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Subsurface Gravel Wetland

Design Specifications

January 2022

University of New Hampshire Stormwater Center (UNHSC)
Gregg Hall ● 35 Colovos Road ● Durham, New Hampshire 03824-3534 ● http://www.unh.edu/erg/cstev

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NOTICE

The specifications listed herein were developed by the UNHSC for UNHSC related projects and represent the author's best professional judgment. No assurances are given for projects other than the intended application. The design specifications provided herein are not a substitute for licensed, qualified engineering oversight and should be reviewed and adapted as necessary including the full recognition of site specific conditions.

ACKNOWLEDGEMENTS

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Thomas P. Ballestero, PE, PhD
UNHSC Lead Scientist
Phone: 603-862-4024
tom.ballestero@unh.edu

James Houle, PhD
UNHSC Director
Phone: 603-862-1445
james.houle@unh.edu

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DESIGN SUMMARY

Category Type: Subsurface Gravel Filtration system and Stormwater Wetland

Layout Description

The subsurface gravel wetland (SGW) is designed as a series of horizontal flow-through treatment cells, preceded by a sedimentation basin (forebay) Figure 1. The original UNHSC SGW system was designed to treat the runoff from a one-inch rainfall event (the water quality volume – WQV) and to temporarily retain 10 percent of the WQV in the forebay and 45 percent of the WQV above each treatment cell. While this is the design that was originally tested, other systems have been subsequently designed and tested that have different configurations and still achieve exceptional water quality performance. The inclusion of a pretreatment forebay may increase maintenance activities and limit nitrogen reduction performance if it is not well drained. It is recommended that if forebays cannot be economically installed to completely drain between storms then concrete inlet structures such as off-line deep sump catch basins be used for pre-treatment as opposed to a forebay structure. A deep sump catch basin or other precast inlet structure may be used and may also be easier to maintain.

The SGW is designed as an underground flow through treatment system where the stormwater travels horizontally through a saturated gravel substrate with a microbe rich environment. The system may be designed with a multi-staged outlet to control various flow conditions such as the Channel Protection Volume (CPV) and still allow for the overflow contingencies of larger storms. By design, the WQV is temporarily retained in the basin geometry above the wetland soil and subsequently treated through the SGW before draining to stormwater conveyance or receiving waters. All surface basin (and forebay) side slopes should be 3H:1V or flatter for maintenance. Standing water of significant depth is not expected other than during large rainfall events. This depth is controlled through the design of the high flow bypass or emergency spillway component of the system. The gravel substrate within the wetland's cells is intended to be continuously saturated below a depth of four to eight inches (10-20 cm) from SGW surface grade in order to promote water quality treatment conditions and support wetland vegetation. To force this near-surface ground water condition the primary outlet from the gravel layer has an invert of 4 – 8 in (10 - 20 cm) below the wetland surface grade.

Hydraulic Inlet Configuration

A critical component to the SGW system is design of the hydraulic inlet for conveying runoff into the gravel layer. Early installations used slotted HDPE riser pipes to function as the primary inlets. These risers often clogged and forced flows to enter the subsurface through grated inlets at the top of the slotted riser pipe. Numerous hydraulic inlet design configurations have since been tested that demonstrate improved hydraulic function and maintenance capacity as well as diminished costs. UNHSC research indicates the hydraulic inlet configuration may be flexible provided it has a much greater hydraulic capacity/efficiency than the primary outlet orifice control. For example, a UNHSC alternative primary inlet design employs a primary inlet composed of woven geotextile placed over the subsurface pea stone layer and covered with 6 – 8 in (15 – 20 cm) diameter stone. The slotted vertical pipes are used as the secondary inlet in the event that the woven geotextile becomes clogged and is due for maintenance. This configuration is installed around the forebay outfall of the inlet pipe (see Figure 2). This design protects the stone filter in the subsurface of the wetland system while also providing a more accessible and maintainable hydraulic inlet feature at the surface that will inevitably be easier and less costly to construct.

