APPENDIX

A

UTILITIES AND GENERAL NOTES

UTILITIES

The following is a general list of utility companies within the Town of Copper Canyon. It is the Engineer and Contractor's responsibility to check if there are additional utilities within the project area:

Utility	Contact – Job Title	Phone Number
Coserv Electric	Jody Padron – Electric Engineering	(940) 321-7800
Atmos Energy	Jeff Wylie –Project Manager	(817) 303-2905
Verizon	Larry Guay – Obligatory Planner/Engineer	(940) 213-3606
Grande Comm.	Ike Butler - Project Manager	(972) 410-0584
Bartonville Water	Jim Leggieri –Manager	(817) 430-3541
Explorer Pipeline	Patrick Nwakoby – Manager	(817) 267-3242
Brazos Electric	Dane Harrison – Operations Manager	(254) 750-6300

GENERAL NOTES **Page**

PAVING GENERAL NOTES

1. All construction shall be in accordance with the standard specifications and details of the Town of Copper Canyon and the Fourth Edition of the "Standard Specifications for Public Works Construction – North Central Texas" herein referred to as "COG". Copies may be obtained from the North Central Texas Council of Governments, 616 Six Flags Drive, Suite 200, Arlington, Texas 76005-5888.

2. Subgrade preparation shall be in accordance with COG Item 301.

3. Lime Stabilized subgrade shall be installed in accordance with COG Item 301.2. Lime shall be placed using the slurry method. Refer to COG Item 301.2.1.1.

4. The Contractor shall install supporting chairs for reinforcing steel on a one per square yard spacing in all concrete pavements. The chairs are to be plastic and installed as per COG Item 303.2.11.

5. 20% (by weight) of the cement content may be replaced with Type C fly ash. Refer to COG Item 303.2.4.

6. Concrete for all paving and curbs within Town of Copper Canyon shall have a minimum strength of 4,000 psi at 28 days for machine paved and 4,500 psi at 28 days for hand poured. The Town shall approve the concrete mix design in writing prior to use.

7. Slump requirements for slip form paving shall be an average of three inches with a maximum of four inches; for hand formed paving it shall be an average of four inches with a maximum of five inches; and for sidewalk & other it shall be specified by the owner. Refer to COG Item 303.3.4.4.

8. Curbs for concrete pavement shall be poured monolithically. Refer to COG Item 303.5.9.

9. The Contractor shall use a liquid membrane-forming compound as per COG Item 303.2.13.1.1.

10. Construction joints shall be used in all bock-outs for driveways and inlets.

11. Transverse joints shall be sawed on 15 foot centers for all pavement thicknesses. The concrete saw must be stationed on the job-site prior to placing the pavements. All joints shall be sawed within an eighteen (18) hour period from the time of the pour.

12. Construction and longitudinal joints shall be placed in accordance with details. Saw joints to be 1/4 inch for each inch of pavement thickness.

13. The Contractor shall submit a Jointing Plan, for review by the Town, prior to placing.

14. Parkway, roadway ditches and adjacent disturbed areas for paving of roadways in undeveloped areas shall be seeded with Bermuda grass. Parkway and adjacent disturbed areas for paving of roadways in developed areas shall be block sodded with either Bermuda or St. Augustine to match the adjacent private property. Medians shall be block sodded. All sodding and seeding will be placed on four inches of topsoil. The Contractor is responsible for maintenance, including mowing and watering until vegetation is established at not less than 20 plants per square foot area, and until accepted by the Town.

15. Unless stated otherwise in the Contract Documents, the Contractor is responsible for all testing. All final reports shall be turned in to the Town Inspector within five (5) working days. Failed samples must be reported to the Town Inspector immediately.

    a. The CONTRACTOR shall be responsible for notifying the Town Inspector at least 24 hours prior to any required testing.

    b. Soil testing technicians shall provide written proof of having minimum of two (2) years of related field experience.

    c. The CONTRACTOR shall coordinate all testing activities with the Town Inspector and shall facilitate required testing throughout the construction period. The Inspector shall be present during all testing.

    d. The Town shall make final decision as to the validity of all testing results.

e. The CONTRACTOR shall be responsible for ensuring that materials to be tested are in compliance with all plans and specifications prior to testing. All materials found not to be in compliance with the plans and specifications before and after testing shall be removed and replaced at the CONTRACTOR'S expense.

f. All costs associated with the retesting of work that fails to meet the specifications required in the contract documents shall be borne by the CONTRACTOR. For Town projects, retesting cost shall be withheld from pay requests submitted by the CONTRACTOR, this cost will be based on the Town's cost with no additional mark-up. A letter of acceptance will not be issued until all testing deficiencies are addressed and all related cost paid.

g. The Town Inspector shall be notified of concrete placement 24 hours in advance for steel and form inspection.

h. Subgrade Testing

1) Samples shall be taken for all classifications of soils on site. Testing for sulfate presence and lime series tests shall be conducted for all samples prior to any stabilization. If sulfate content is greater than 2,000 ppm (parts per million), specific recommendation shall be made by geotechnical engineer for subgrade preparation. The use of lime or cement and the percent content shall comply with the Geotech Engineer recommendations. Additional geotechnical testing and recommendations may be required by Town as field conditions dictate. Atterberg Limits shall be determined on all Proctor samples.

2) Gradations for lime treated subgrade shall be taken at intervals not exceeding 300 feet along road and must pass 100% through a 1 3/4" sieve and 60% through a No. 4 sieve according to NCTCOG Item 301.2.3.5.1.

3) 3) Gradations for Portland cement treated subgrade shall be taken at intervals not exceeding 100 feet along road and must pass 100% through a 1" sieve and 80% through a No. 4 sieve according to NCTCOG Item 301.3.3.2.

4) Lime subgrade shall be tested in accordance with NCTCOG Item 301.2.1.3. Tests will be performed by excavating deeper than lime treatment and administering a phenolphthalein indicator.

5) Densities shall be taken on subgrade in accordance with the Wastewater General Notes 15.i.3 Mechanical Tamping and in accordance with NCTCOG Item 301.2.3.6 unless otherwise stated on the plans or in the specifications.

6) All subgrade shall be visually inspected by town engineer to ensure no failures, cracks, or defects after it is trimmed and prior to placement of steel.

7) Densities shall be taken at least 72 hours before concrete placement (NCTCOG Item 303.5.1). If more than 72 hours elapse, densities must be retaken unless an approved emulsion sealant is used in accordance with NCTCOG Item 302.3.5.

8) Locations for densities, gradations, and depth checks shall be at the discretion of the Inspector and shall be representative of the entire cross section of the subgrade.

9) Subgrade failures shall be defined by Inspector or ENGINEER. Repair method will be discussed with Inspector or ENGINEER and approved prior to beginning repair work.

10) Multiple tests may be required across width of right-of-way.

11) For emulsion placement over subgrade refer to NCTCOG Item 302.3.5.2.

i. Concrete Testing for Pavements, Curbs, Sidewalks and Driveways.

1) A concrete mix design must be submitted and approved by the Town prior to any placement of concrete. A minimum of four (4) test cylinders shall be obtained per one hundred cubic yard (100 cy) of concrete placed with a minimum of four cylinders per placement. Tests shall also include slump, air contents and temperature of concrete mixture; each mix design of concrete placed each day shall also be tested. Concrete strength shall be tested at 7 days (2 cylinders) and 28 days (2 cylinders). Additional cylinders and or tests may be requested at the Town Inspector's discretion.

2) Concrete with a temperature of 85 degrees or higher will require a retarding agent admixture.

3) The maximum temperature of concrete at the time of placement shall not exceed 95 degrees. It shall be the CONTRACTOR and/or his supplier's responsibility to take steps to control the temperature of concrete. All concrete that exceeds the temperature limit of 95 degrees will be rejected.

