hours for this volume of water to infiltrate through the basin during peak storm events. Forages or other crops maintained in the VIB will need to withstand flooding and saturated conditions over this time period, but also tolerate drier conditions that may predominate in the basin most of the time, especially in high plains states.
- *Tolerance to salts*—Because of the volumes of water that will move through the soil profile, soluble salt accumulation in the root zone may not be a large concern. However, a period of multiple small storms with little infiltration through to the tile lines may produce periods of salt accumulation in the VIB. Salt tolerance of the crop should be considered in selecting appropriate forage or grass species. Figure 7–4 provides an indication of some crops more tolerant to higher EC levels. Salt tolerance of locally specific crops should be available by contacting your local county coop-

Figure 7–4 Effect of soil salinity on growth of selected forage crops (USDA Soil Conservation Service Agricultural Waste Management Field Handbook, ch. 6)



erative extension program or the local NRCS service center.

Runoff associated with rainfall events is the primary source of water that will be collected by a VIB. Average reported electrical conductivity (EC) levels ranges from 3.2 millimhos per centimeter for eastern Nebraska to 8.6 millimhos per centimeter for central Colorado. Drier climates typically produce the higher average EC levels. Smaller, less intense precipitation events typically produce higher salt concentration in runoff. Winter runoff is also likely to produce higher EC levels. A Nebraska study suggests EC levels were approximately three times greater for winter runoff as compared to rainstorm runoff. These EC levels will be diluted by rainfall directly on the settling and VIBs.

- *Tolerance to ammonia*—Many plants cannot tolerate high concentrations of ammonia. Influent concentrations should be 200 milligrams per liter or less. Typical feedlot runoff may contain higher ammonia concentrations (400–700 mg/L) than the plants can tolerate, although actual concentrations may vary significantly. Higher concentrations are expected from densely stocked lots and infrequently scraped lots. If higher ammonia concentrations enter the VIB than the plants can tolerate, vegetation will be lost. If high concentrations are anticipated, pretreat by blending the settling basin effluent with outside clean water to lower the influent concentration. Blending increases the total drainage area and will result in a larger VIB.

In addition to the crop's tolerance to the previously discussed limiting conditions, a preferred crop for a VIB should have some of the following characteristics:

- *High nutrient uptake*—Forages that harvest high levels of nitrogen coupled with regular harvesting of forages is important for minimizing excess nitrogen movement through VIBs. However, with effluent existing from VIBs only through dedicated drainage tiles (no surface runoff discharge), soil phosphorus accumulation will be of limited concern in most situations. VIBs that directly discharge via tile lines to a VTA should provide sufficient opportunity for managing dissolved phosphorus.
- *Value as animal feed*—VIB basin forage growth will need to be harvested regularly. It is preferable to select forages that will be of value as an animal feed to gain some value for the land committed to a VIB. If harvested forage cannot be used for animal feed, alternative uses (bedding or carbon source for composting) are preferable to stock piling undesirable forage.
- *High evapotranspiration rates*—VIBs can reduce the total water volume supplied to secondary treatment (VTA) if a forage or grass is selected for its high evapotranspiration rates.
- *Perennials*—Infiltration basins should utilize perennial vegetation that provides growing plants from early spring into late fall for maximum nutrient uptake and water evapotranspiration. Grass and forages with long growing seasons would be preferable to row crops such as corn for utilizing nutrients from early spring through mid-fall runoff events. Combinations of warm- and cool-season grasses can create a long growing season in many applications. Late fall and winter application of runoff will add ammonium and some organic nitrogen to the VIB, both of which are immobile in most soils. These forms of nitrogen are unlikely to be converted to mobile nitrate nitrogen until the soil warms in the spring. Perennial grasses and forages with long growing seasons should allow removal of mobile nitrate nitrogen during an extended period of the year when nitrogen in this form is available.
- *Large root mass and surface area* provides an environment that encourages microbial activity. Aerobic decompositions of organic solids and mineralization and nitrification of nitrogen in runoff require active biological environments. Plants with large root mass contribute to an active biological environment. Plants with large taproots are undesirable, increasing the potential for preferential flow.

To date, only limited field experiences with VIBs can be drawn on for the selection of plant materials. A VIB used with a small beef cattle feedlot observed that Reed Canary grass performed well. A VIB operating on a central Iowa feedlot has also observed that Reed Canary grass has survived well over a 5-year period. Grass and forage species selected for VIB should be tolerant of local growing conditions.

VIB effluent management

Effluent from the VIB is removed via the underground tile drainage system. Based on data from Iowa's research system, even though significant contaminant reductions will have occurred, the water quality in the tile flow should not be discharged directly to surface waters. The tile flow should be brought to the soil surface for further treatment via a VTA, wetland, or grass waterway.

Management considerations specific to VIBs include:

- Harvesting of forage regularly to remove as many nutrients as possible and maintain lush plant growth. Utilize the forage for animal feeding (if quality is reasonable) or alternative uses such as animal bedding. Avoid stock piling of unusable forage.
- Monitor crop nitrate levels if crop is fed to livestock.
- Soil test every 3 to 5 years to monitor potential phosphorus or salt buildup in the soil profile.
- Maintain records on precipitation events, peak VIB water levels, repairs and maintenance, inspections of site, and soil and plant tissue testing.
- Annually sample tile drain flow for nutrient and solids concentration.
- Prevent growth of trees and weeds with large taproots to minimize macro-pore flow. Every few years, the VIB should be tilled with a heavy tandem disk or chisel plow to disturb surface macropore flow and reestablish VIB vegetation.

Additional discussion on management of plant based treatment systems is contained in section 8.

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