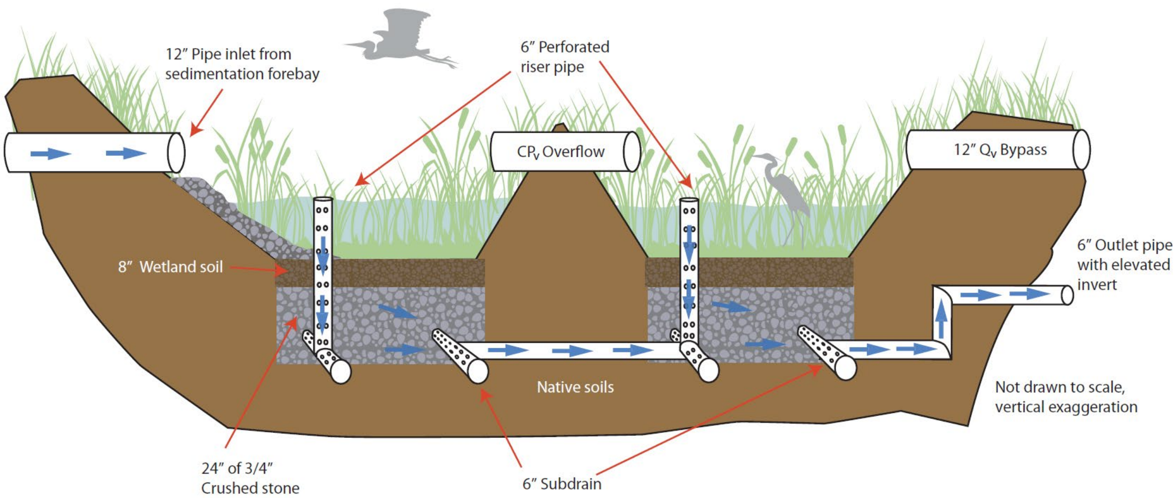
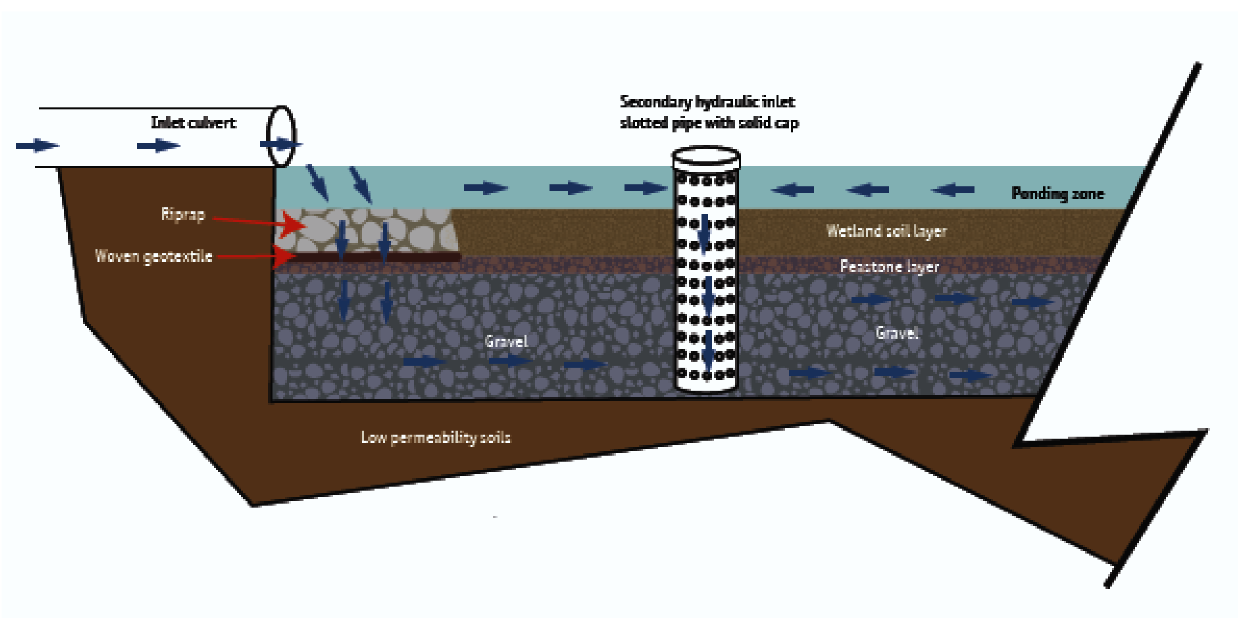


Figure 1: Basic components of a typical subsurface gravel wetland system.