4) Forms shall not be removed from pavement, sidewalks, ramps, or retaining walls for 24 hours minimum, and shall not be backfilled less than 72 hours after concrete placement. Pavement shall have a minimum cure time of 7 days, but may be opened to traffic earlier at the discretion of the Inspector or ENGINEER only after review of compressive strength data. Temporary perpendicular crossings may be made after 72 hours by ramping soil over the new pavement at a depth of not less than 18-inches and a width of not less than 10-feet. Prior to grout wiping any concrete, CONTRACTOR shall demonstrate method of surface preparation to ensure adhesion of grout.

5) All street pavement shall be cored to verify proper pavement thickness and strength prior to acceptance. Cores for strength and depth shall be 4-inches diameter and taken at intervals not exceeding 600 feet; cores for depth only shall be 2-inches diameter and shall be taken at intermediate intervals not exceeding 300-feet. Locations will be approved by the Town. Multiple cores may be required at each interval to represent entire cross section. All cores shall be taken at 28 days and results shall be correlated with the cylinder test results. Evaluation of cores will be in accordance with NCTCOG Item 303.8.2. All required pavement replacement shall be in full panel increments.

j. Hot-Mix Asphalt Concrete Pavement Testing

1) Specifications shall follow COG Item 302 and conform to the TxDOT Standard for Hot-Mix Asphaltic Concrete.

2) The asphaltic mixture shall be tested for oven burn off/gradation and stability.

3) A relative density of not less than 92% will be required after final compaction of the in-place pavement section. The CONTRACTOR shall schedule the CMT Laboratory to come out in the field and establish a rolling pattern. The use of nuclear field density determinations shall not be accepted as the basis for acceptance with respect to density. The CONTRACTOR shall be responsible for assuring that the compaction of the asphaltic concrete in place will attain between

5% and 9% (five and nine percent) air voids. The CONTRACTOR's responsibility for the required compaction includes the selection of rolling equipment and selection of rolling patterns to achieve the required compaction.

4) HMAC mix temperature range at time of placement shall be between 260 degrees and 325 degrees. The asphaltic mixture shall not be placed when the air temperature is below 50 degrees but may be placed when the air temperature is above 40 degrees and rising, the temperature being taken in the shade and away from artificial heat.

5) In-place compaction control is required for all mixtures. Asphaltic concrete should be placed and compacted to contain not more than 9% (nine percent) nor less than 5% (five percent) air void unless otherwise indicated. The percent air voids will be calibrated using the maximum theoretical specific gravity of the mixture determined according to TxDOT Test Method Tex-227-F Roadway Specimen, which shall either be cores or sections of pavement, will be tested according to TxDOT Test Method Tex-207-F. The same specimen shall be used in determining both the theoretical density and field density.

6) Prime coat will follow COG Items 302.7 and 302.9.6.1.

7) Tack coat will follow COG Specifications item 302.9.6.2.

8) HMAC mix designs shall follow COG Item 302.9.3 and the grading tables included in this section. These mixtures will be in accordance with TXDOT Test Method Tex-204-F, design of Bituminous Mixtures.

WATER GENERAL NOTES

1. All construction shall be in accordance with the standard specifications and details of the Town of Copper Canyon, Bartonville Water Supply Corporation, and the Fourth Edition of the "Standard Specifications for Public Works Construction – North Central Texas" herein referred to as "COG". Copies may be obtained from the North Central Texas Council of Governments, 616 Six Flags Drive, Suite 200, Arlington, Texas 76005-5888.

2. For 6-inch to 24-inch sizes, water lines shall be AWWA C900-07 Polyvinyl Chloride Pressure Class 235 (DR18) or greater.

   For pipes larger than 24-inches, the pipe type shall be determined by Bartonville Water Supply Corporation.

3. Fittings shall be cast iron or ductile iron, with 89-mil polywrap per COG Item 501.7.4. All fittings shall be Mega Lug or equivalent unless specified otherwise. Beveled ends of the pipe shall be removed when used with Mega Lug fittings. Fittings shall be blocked as per the Concrete Blocking details.

4. Water pipe shall be blue in color.

5. All pipe joints shall be gasketed, bell and spigot, push-on type.

6. For creek crossings with less than 5 feet of cover to the creek flowline, the pipe shall be PVC with concrete encasement.

7. Embedment and backfill shall be as per the Water Details for pipes up to 12-inch diameter. For pipes larger than 12-inch size, the Engineer shall specify embedment.

8. Minimum cover over water lines shall be as follows:

   a. 48 inches for water lines 12-inches in diameter or less

   b. 60 inches for water lines larger than 12-inches in diameter.

   Cover over 72 inches must be approved by the Town.

9. Clay cut-off walls shall be constructed as per the Water Details.

10. PVC Water pipe is allowed to be stored a maximum of six (6) months without cover. Thereafter all pipes should be covered or protected from sunlight and to be protected from other elements.

11. When PVC water pipe is installed in casing, skids must be used to prevent damage to the pipe and bell during installation. PVC pipe should not rest on the Bells. Plastic spacers such as RACI or approved equal shall be used.

12. Valves installed on waterlines 16-inches diameter or less shall be vertical gate valves with non-rising stems and resilient wedge seal.

13. Valves installed on waterlines larger than 16-inches diameter shall be butterfly valves. An offset manhole shall be installed at the butterfly valve operator.

14. Valves and fire hydrants shall be installed in line with lot and ROW lines, where possible.

15. Valve locations shall be marked with "V" stamped or cut on the curb and painted blue for water mains and silver for fire hydrants.

16. All property corners shall be staked with iron pins prior to the installation of any water services. The locations of the water service shall be staked according to the plans.

17. Unless otherwise stated in the Contract Documents the Contractor is responsible for all testing. All final reports shall be turned in to the Town Inspector within five (5) working days. Failed samples must be reported to the Town Inspector immediately.

18. Water mains shall be standard sizes that are readily available such as 8-inch, 12-inch, 18-inch, 20-inch, 30-inch, and 36-inch.

    a. The CONTRACTOR shall be responsible for notifying the Town Inspector at least 24 hours prior to any required testing.

    b. Soil and material testing technicians shall provide written proof of having minimum of two (2) years of related field experience.

    c. The CONTRACTOR shall coordinate all testing activities with the Town Inspector and shall facilitate required testing throughout the construction period. The Inspector shall be present during all testing.

    d. The Town shall make final decision as to the validity of all testing results.

    e. The CONTRACTOR shall be responsible for ensuring that materials to be tested are in compliance with all plans and specifications prior to testing. All materials found not to be in compliance with the plans and specifications before and after testing shall be removed and replaced at the CONTRACTOR'S expense.

    f. All costs associated with the retesting of work that fails to meet the specifications required in the contract documents shall be borne by the CONTRACTOR. For Town projects, retesting cost shall be withheld from pay requests submitted by the CONTRACTOR, this cost will be based on the Town's cost with no additional mark-up. A letter of acceptance will not be issued until all testing deficiencies are addressed and all related cost paid.

    g. The Town Inspector shall be notified of concrete placement 24 hours in advance for steel and form inspection.

    h. One set of four cylinders (2-7 day, 2-28 day) for cast-in-place concrete shall be made for every day that concrete is placed (ASTM C-31). Air, slump, and temperature tests shall be taken for every set of cylinders made. Concrete with a temperature above 95 degrees will be rejected. Additional cylinders and or tests may be requested at the Inspector or ENGINEER's discretion. Exterior forms shall not be removed for a minimum of 24 hours unless approved by Inspector or ENGINEER. Sulfate resistant concrete shall be used for all manholes.

i. Backfill and Density Testing

1) All trenches shall be backfilled in accordance with standard details and mechanically compacted with approved vibratory methods in accordance with COG Item 504.5.3.2.1 and paragraph 3) below unless otherwise stated on the plans or in the specifications.

2) Densities shall conform to standard trench details, COG Item 504.5.3.2.1, and Paragraph 3) below unless otherwise stated on the plans or in the specifications. Proctor samples shall be taken for all classifications of soil on site. Atterberg Limits shall be determined on all Proctor samples. No “potholing” will be allowed. Densities shall be taken on all water services both sides of the street within the Right-of-Way and shall conform to Paragraph 3) below and COG Item 504.5.3.2.1, unless otherwise stated on the plans or in the specifications. Backfill adjacent to all structures shall be compacted manually and density tested on every lift.

3) Mechanical Tamping of Backfill

a) All ditch lines and bore pits shall be mechanically tamped.

b) Backfill, other than select fill, may consist of onsite or offsite inorganic soils and should be placed in loose lifts 6-inches – 8-inches in thickness (not to exceed 12-inches) and should be mechanically compacted to 98 percent of the maximum dry density as defined by ASTM D-698 (Standard Proctor) procedures under existing and proposed pavement, and to 95 percent standard proctor procedures elsewhere. The moisture content of the fill at the time of compaction shall be between minus 2% of optimum to four percentage points above the proctor optimum value.

c) All backfill material to be select native material, 6” diameter clods and smaller, unless directed otherwise on the plans or in the specifications and to be mechanically tamped and density controlled as described in Paragraph b) above.

d) Water jetting is not permitted.

e) Densities shall be taken every one (1) lift at staggered locations not to exceed 200 feet increments. Offset fifty (50’) feet every other lift.

f) Densities may be taken at typical locations as shown below; also, densities will be taken at random locations and at the geo-technician's discretion.

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- (Legend: X denotes densities)

j. Purging - All water lines greater than 200 feet in length and 12-inches in diameter or less shall be purged using the "Polly-Pig" method with the "Poly-Pig" to enter and exit at an approved location. Purging shall be in accordance with COG Item 506.7.3.1. Lines larger than 12-inches in diameter shall be purged using the flushing method in accordance with COG Item 506.7.3.2. The Town Inspector must be present.

k. Hydrostatic Testing - All water lines shall be tested in accordance with COG Item 506.5. The Town Inspector must be present.

l. Disinfection - All water lines shall be disinfected in accordance with COG Item 506.7.5 and as approved by the Town. All bleeders shall have corporation stopes at the main. One water sample shall be obtained for each street name (no greater than 1,000 feet) or as approved by the Bartonville Water Supply Corporation.

WASTEWATER GENERAL NOTES

1. All construction shall be in accordance with the standard specifications and details of the Town of Copper Canyon and the Fourth Edition of the "Standard Specifications for Public Works Construction – North Central Texas" herein referred to as "COG". Copies may be obtained from the North Central Texas Council of Governments, 616 Six Flags Drive, Suite 200, Arlington, Texas 76005-5888.

2. For 6-inch to 15-inch sizes, wastewater lines shall be ASTM D3034 Polyvinyl Chloride (PVC) SDR 35 for depths less than 14 feet. For depths greater than 14 feet, SDR 26 shall be used.

3. For 18-inch to 48-inch size wastewater mains shall be one of the following types:

    a. ASTM F679 PVC, Large-Diameter Plastic Gravity Sewer Pipe and Fittings

    b. ASTM F794 PVC, Profile Gravity Sewer Pipe and Fittings based on a Controlled, Inside Diameter

    c. ASTM F949 PVC, Corrugated Sewer Pipe with a Smooth Interior Lining

    d. ASTM F1803 PVC, Closed Profile Gravity Sewer Pipe and Fittings based on Controlled, Inside Diameter

4. All pipe joints shall be gasketed, bell and spigot, push-on type conforming to ASTM D3212 and compatible with the type of pipe to which they are attached.

5. All PVC pipe shall have a minimum pipe stiffness that equals or exceeds 46 psi.

6. For creek crossings with less than 5 feet of cover to the creek flowline, the pipe shall be PVC with concrete encasement.

7. Embedment and backfill shall be as per the Wastewater Details for pipes 6-inch to 15-inch diameter. Larger pipes shall be installed per ASTM D2321 and manufacturers recommendations with embedment and backfill details shown on the plans.

8. The minimum cover over all wastewater mains is 4 feet, unless approved by the Town. Approved mains with less than 3.5 feet of cover shall be capped as per details.

9. Clay cut-off walls shall be constructed as per the Wastewater Details.

10. PVC wastewater pipe is allowed to be stored a maximum of six (6) months without cover. Thereafter all pipes should be covered or protected from sunlight and to be protected from other elements.

11. When PVC wastewater pipe is installed in casing, skids must be used to prevent damage to the pipe and bell during installation. PVC pipe should not rest on the Bells. Plastic spacers such as RACI or approved equal shall be used.

12. All property corners shall be staked with iron pins prior to the installation of any wastewater services. The locations of the wastewater service shall be staked according to the plans.

13. Wastewater services to be marked with “S” stamped or cut in the curb.

14. All new manhole locations shall be marked with “MH” stamped or cut on the curb.

15. All wastewater shall be one of the following standard sizes, 8-inch, 10-inch, 12-inch, 15-inch, 18-inch, 21-inch, 24-inch, 30-inch, or 36-inch.

    a. The CONTRACTOR shall be responsible for notifying the Town Inspector at least 24 hours prior to any required testing.

    b. Soil and material testing technicians shall provide written proof of having minimum of two (2) years of related field experience.

    c. The CONTRACTOR shall coordinate all testing activities with the Town Inspector and shall facilitate required testing throughout the construction period. The Inspector shall be present during all testing.

    d. The Town shall make final decision as to the validity of all testing results.

    e. The CONTRACTOR shall be responsible for ensuring that materials to be tested are in compliance with all plans and specifications prior to testing. All materials found not to be in compliance with the plans and specifications before and after testing shall be removed and replaced at the CONTRACTOR’S expense.

    f. All costs associated with the retesting of work that fails to meet the specifications required in the contract documents shall be borne by the CONTRACTOR. For Town projects, retesting cost shall be withheld from pay requests submitted by the CONTRACTOR, this cost will be based on the Town’s cost with no additional mark-up. A letter of acceptance will not be issued until all testing deficiencies are addressed and all related cost paid.

    g. The Town Inspector shall be notified of concrete placement 24 hours in advance for steel and form inspection.

    h. One set of four cylinders (2-7 day, 2-28 day) for cast-in-place concrete shall be made for every day that concrete is placed (ASTM C-31). Air, slump, and temperature tests shall be taken for every set of cylinders made. Concrete with a temperature above 95 degrees will be rejected. Additional cylinders and or tests may be requested at the Inspector or ENGINEER’s discretion. Exterior forms shall not be removed for a minimum of 24 hours unless approved by Inspector or ENGINEER. Sulfate resistant concrete shall be used for all manholes.

    i. Backfill and Density Testing

        1) All trenches shall be backfilled in accordance with standard details and mechanically compacted with approved vibratory methods in accordance with COG Item 504.5.3.2.1 and paragraph 3) below unless otherwise stated on the plans or in the specifications.

2) Densities shall conform to standard trench details, COG Item 504.5.3.2.1, and Paragraph 3) below unless otherwise stated on the plans or in the specifications. Proctor samples shall be taken for all classifications of soil on site. Atterberg Limits shall be determined on all Proctor samples. No "potholing" will be allowed. Densities shall be taken on all sewer services both sides of the street within the Right-of-Way and shall conform to Paragraph 3) below and COG Item 504.5.3.2.1, unless otherwise stated on the plans or in the specifications. Backfill adjacent to all structures shall be compacted manually and density tested on every lift.