Similar to inlet controls, the configurations of outlet controls for SGW systems vary. The most important considerations are that the primary outlet is the hydraulically most restrictive component of the entire system and that the WQV drains in a reasonable amount of time (24 hours is common). The hydraulic inlet delivers system inflows to the subsurface gravel layer. Within the gravel layer, horizontal subdrains (vertically centered in the gravel layer) distribute the incoming flow across the width of the gravel, the flow then passes through the gravel substrate to subdrains on the downstream end (also vertically centered in the gravel layer). These downstream subdrains collect the flow and deliver it into the next cell which has an identical flow pattern. ***Hydraulic control of the system occurs at the primary outlet. For large precipitation events this hydraulic control throttles the flow through the system and forces stormwater inflow to be temporarily stored above the wetland surfaces***. By design, the ponded water slowly drains down into the gravel layer below and is filtered prior to leaving the system. Precipitation events larger than the design volume will have some portion that overflows to receiving waters through an emergency (secondary) spillway. At a minimum these large stormwater runoff events will have received treatment of the first flush up to the designed storage volume. UNHSC worked with EPA Region I and TetraTech consultants to develop pollutant load reduction metrics for all innovative stormwater control measures (SCMs) that are designed to manage less than the WQV. See UNHSC, 2015 for more information. The SGW may be plumbed via inline or offline configuration

System Functionality

System functionality in a SGW has multiple components. The unit processes involved include: sedimentation, filtration, physical and chemical sorption, microbially mediated transformations, vegetative uptake, evapotranspiration, and surface storage. In addition, water quality treatment mediated by the wetland plants and their root systems is highly likely but undocumented. Within the gravel layer the treatment processes include filtration, sorption, uptake and storage, and microbially mediated transformation. The conversion and removal of nitrogen is dependent on two conditions that are incorporated into SGW design: an aerobic sedimentation forebay followed by subsurface anaerobic treatment cells. Aerobic conditions exist in the forebay when it is designed *and maintained* as a dry area with temporary ponding conditions during storm events. The anaerobic condition in the treatment cells is created by maintaining the saturated zone within the gravel layer as well as the slow flow through the system throttled by the primary outlet. The microbial respiration in the gravel layer results from the consumption of dissolved organic carbon and drives the dissolved oxygen level down thereby creating conditions favorable for microbially-mediated nitrate conversion to nitrogen or nitrous oxide gas.

Stormwater Pond Retrofit Options

SGWs are well suited for retrofitting stormwater pond systems primarily because older stormwater ponds were typically sized for the 10-year or larger events whereas green stormwater infrastructure like the SGW is designed for much more frequent, smaller events. The rationale behind retrofitting existing stormwater ponds into SGW systems include: 1) there is a limited hydraulic head requirement, 2) the SGW may be lined, 3) the SGW does not necessarily require separation from groundwater, and 4) there is a straightforward placement of the system within the footprint of existing stormwater ponds. Minimum hydraulic head requirements for a SGW are from the invert of the primary inlet to approximately 4 in (10 cm) below the SGW wetland soil surface (the primary outlet invert). In contrast, underdrained filtration systems such as a bioretention system may require a hydraulic head to move water through the system as much as three feet (one meter) or more. Because the SGW is a horizontal porous media flow system it does not require a large hydraulic head to drive the water through the system. At the maximum, the driving head is the vertical difference between the elevation of the high flow bypass and the invert of the primary outlet. To maintain its subsurface saturated condition, the SGW must be situated in low hydraulic conductivity soils or lined below and along the vertical walls of the gravel layer. Because infiltration is not designed to occur, separation from groundwater is not required and SGWs may be sited much like stormwater ponds. However, groundwater inflows to a SGW must not be so large that the anaerobic conditions do not occur. While SGWs have a relatively large footprint for a stormwater quality treatment technology, they easily fit within the footprint of existing stormwater ponds that were sized for flood control. When retrofitting a SGW system into a stormwater pond, it is best to locate it towards the outlet of the pond. The area within the pond preceding the SGW may then be used for pretreatment. A wet pond retrofit would require a conversion to a dry pond by the elimination of the permanent pool.