3) Mechanical Tamping of Backfill

a) All ditch lines and bore pits shall be mechanically tamped.

b) Backfill, other than select fill, may consist of onsite or offsite inorganic soils and should be placed in loose lifts 6-inches – 8-inches in thickness (not to exceed 12-inches) and should be mechanically compacted to 98 percent of the maximum dry density as defined by ASTM D-698 (Standard Proctor) procedures under existing and proposed pavement, and to 95 percent standard proctor procedures elsewhere. The moisture content of the fill at the time of compaction shall be between minus 2% of optimum to four percentage points above the proctor optimum value.

c) All backfill material to be select native material, 6-inch diameter clods and smaller, unless directed otherwise on the plans or in the specifications and to be mechanically tamped and density controlled as described in Paragraph b) above.

d) Water jetting is not permitted.

e) Densities shall be taken every one (1) lift at staggered locations not to exceed 200 feet increments. Offset fifty (50) feet every other lift.

f) Densities may be taken at typical locations as shown below; also, densities will be taken at random locations and at the geo-technician's discretion.

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  0+00    1+00     2+00 (MAX)
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- (Legend: X denotes densities)

j. Deflection Testing - All sewer lines shall be tested with a mandrel for 5% deflection (max.) in accordance with COG Item 507.5.1.4.1. The Town Inspector must be present.

k. Air Testing - All sewer lines shall be tested by a low pressure air test according to the COG Item 507.5.1.3. The Town Inspector must be present.

l. Television Inspection - All sewer lines shall be televised in accordance with COG Item 507.5.2 and placed on DVD. A copy of the DVD and stationed report shall be submitted to the Town prior to any paving activities so failures may be identified and repaired accordingly (COG Item 507.5.2). All services shall be “panned.”

m. Manhole Testing – Vacuum testing of manholes shall be performed in accordance with COG Item 502.1.5.

n. Deflection Testing, Air Testing, and Television Inspection shall not be performed until all utilities are complete in place and backfilled.

STORM DRAIN GENERAL NOTES

1. All construction shall be in accordance with the standard specifications of the Town of Copper Canyon and the Fourth Edition of the "Standard Specifications for Public Works Construction - North Central Texas" herein referred to as "COG" specifications. Copies may be obtained from the North Central Texas Council of Governments, 616 Six Flags Drive, Suite 200, Arlington, Texas 76005-5888. (817) 640- 3300.

2. Storm drain lines shall be installed per COG Item 508 specifications.

3. Only Reinforced Concrete Pipe (RCP) or Reinforced Concrete Box (RCB) is approved for use in public right-of-way or easement. RCP shall have a minimum class III and for culvert with 2 feet of cover or less, it shall be class IV.

4. For pipes, embedment shall be per the Street Backfill & Repair detail on the Backfill / Embedment Standard Detail. For box culverts, embedment shall be per the Box Culvert Embedment detail on the Backfill / Embedment Standard Detail.

   Note that flowable backfill is only required below pavement repair.

5. The CONTRACTOR shall seal all joints on closed conduits with Omni-Flex joint seals, or equal; unless approved otherwise by the Town.

6. All concrete to be used in pre-cast products for reinforced concrete pipes or boxes shall come from plants certified by the National Pre-cast Concrete Association.

7. The CONTRACTOR shall use only pre-fabricated fittings on new construction projects. Field connections shall be made only to existing pipe with Town approval. The connection shall be a smooth connection and concrete wrapped on the outside and inside.

8. Concrete collars shall be constructed per the Concrete Collar Details on the Headwalls & Pipe Collars Standard Detail at all storm drain size and at grade changes or in curves where the joint is being pulled more than recommended by the manufacturer. Please refer to the details on the Headwalls & Pipe Collars Standard Detail and COG Item 508.3.4.1 specifications.

9. All inlets shall be poured in place. Precast inlets, junction boxes, manholes, and headwalls are not allowed without prior approval from Town Engineer.

10. Bottoms, tops, and variable height curb to be separate pours (3 pours) for curb inlets.

11. Curb inlet bottoms shall be poured prior to any paving.

12. Ring and cover on curb inlets to be located directly over the outlet pipe.

13. Concrete shall be made with a minimum of 5 sacks of cement and have a minimum compressive strength of 3,600 PSI at 28 days.

14. All reinforcing steel shall be new, neat, billet-steel per ASTM designation A-615, Grade 60, and shall be detailed and placed for ACI Manuals SP-88 and 318, latest additions. All reinforcing steel shall have minimum 15 inch lap splices, unless noted otherwise on the plans.

15. The CONTRACTOR shall use a liquid membrane-forming curing compound per COG Item 303.2.13.1.1.

16. All exposed surfaces shall have 3/4 -inch chamfer.

17. All closed conduits shall be Television Inspected.

18. The CONTRACTOR shall be responsible for notifying the Town Inspector at least 24 hours prior to any required testing.

    a. Soil and material testing technicians shall provide written proof of having minimum of two (2) years of related field experience.

    b. The CONTRACTOR shall coordinate all testing activities with the Town Inspector and shall facilitate required testing throughout the construction period. The Inspector shall be present during all testing.

    c. The Town shall make final decision as to the validity of all testing results.

    d. The CONTRACTOR shall be responsible for ensuring that materials to be tested are in compliance with all plans and specifications prior to testing. All materials found not to be in compliance with the plans and specifications before and after testing shall be removed and replaced at the CONTRACTOR'S expense.

    e. All costs associated with the retesting of work that fails to meet the specifications required in the contract documents shall be borne by the CONTRACTOR. For Town projects, retesting cost shall be withheld from pay requests submitted by the CONTRACTOR, this cost will be based on the Town's cost with no additional mark-up. A letter of acceptance will not be issued until all testing deficiencies are addressed and all related cost paid.

    f. The Town Inspector shall be notified of concrete placement 24 hours in advance for steel and form inspection.

    g. One set of four cylinders (2-7 day, 2-28 day) for cast-in-place concrete shall be made for every day that concrete is placed (ASTM C-31). Air, slump, and temperature tests shall be taken for every set of cylinders made. Concrete with a temperature above 95 degrees will be rejected. Additional cylinders and or tests may be requested at the Inspector or ENGINEER's discretion. Exterior forms shall not be removed for a minimum of 24 hours unless approved by Inspector or ENGINEER. Sulfate resistant concrete shall be used for all manholes.

    h. Backfill and Density Testing

        1) All trenches shall be backfilled in accordance with standard details and mechanically compacted with approved vibratory methods in accordance with COG Item 504.5.3.2.1 and paragraph 3) below unless otherwise stated on the plans or in the specifications.

2) Densities shall conform to standard trench details, COG Item 504.5.3.2.1, and Paragraph 3) below unless otherwise stated on the plans or in the specifications. Proctor samples shall be taken for all classifications of soil on site. Atterberg Limits shall be determined on all Proctor samples. No "potholing" will be allowed. Densities shall be taken on all storm drain laterals within the Right-of-Way and shall conform to Paragraph 3) below and COG Item 504.5.3.2.1, unless otherwise stated on the plans or in the specifications. Backfill adjacent to all structures shall be compacted manually and density tested on every lift.

3) Mechanical Tamping of Backfill

   a) All ditch lines and bore pits shall be mechanically tamped.

   b) Backfill, other than select fill, may consist of onsite or offsite inorganic soils and should be placed in loose lifts 6-inches – 8-inches in thickness (not to exceed 12-inches) and should be mechanically compacted to 98 percent of the maximum dry density as defined by ASTM D-698 (Standard Proctor) procedures under existing and proposed pavement, and to 95 percent standard proctor procedures elsewhere. The moisture content of the fill at the time of compaction shall be between minus 2% of optimum to four percentage points above the proctor optimum value.

   c) All backfill material to be select native material, 6" diameter clods and smaller, unless directed otherwise on the plans or in the specifications and to be mechanically tamped and density controlled as described in Paragraph b) above.

   d) Water jetting is not permitted.

   e) Densities shall be taken every one (1) lift at staggered locations not to exceed 200 feet increments. Offset fifty (50') feet every other lift.

   f) Densities may be taken at typical locations as shown below; also, densities will be taken at random locations and at the geotechnician's discretion.

```
0+00    0+50     2+00 (MAX)
  x- - - - - - - - - - --x- - - - - - - - - - -x- - - - - - - - - - - x
  ¦          ¦          ¦          ¦          ¦          ¦          ¦
  ¦- - - -- x - - - - - - - - - - --x - - - - -- - - - - - x - - - - -¦
  ¦          ¦          ¦          ¦          ¦          ¦          ¦
  x- - - - - - - - - - --x- - - - - - - - - - -x- - - - - - - - - - - x
  ¦          ¦          ¦  FILL¦AREA  ¦          ¦          ¦
  ¦- - - --x - - - - - - - - - -  x - - - - -- - - - - - x - - - - -¦
  ¦          ¦          ¦          ¦          ¦          ¦          ¦
  x- - - - - - - - - - --x- - - - - - - - - -  x- - - - - - - - - - - x
  ¦          ¦          ¦          ¦          ¦          ¦          ¦
  ¦- - - --x - - - - - - - - - -  x - - - - -- - - - - - x - - - - -¦
             - (Legend: X denotes densities)
```

PRIVATE DEVELOPMENT GENERAL NOTES

1. All work shall be done in accordance with the Town of Copper Canyon standard details and specifications which has adopted the North Central Texas Council of Governments (N.C.T.C.O.G.) "STANDARD SPECIFICATIONS FOR PUBLIC WORKS CONSTRUCTION", Fourth Edition and Addenda. Copies may be obtained from the "NORTH CENTRAL COUNCIL OF GOVERNMENTS", PO Drawer 5888, Arlington, Texas, 76005-5888, Phone (817) 640-3300; also available at www.publicworks.dfwinfo.com A copy of the contract documents, plans and specifications shall be available on-site at all times by the Contractor.

2. The location and depth of all utilities shown on the plans are approximate and there may be other unknown existing utilities not shown on the plans. All existing utilities shall be field verified and protected by the Contractor prior to the start of construction. Also see **General Note No. 3(D)**. The contractor shall contact the following utility companies 72 hours prior to doing any work in the area:

Utility	Contact – Job Title	Phone Number
Coserv Electric	Jody Padron – Electric Engineering	(940) 321-7800
Atmos Energy	Jeff Wylie –Project Manager	(817) 303-2905
Verizon	Larry Guay – Obligatory Planner/Engineer	(940) 213-3606
Grande Comm.	Ike Butler - Project Manager	(972) 410-0584
Bartonville Water	Jim Leggieri –Manager	(817) 430-3541
Explorer Pipeline	Patrick Nwakoby – Manager	(817) 267-3242
Brazos Electric	Dane Harrison – Operations Manager	(254) 750-6300

3. It shall be the responsibility of the Contractor to perform the following:

   a. Prevent any property damage to property owner's poles, fences, shrubs, mailboxes, etc.
   b. Provide access to all drives during construction.
   c. Protect all underground and overhead utilities and repair any damages. Also see **General Note No. 2.**
   d. Notify all Utility Companies and verify location of all utilities prior to the start of construction.
   e. Cooperate with the Utility Companies where utilities are required or specified to be relocated.
   f. Work in close proximity to and protect existing Utility Mains, traffic lights and poles.
   g. Any item not specifically called out to be removed shall be brought to the attention of the Engineer prior to removing that item or it shall be replaced at the Contractor's own expense.
   h. Any tree, shrub, or grassed areas damaged by the Contractor's work shall be repaired at the Contractor's expense.

4. In the preparation of the plans and specifications, the Engineer has endeavored to indicate the location of existing underground utilities. It is not guaranteed that all lines or structures have been shown on the plans.

5. The Contractor shall verify, locate, and protect existing water, sanitary sewer, storm sewer, gas, electric, telephone mains and services and restore service in case of any damage.

6. The Contractor shall provide proper barricades and maintain traffic flow as per Manual on Uniform Traffic Control Devices (MUTCD) at all times.

7. The location for the disposal of construction material shall be approved by the Town of Copper Canyon prior to the start of construction.

8. All phases of construction must be coordinated with the Engineer. Also, the Contractor is required to coordinate with the property owners in order to minimize conflicts.

9. Field adjustments may be necessary and will be carried out as directed by the Engineer.

10. The Contractor shall contact the Town of Copper Canyon prior to any sign removal. Please See General Note No. 3. Sign removal and reinstallation/relocation shall be in good condition equal to or better than existing condition, and as per the Engineer's specifications.

11. All fences, signs, and property corner monuments removed for, or damaged during construction shall be replaced with new material as per the Engineer's specifications.

12. The Contractor shall relocate existing mailboxes in conflict with the proposed improvements and as specified on the plans, in good condition equal to or better than existing condition, complete in place. The mailboxes shall be accessible at all times for mail delivery.

13. The Contractor shall be responsible for taking all precautions to protect existing trees outside the scope of this Project.

14. The Contractor shall be responsible for repairing any damage caused by the Contractor outside of the designated work area with new quality material at the Contractor's expense.

15. The Contractor shall locate, verify working condition and protect all existing sprinkler systems lines and heads (if any). Remove, adjust and reinstall in good condition equal to or better than existing condition; replace, if in direct conflict, with the same or better quality material and appurtenances.

16. All existing grades shown on the plans are approximate and shown based on the best information available.

17. All backfill for ditch lines are to be mechanically tamped to 95% STD Proctor density (ASTM D698), at a moisture content near optimum (-1% to +3%).

18. Contractor to fill all voids under existing pavement when installing new line. Also all ditch lines must be filled at the end of each day’s work.

19. All pipe shall be kept free of trash and dirt at all time. At the end of each day, the pipe shall be temporarily connected/sealed.

20. The Contractor shall keep the existing fire hydrants in service at all times.

21. The Contractor shall maintain the existing water mains in service during all phases of construction. Leaks caused by the Contractor shall be repaired immediately at the Contractor's

expense. Contractor shall coordination with Bartonville Water Supply Corp. for leaks along the existing water main close to the working area, caused by vibration, etc. The Bartonville Water Supply Corp may repair all leaks if the Contractor is not on the job-site; if the leak is directly caused by the Contractor and not repaired, all charges incurred shall be billed to the Contractor.

22. All cutting and plugging of the existing water main where specified on the plans, shall include all labor, fittings and appurtenances required to perform this work. The cost for this work is incidental to the project.

23. The Contractor shall maintain the existing sanitary sewer mains and services in operation when installing the proposed sanitary sewer main. This shall include any temporary connections, if required.

24. Clearances on water and wastewater lines shall meet Texas Commission on Environmental Quality (TCEQ) requirements. Minimum clearances for water and wastewater lines **crossing** each other storm drains shall be two (2) feet or one-half (0.5) feet when the water or wastewater line is concrete encased. When running in **parallel**, water and wastewater lines shall be no closer than 9' from the outside edge of each pipe.

25. Street closing requests shall be submitted to the Town of Copper Canyon in writing, a minimum of two weeks in advance of any street closing for notifications to Police, Fire, Mail, Garbage and School. There are no guarantees that street closings will be approved by the Town.

26. Seed/sod shall be furnished to establish ground cover over all disturbed areas as an erosion control measure. The Contractor shall not wait until the completion of the entire project before doing this work. The project shall not be accepted by the Town prior to the establishment of ground cover.

27. Sheeting, shoring, and bracing: The contractor will abide by all applicable federal, state, and local laws governing excavation, Trench's side slopes shall meet Occupational Safety and Health Administration (OSHA) standards that are in effect at the time of construction. Sheeting shoring and bracing shall be required if side slope standards are not met. A pull box, meeting OSHA standards, will be acceptable. The Contractor will submit detailed plans and specifications for trench safety systems that meet OSHA standards that are in effect at the time of development of project when trench excavation will exceed a depth of five (5) feet. These plans will be sealed by an Engineer registered by the State of Texas and submitted to the Town before obtaining a construction permit.