SURFACE INFILTRATION RATES AND HYDROGEOLOGIC MATERIALS

Subsurface Gravel Wetland Material Layers

Wetland soil: The surface infiltration rates of the gravel wetland soil should be similar to a low hydraulic conductivity wetland soil (0.1-0.01 ft/day = 3.5 x 10^{-5} cm/sec to 3.5 x 10^{-6} cm/sec). This soil may be manufactured using a combination of loam, sand, and some fine soils blended to a high % organic matter content soil (≥15% organic matter). The organic matter in the wetland soil is one source of dissolved organic carbon to the gravel layer below. Avoid a final wetland soil mix with clay content in excess of 15%: that may result in drying and cracking and potential migration of fines into the subsurface gravel layer. Do not use geotextiles between the horizontal layers of this system as they will clog due to fines and may restrict root growth.

Filter layer: An intermediate layer of a graded aggregate filter (i.e., ⅜-in pea gravel) is needed to prevent the finer particles in the wetland soil from migrating down into the coarse gravel sub-layer. Material compatibility should be evaluated using the following FHWA criteria:

Criteria 1: $D_{15,\,COARSE\ \ SUBLAYER} \leq 5\,x\,D_{85,\,SETTING\ \ BED}$

Criteria 2: $D_{50,\,COARSE\ \ SUBLAYER} \leq 25\,x\,D_{50,\ SETTING\ \ BED}$

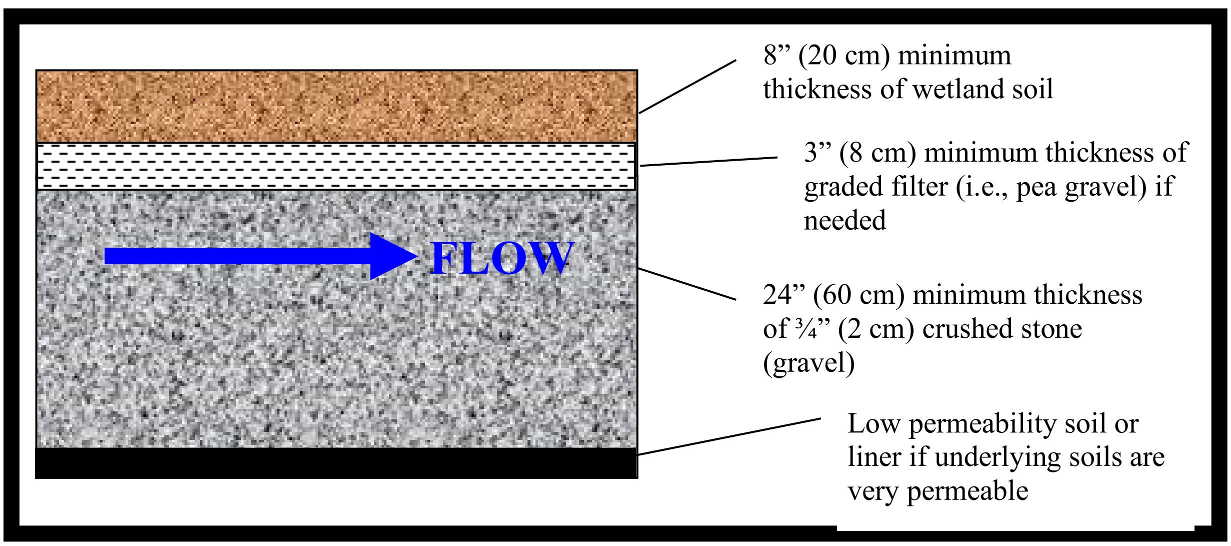
In these criteria, the "course layer" is the larger material and the "setting bed" is the finer material. Comparisons should be made between the wetland soil and the pea gravel (graded filter layer) as well as the pea gravel and the gravel layer below. The UNHSC recommended particle size distribution (PSD) for wetland soil is provided in Table 1 and reflects a poorly drained soil with a median particle size (D_{50}) of 0.15 mm and is classified as a clay or silt loam in the USDA soil textural triangle. This wetland soil must exclude any sticks, roots, stones, etc. that violate the suggested PSD. UNHSC believes that this specification allows for more cost-effective bidding of appropriate soil types with the potential to utilize appropriate onsite excavated materials. Onsite materials should be evaluated by the design and/or site construction engineer to ensure suitability.