28. Contractor shall conform activities to the SWPPP as specified, including installing, maintaining, and removing pollution controls, conducting and documenting inspections of pollution controls, sprinkling for dust control, maintaining spill response equipment on-site, and "good housekeeping". Pollution controls include silt fences, stabilized construction entrance, establishing grass, sprinkling for dust control. The Contractor shall also be responsible for submitting Notice of Intent (NOI) and Notice of Termination (NOT) to the Texas Commission on Environmental Quality (TCEQ).

29. The Contractor shall maintain the existing water mains and services in operation when installing the proposed water main. This shall include any temporary connections, if required in areas of conflict.

30. Contractor must notify each property owner 24 hours prior to shutting off water for connection to new main.

31. The Contractor shall contact the Bartonville Water Supply Corp. at (817) 430-3541 for the operation of all water valves.

32. The cost of replacing all pavement markers, traffic buttons, striping, etc., disturbed during the construction shall be Contractor's responsibility to maintain, repair or replace.

33. The Contractor shall maintain the flow of traffic at all times and provide access to all drives.

34. The maximum deflection of pipe joints shall not exceed that recommended by the pipe manufacturer. If it is necessary to deflect the pipe (greater that the recommended amount) the Contractor shall provide fittings or specials.

35. The Contractor shall notify the Town and Bartonville Water Supply Corp. for inspection 48 hours in advance for all water locates or turnoffs of water.

36. The Contractor shall notify the Town and wastewater collection provider (i.e. Town of Flower Mound, Upper Trinity, Highland Village) for inspection 48 hours in advance for all wastewater locates.

37. Prior to the start of construction, Inspection, Water/Wastewater and the Contractor shall make a dry run to the system to insure, to the extent possible, that the utility can be found and secured.

38. Work may not be backfilled until it has been inspected by the Town and water and sewer collection agencies.

Appendix B

Miscellaneous Federal, State & Regional Initiatives

APPENDIX

B

FEDERAL, STATE & REGIONAL INITIATIVES

Table of Contents

List of Tables

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B.1 Overview

As a result of the need to address the potential negative impacts of development and storm water runoff, numerous federal, state, and regional programs and regulations have been created to deal with the problems of urban runoff and nonpoint source pollution. It is at the local level, however, where a storm water management program is best implemented, due to the fact that local communities can influence land use and development related decisions. Federal and state legislation greatly influence and support local governments in their efforts to manage storm water runoff in their communities.

It is the intent of this Storm Water Management Design Manual to complement the federal, state, and regional initiatives in an integrated partnership approach to storm water management.

The purpose of this section is to provide a brief overview of many of the regional, state, and federal laws, regulations, and programs that are required of local government entities in the North Central Texas region that may impact local storm water management programs and activities. The initiatives are summarized in Table B.2-1 as a general guide for developers and communities indicating areas where federal, state, or regional initiatives may affect their project.

As this is not intended to be a detailed analysis of each requirement, it would be advisable to obtain a copy of the specific administrative rules for each program from the appropriate regulatory agency.

B.2 Federal Initiatives

B.2.1 National Flood Insurance Program

Established under the National Flood Insurance Act of 1968 and broadened with the passage of the Flood Disaster Protection Act of 1973, the National Flood Insurance Program (NFIP) provides federally supported flood insurance to residents in communities that voluntarily adopt and enforce regulations to reduce future flood damage. As part of the program, the Federal Emergency Management Agency (FEMA) defines minimum standards for floodplain development that the local communities must adopt to be eligible for program benefits. New construction and substantial improvements must be built at or above the base flood elevation, which is the computed elevation of the “100 year flood”. Also, new development that would result in an increase in flood heights is prohibited in the defined floodways. More information on the NFIP and floodplain management in general is available from the FEMA – Region VI office in Denton, TX.

Contact Agency	Phone	Address
Federal Emergency Management Agency (FEMA) Region VI	940-898-5399	800 N. Loop 288 Denton, TX 76209

Website: http://www.fema.gov/regions/vi/index.shtm

B.2.2 U.S. Army Corps of Engineers Regulatory Program

The U.S. Army Corps of Engineers (USACE) Regulatory Program implements Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899, through regulations that serve to protect the Nation’s valuable aquatic resources.

Under Section 404 of the Clean Water Act, permits are required for the discharge of dredged or fill material into waters of the United States (U.S.). Waters of the U.S. include all surface waters, such as coastal and navigable inland waters, lakes, rivers, streams, and their tributaries; interstate waters and their tributaries; wetlands adjacent to the above (e.g. swamps, marshes, bogs, or other land areas); and isolated wetlands and lakes, intermittent streams, and other waters where degradation could affect interstate commerce. The TCEQ is responsible for conducting water quality certification reviews for 404 permits in Texas. The certification reviews are required by Section 401 of the Clean Water Act. The goal of these certification reviews is to determine whether a proposed discharge will comply with state water quality standards. The Railroad Commission of Texas is the certifying agency in Texas for projects associated with oil and gas.

Under Section 10 of the Rivers and Harbors Act of 1899, the Corps regulates all work and structures in or affecting the course, condition, or capacity of navigable waters of the U.S. Navigable waters of the U.S. are those waters that are subject to the ebb and flow of the tide shoreward to the mean high water mark and/or are presently used, have been used in the past, or may be susceptible to use in the transport of interstate or foreign commerce.

Contact Agency	Phone	Address
Texas Commission on Environmental Quality	512-239-0400	MC 174 P.O. Box 13087, Austin, TX 78711-3087
US Army Corps of Engineers, Fort Worth District (for North Area of State)	817-886-1731	CESWF-PER-R 819 Taylor St P.O. Box 17300 Fort Worth, TX 76102-0300

Website: www.tceq.state.tx.us and http://www.swf.usace.army.mil

B.2.3 National Environmental Policy Act, Council on Environmental Quality

Congress established the Council on Environmental Quality within the Executive Office of the President as part of the National Environmental Policy Act of 1969 (NEPA). NEPA establishes the Federal government's environmental policy to help public officials make decisions based on an understanding of the environmental consequences of their actions, and to take actions that protect, restore, and enhance the environment. To accomplish this, NEPA requires Federal agencies to either prepare or have prepared written assessments of statements that describe the:

- Affected environment and environmental consequences of a proposed project;
- Reasonable or practical alternatives to the proposed project; and
- Any mitigation measures necessary to avoid or minimize adverse environmental effects.

If a project is either directly or indirectly funded by a federal source, then the agency providing funds to the project owner is responsible for seeing that the appropriate level of environmental assessment is performed.

B.2.4 Wildlife and Habitat

The mission of the U.S. Fish and Wildlife Service (USFWS) is to conserve, protect, and enhance fish and wildlife, and their habitats for the continuing benefit of the American people. USFWS activities include, but are not limited to enforcing the federal Endangered Species Act (ESA); acquiring wetlands, fishery habitats, and other lands for restoration and preservation; insuring compliance with the National Environmental Policy Act (NEPA); managing National Wildlife Refuges and National Fish Hatcheries; and reviewing and commenting on all water resource projects.

Table B.2-1 Federal, State and Regional Initiative Indicators

Indicator Questions	Potentially Applicable Initiative(s)
Are **Federal funds** to be used? Is a **Federal Action Permit** required?	**National Environmental Policy Act, Council on Environmental Quality** (Section B.2.3) **Federal Agency with Action**
Are **structures** or **manmade features** to be disturbed?	**Texas Historical Commission** (Section B.3.11)
Is this a **construction** project with land disturbing activity?	**TPDES Storm Water Permits for Construction Activities** (Section B.3.2)
Is there new **landscaping** and/or **erosion potential**?	**Local Ordinances**
Will storm water **discharge to an MS4**?	**TPDES MS4 Storm Water Permit Program (Phase I and II)** (Section B.3.1)
Is this an **industrial** facility?	**TPDES Industrial Storm Water Permit Program** (Section B.3.3)
Is there a **wastewater** discharge?	**TPDES Wastewater Discharge Permit Program** (Section B.3.4)
Is there a nearby **public water supply**?	**Source Water Assessment Program** (Section B.3.8)
Are there nearby **groundwater** usages?	**Texas Groundwater Protection Committee Local Groundwater District** (Section B.3.9)
Are there adjacent or nearby **surface water features** or **wetlands** that may be affected?	**U.S. Army Corps of Engineers Regulatory Program** (Section B.2.2) **Texas Railroad Commission** (Section B.2.2) **Water Quality Management Plan – TCEQ** (Section B.3.5) **Surface Water Quality Standards – TCEQ** (Section B.3.6) **Total Maximum Daily Load Program – TCEQ** (Section B.3.7) **Texas General Land Office** (Section B.3.12)
Will there be **dredging**?	**U.S. Army Corps of Engineers Regulatory Program** (Section B.2.2) **Sand, Gravel, Shell, and Marl Protection – TCEQ** (Section B.3.13) **Texas Parks and Wildlife Department** (Section B.3.14)
Will a **dam** be constructed or modified?	**U.S. Army Corps of Engineers Regulatory Program** (Section B.2.2) **Dam Safety Program – TCEQ** (Section B.3.10)
Is the project in a **floodplain**?	**National Flood Insurance Program** (Section B.2.1) **Hazard Mitigation Action Planning** (Section B.4.2)
Are there potential impacts on **fish, wildlife,** or **habitats**?	**Texas Parks and Wildlife Department** (Section B.3.14) **U.S. Fish and Wildlife Service** (Section B.2.4)

B.3 State of Texas Initiatives

B.3.1 TPDES MS4 Storm Water Permit Program (Phase I and II)

The National Pollutant Discharge Elimination System (NPDES) permit system was originally established by the Clean Water Act of 1972 to control wastewater discharges from various industries and wastewater treatment plants known as “point” sources. Congress amended the Clean Water Act with the Water Quality Act of 1987 to expand the NPDES permit program to address “nonpoint” source pollution through schedules for permitting municipal storm water discharges. The Municipal Separate Storm Sewer System (MS4) storm water discharge permit establishes requirements for municipalities to minimize pollutants in storm water runoff to the “maximum extent practicable.”

In Texas, the Texas Commission on Environmental Quality (TCEQ) has authority to administer the NPDES program (TPDES – Texas Pollutant Discharge Elimination System). Under the TCEQ’s Municipal Separate Storm Sewer System (MS4) permit program, local governments and public entities in regulated areas are required to establish and implement a comprehensive Storm Water Management Program (SWMP) to control potential pollutants in storm water runoff discharging to Waters in the State to the maximum extent practicable and to eliminate non-storm water discharges entering the storm water system.

Contact Agency	Phone	Address
TCEQ – Storm Water and General Permits Team	512-239-4527	MC 148 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tceq.state.tx.us and www.dfwstormwater.com

This is accomplished by a municipal program which includes the implementation of structural and non-structural storm water measures to protect storm water quality. These measures are called best management practices (BMP’s). BMP’s include public education and public involvement activities, ordinance or other enforcement mechanisms, inspections and enforcement, employee training, and structural controls. Storm water management ordinances, erosion and sediment control ordinances, development regulations, and other local regulations provide enforcement authority and criteria for controlling significant components of the Storm Water Management Program.

Since 1993, the Phase I permit requirements have applied in Texas to large and medium municipal separate storm sewer systems (defined by a population greater than 250,000 and population between 100,000 and 250,000, respectively, based on the 1990 census, or those areas contributing to water quality violations). In Texas, 22 entities are in the Phase I program, NOT including the Town of Copper Canyon.

Federal regulations were issued in 1999 to extend the NPDES MS4 permit program to smaller (Phase II) communities. Based on 2010 Census, Copper Canyon will be included URBAN AREA and will be included in the 2013 NPDES MS4 permit. In Texas, the TCEQ administers this permit program. The Phase II rules take a slightly different approach than Phase I rules for the implementation of local storm water management programs. Unlike Phase I communities that were required to develop detailed individual permits, each Phase II community that is the operator of a municipal storm sewer system will be required to develop a storm water management program (SWMP) to protect water quality. The SWMP will be required to either meet the conditions of a general permit or an individual permit authorized by the TCEQ.

Under the TCEQ Phase II MS4 general permit (General Permit No. TXR040000), regulated entities are required to develop and submit to the TCEQ a plan for their SWMP within 180 days from the date the permit is issued. Additional communities may be added to the Phase II program if the TCEQ determines that storm water in the community is adversely impacting the quality of receiving waters such as streams, lakes, and estuaries. Communities added to the program by the TCEQ will have 180 days from the date of notification to develop and submit a plan for their SWMP.

The U.S. EPA and TCEQ established six elements, termed “minimum control measures,” that each Phase II SWMP must address. The TCEQ has added an optional seventh minimum control measure. Each of the control measures is listed below:

1. Public Education and Outreach
2. Public Participation / Involvement
3. Illicit Discharge Detection and Elimination
4. Construction Site Runoff Control
5. Post-Construction Runoff Control
6. Pollution Prevention / Good Housekeeping
7. Municipal Construction Activity

The seventh optional minimum control measure allows regulated communities the option of including municipal construction activity in the MS4 general permit instead of having to obtain a permit for each construction site over five acres. The goal of this option is to reduce paperwork for regulated communities with numerous construction projects.

Each Phase II MS4 community is required to develop and submit a plan for their SWMP to the TCEQ. In the plan, the regulated community must identify its selection of BMP’s for each required minimum control measure. Additionally, measurable goals to track the implementation progress and success of each BMP must be identified, and a timeline is required for the implementation of the BMP’s over the five-year permit term.

B.3.2 TPDES Storm Water Permits for Construction Activities

The TPDES storm water permit for construction activities is directed toward controlling the quality of storm water runoff from construction activities. The permit requires the development of a construction Storm Water Pollution Prevention Plan (SWPPP) that emphasizes the application of BMP’s to protect storm water quality from erosion and sedimentation processes, as well as construction materials and wastes, during the construction phase of development. In Texas, this program which became effective March 5, 2008, is managed by TCEQ.

Operators of construction sites five acres or greater are required to obtain storm water permits from the TCEQ by developing a SWPPP and filing a Notice of Intent (NOI) 48 hours prior to initiating construction activities.

Construction sites one to five acres in size require a SWPPP to be developed, but an NOI is not required to be submitted to the TCEQ. Construction sites that are part of a larger common plan of development, such as a subdivision, that is collectively greater than one or five acres, must be evaluated according to the size of the larger common plan of development when considering permit requirements. For example, a person constructing on a ¼-acre site located within a 10-acre subdivision under construction would be required to comply with the permit requirements for sites disturbing 5 acres or more.

If storm water runoff from the construction site enters a municipal storm sewer system, the construction site operator and/or owner is also required to notify the MS4 operator about the construction activity. For large construction sites, submitting a copy of the NOI to the MS4 operator is required, and for small construction sites, a copy of the Construction Site Notice is required. Local ordinances should be checked for additional requirements. For example, in some communities the SWPPP must also be submitted to the MS4 operator.

Construction site operators on sites with an NOI are further required to submit a Notice of Termination (NOT) to TCEQ when final stabilization has been achieved on all portions of the site under their control. Refer to TPDES General Permit TXR150000 for specific permit requirements.

B.3.3 Industrial TPDES Storm Water Permit Program

The TPDES program also requires that the discharge of storm water from certain types of industrial facilities be regulated under a permit program. Industrial storm water is defined as that discharged from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing, or materials storage areas. Discharge of storm water from regulated industrial facilities in Texas is managed by the TCEQ under a single general permit issued in 2001.