Table 1: Particle size distribution and testing tolerances for wetland soil for the subsurface gravel wetland system

US Standard Sieve Size in/mm	Percent Passing	Percent Passing Testing Tolerances
0.5/12.5	100	± 10.0
#10/2.00	90 - 75	± 5.0
#100/0.15	40-50	± 5.0
#200/0.075	25-50	± 5.0

Gravel layer: Below the wetland soil and pea gravel is a gravel (crushed stone) sublayer with a 24 in. (0.6 m) minimum thickness. Angular crushed stone is needed with a minimum size ~3/4 in (2 cm). Large particle, angular coarse to very coarse gravel is needed to maintain system longevity as well as possess very high permeability characteristics.

Figure 3: Gravel Wetland Materials Cross -Section



Native Materials, Low Permeability Layer, and Liner

If a native, low hydraulic conductivity soil is not present below the gravel layer, a low permeability liner or soil layer should be used to: minimize infiltration, preserve horizontal flow in the gravel, and maintain the wetland plants. *The success of the subsurface gravel wetland system's high nitrate removal depends on the gravel layer remaining permanently saturated.* The recommended maximum hydraulic conductivity of native soils below and surrounding the SGW is 0.028 ft/day (1 x 10^{-5} cm/sec). If native soils fail to meet this hydraulic conductivity specification, a first recommendation is to assess whether the native soil may be compacted to create the desired performance. This process would then define the compaction methods and requirements to be used in construction of the SGW. If in situ permeability testing confirms the need for a liner or low permeability soil layer, acceptable options include: (a) 6 – 12 in (15 – 30 cm) of clay soil (minimum 15% passing the #200 sieve and a maximum permeability of 1 x 10^{-5} cm/sec), (b) a 30 mil HDPE liner (or equivalent material/thickness synthetic liner), (c) bentonite layer with minimum thickness of 4 in (10 cm), (d) use of chemical additives (see NRCS Agricultural Handbook No. 386, dated 1961, or Engineering Field Manual), or (e) a design prepared by a Professional Engineer. Should a synthetic liner be selected, sealing and seaming of the liner must be included in the liner specification as well as the field-testing methods to demonstrate that the liner will meet the SGW hydraulic conductivity specification.

MAINTENANCE

Inspection and maintenance is a critical component of the long term function and effectiveness of any stormwater control measure. The UNHSC has produced operation and maintenance guidelines as well as an inspection checklist for these systems which are available online at the UNHSC website. Inspection is critical to assess as-built functionality in addition to identifying unique maintenance tasks that may be less general in nature and more site specific. Post construction inspections are critical just after newly constructed SGW systems are placed online. Beyond construction and installation issues the primary maintenance need identified through UNHSC inspections of its SGW system operations is simple maintenance of the established wetland vegetation. Most installed facilities are in need of this type of maintenance which involves cutting the existing plants down to the base and removing it from the system to prevent breakdown and rerelease of nitrogen. Removal of vegetation should occur at least once every three growing seasons.

COST

UNHSC has worked with EPA Region I, TetraTech and other partners on the development of BMP cost information for the New England Stormwater Management Optimization Tool (Opti-Tool, EPA Region 1, 2016). The general cost function formula consists of three factors: the BMP storage volume, the proposed BMP storage volume cost estimate (which includes a 35% design contingency), and the adjustment factor. Table 2 summarizes the proposed BMP cost estimates for the Opti-Tool.

Table 2: Costs associated with SGWS construction based on the system storage capacity in cubic feet.

BMP (From Opti-Tool)	Cost ($/ft³) 1	Cost ($/ft³) 2015 dollars4
Gravel Wetland System (aka-subsurface gravel wetland)	7.59 2,3	8.31

1. Includes 35% add on for design engineering and contingencies
2. Costs in 2010 dollars
3. From UNHSC Cost Estimates
4. Conversions made using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

SPECIFICATIONS SUMMARY

- May be preceded by a variety of pre-treatment options including: forebay, off-line deep sump catch basin, hydrodynamic separator, or swale.
- Documented performance metrics pertain to SGW systems designed with two treatment cells. There is no present research suggesting that this original configuration is unnecessary.
- A subsurface saturated condition is permanently maintained by the design of the outlet invert elevation situated 4 – 8 in (10 – 20 cm) below the wetland soil surface.
- In system residence time is critical for increasing nitrogen removal which requires the primary outlet orifice control to be sized for 24 to 30 hours of water residence time
- The outlet orifice should only receive water filtered through the gravel layer. In this manner, small orifices will not clog due to sediment or gross solids. The outlet orifice should be protected from surface flow or wind-blown clogging from the downstream side.
- No geotextile or geofabric *horizontal* layers are used within this system. Geofabrics may be used to line walls in order to prevent the migration of soil fines into the SGW layers. In addition, as presented in Figure 2, a geotextile may be a component of the SGW hydraulic inlet.
- If a native low hydraulic conductivity soil is not present below the desired location of the SGW, a low permeability liner or soil layer (hydraulic conductivity less than 10^{-5} cm/sec = 0.028 ft/day) below the gravel layer should be used to minimize infiltration, preserve horizontal flow in the gravel, and maintain the wetland plants. If nitrogen reductions are not the primary driver for the selection of the SGW system, then alternate stormwater management BMPs should likely be considered.
- 8 in. (20 cm) minimum thickness of a wetland soil as the top layer. (See the section on particle size distribution specifications for guidance). This layer is leveled (constructed with a surface slope of zero). Cells may be terraced in order to accommodate site slope constraints.
- 3 in. (8 cm) minimum thickness of an intermediate layer of a graded aggregate filter is needed to prevent the wetland soil from moving down into the gravel sub-layer. Material compatibility between layers needs to be evaluated (see Criteria 1 and Criteria 2). This layer is intended to act as a graded filter for wetland soil stability.
- 24 in. (0.6 m) minimum thickness of ¾-in (2 cm) crushed-stone (gravel) sub-layer. This is the active zone where treatment occurs
- The primary outlet invert shall be located 4 – 8 in (10 - 20 cm) below the elevation of the wetland soil surface to control in-system water elevation. Care should be taken to not design a siphon that would drain the wetland; therefore the primary outlet location must be open or vented. Smaller outlet controls do require protection of the "clean" or filtered side of the orifice from larger debris delivered by high flows or wind-blown mechanisms from the downstream side. This may mean that high flow contingencies are in secondary structures or at least situated such that large debris does not have access to the clean side of the orifice.
- An optional high capacity outlet at equal elevation or lower to the primary outlet may be installed for maintenance purposes. This outlet is plugged/sealed during normal operation but allows for flushing of the treatment cells at higher flow rates should that be desired. If it is located at an elevation lower than the primary outlet, it may be used to drain the system for maintenance or repairs.
- The bypass outlet (emergency spillway or secondary spillway) is sized to pass design flows (10-year, 25-year, etc.). This outlet is sized by using conventional routing calculations of the

inflow hydrograph through the surface storage provided by the subsurface gravel wetland system. Local criteria for peak flow reductions are then employed to size this outlet to meet those criteria.

- The primary outlet structure and its hydraulic rating curve are based on a calculated release rate by orifice control to drain the WQV in 24 – 48 hrs. For orifice diameter calculations refer to HDS 5 (FHWA, 2012) for details.
- The minimum spacing between the subsurface perforated distribution line and the subsurface perforated collection drain, at either end of the gravel in each treatment cell, is 15 ft (4.6 m): there should be a minimum horizontal travel distance of 15 ft (4.6 m) within the gravel layer in each cell.
- Vertical cleanouts connected to the distribution and collection subdrains, at each end, shall be perforated or slotted only within the gravel layer, and solid within the wetland soil, filter layer, and storage area above. This is important to prevent short-circuiting and soil piping. To date these structures have not been necessary for maintenance in any systems studied by UNHSC.
- Berms and weirs separating the forebay and treatment cells should be constructed with clay, or very low hydraulic conductivity soils, and/or a fine geotextile, or some combination thereof, to avoid water seepage and soil piping through these earthen dividers.
- The system should be planted to achieve a rigorous root mat.
- Maintenance guidelines and inspection checklist can be found at the University of New Hampshire Stormwater Center website: http://unh.edu/unhsc/maintenance
- Minimum maintenance requires cutting and removal of vegetation from wetland surface every three years.

REFERENCES

The primary design sources for the development of the subsurface gravel wetland are listed below, in the order of use.

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