Currently, the following thirty categories of industrial facilities identified in the Multi-Sector General Permit are required to have an NPDES permit for their storm water discharge:

- Timber Products
- Paper and Allied Products
- Chemical and Allied Products
- Asphalt Paving and Roofing Materials and Lubricants
- Glass, Clay, Cement, Concrete, and Gypsum Products
- Primary Metals
- Metal Mining (Ore Mining and Dressing)
- Coal Mines and Coal Mining Related Facilities
- Oil and Gas Extraction
- Mineral Mining and Dressing
- Hazardous Waste Storage Facilities
- Landfills and Land Application Sites
- Automobile Salvage Yards
- Scrap Recycling Facilities
- Steam Electric Generating Facilities
- Land Transportation and Warehousing
- Water Transportation
- Ship and Boat Building or Repairing Yards
- Air Transportation
- Treatment Works
- Food and Kindred Products
- Textile Mills, Apparel, and Other Fabric Product Manufacturing, Leather and Leather Products
- Furniture and Fixtures
- Printing and Publishing
- Rubber, Miscellaneous Plastic Products, and Miscellaneous Manufacturing Industries
- Leather Tanning and Finishing
- Fabricated Metal Products
- Transportation Equipment, Industrial or Commercial Machinery
- Electronic, Electrical, Photographic, and Optical Goods
- Miscellaneous Industrial Activities

Regulated industrial facilities are required to develop a storm water pollution prevention plan (SWPPP) and submit a Notice of Intent (NOI) for permit coverage to the TCEQ. Components of the SWPPP include identification and elimination of potential sources of storm water contamination, storm water monitoring at each storm water outfall, employee training, and other storm water protection activities. New industrial facilities are required to submit an NOI 48 hours prior to conducting any new activity.

B.3.4 TPDES Wastewater Discharge Permit Program

Municipalities, communities, and industrial facilities are required to obtain an NPDES permit to discharge wastewater to waters of the U.S. These point source discharges have been regulated by the EPA for more than 30 years. The TCEQ administers the wastewater discharge permit program in Texas. Permit effluent limitations are developed based on the quality of the receiving water. More stringent limitations are placed on discharges to waters listed on the 303(d) list of impaired waters. As part of the permitting process, applicants are required to characterize the quality of the proposed effluent, evaluate the conditions of the receiving water, identify nearby water supply intakes, and conduct other activities to document the continued protection of water quality.

Contact Agency	Phone	Address
TCEQ – Wastewater Permitting Section	512-239-4433	MC 148 P.O. Box 13087 Austin, TX 789711-3087

Website: www.tceq.state.tx.us and www.tnrcc.state.tx.us/water/quality/tmdl/index.html

B.3.5 Water Quality Management Plan

The Water Quality Management Plan (WQMP) for Texas is developed and updated by the TCEQ as part of the requirements of the Clean Water Act. The plan provides long-range planning and technical data for water quality management activities required under the Texas Water Code and the Clean Water Act. Projected effluent limitations for dischargers are based on the recommendations in the WQMP. The Texas State Soil and Water Conservation Board (TSSWCB) is responsible for addressing water quality issues from nonpoint source pollution from agricultural and silvicultural activities. All new and amended permits are reviewed by the TCEQ for conformance with the recommendations of the WQMP. The plan is updated on a quarterly basis by the State.

For Copper Canyon, the North Central Texas Council of Governments (NCTCOG) is the designated water quality management planning agency. Under guidance of its Environmental Planning Department, NCTCOG annually updates the plan and submits amendments to the TCEQ for certification.

Contact Agency	Phone	Address
TCEQ – Office of Environmental Policy, Analysis, and Assessment	817-239-4900	MC 147 P.O. Box 13087, Austin, TX 789711-3087
TSSWCB – Technical Assistance	254-773-2250	Temple, TX 76501
NCTCOG – Regional Plan	(817) 640-3300	616 Six Flags Drive P.O. Box 5888 Arlington, TX 76005-5888

Website: www.tceq.state.tx.us and www.dfwstormwater.com

B.3.6 Surface Water Quality Standards

The TCEQ sets surface water quality standards in an effort to maintain the quality of water in the state consistent with public health and enjoyment, protection of aquatic life, operation of existing industries, and economic development of the state, as well as to encourage and promote development and use of regional and area-wide wastewater collection, treatment, and disposal systems. Standards are implemented primarily through effluent limits established in permits that allow discharges of wastewater into the surface waters of the state. Currently, the State of Texas has no numerical criteria for nutrients in the Texas Surface Water Quality Standards (TSWQS). The EPA is requiring states to develop nutrient criteria. The TCEQ is currently developing and evaluating criteria to address nutrients and eutrophication.

Contact Agency	Phone	Address
TCEQ – Water Quality Assessment Section	817-239-4576	MC 150 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tceq.state.tx.us

B.3.7 Total Maximum Daily Load (TMDL) Program

Under Section 303(d) of the Clean Water Act, the State of Texas is required to develop a list of impaired waters that do not meet water quality standards. The TCEQ must then establish priority rankings for waters on the list and develop Total Maximum Daily Loads (TMDL's) for listed waters. The TMDL specifies the maximum amount of a specific pollutant of concern that a designated segment of a water body can receive and still meet water quality standards. The TMDL also allocates pollutant loadings among point and nonpoint pollutant sources, including storm water runoff. If a TMDL has been established for a water body, the impact of new point and nonpoint sources must be assessed prior to TCEQ approval of new or amended discharge or storm water permits.

For each pollutant identified, a TMDL implementation plan must be developed. The implementation plans must identify the sources of the pollutant and provide a list of actions or management measures needed to reduce the pollutant, a schedule for implementing controls or measures, milestones for implementation, and a monitoring program to measure progress. Controls and management measures need to be in place five years after the plan is developed.

The TMDL program has a broad impact on local storm water management programs because nonpoint sources of pollutants must be addressed at the local level. Currently, the EPA TMDL requirements have been withdrawn and are under evaluation by EPA to determine whether and how the TMDL program can best be implemented to achieve the goals of the Clean Water Act. TMDL's have not been established for Denton County and the Town of Copper Canyon.

Contact Agency	Phone	Address
U.S. EPA – Region 6	214- 665-6444	1445 Ross Avenue, Suite 1200 Dallas, TX 75202 (214) 665-6444
TCEQ – TMDL Section	817-239-4300	MC 150 P.O. Box 13087, Austin, TX 789711-3087

Website: http://www.epa.gov/region6/index.htm and http://www.tceq.state.tx.us

B.3.8 Source Water Assessment Program (SWAP)

The 1996 amendments to the Federal Safe Drinking Water Act brought about a new approach for ensuring clean and safe drinking water served by public water supplies known as the Source Water Assessment Program. The U.S. EPA is advocating prevention as an important tool in the protection of public drinking water sources from contamination. In order to implement source protection, an assessment of potential pollutant sources in water supply watersheds must be conducted. The goals of this assessment will be reached through implementation of a four-step method which includes watershed delineation, inventory of potential pollutant sources within the watershed, analysis of susceptibility of a water intake to the pollutant sources, and communication of this information to the public.

As many pollutants can enter waterways and reservoirs through storm water drainage systems, the SWAP efforts will provide an informational resource to local storm water pollution prevention and mitigation programs. Future water supply protection efforts to control the identified pollution sources should be coordinated with and included as part of a local storm water program.

The TCEQ's Source Water Assessment Program consists of source water protection, source water assessments, and vulnerability assessments. The Source Water Protection (SWP) program is a voluntary program that public water supply systems participate in to prevent pollution from entering surface or ground water supplies. It was created by the 1996 Amendments to the Safe Drinking Water Act and is an expansion of the Wellhead Protection (WHP) program, which protects public water supplies that use groundwater. Source water assessments and vulnerability assessments are conducted to evaluate a public water supply systems susceptibility to a wide range of contaminants.

Contact Agency	Phone	Address
TCEQ – Public Drinking Water Section	512-239-4782	MC 155 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tceq.state.tx.us

B.3.9 Texas Groundwater Protection Committee

The Texas legislature established the Texas Groundwater Protection Committee (TGPC) in 1989 with a specific charge to "*. . . develop and update a comprehensive groundwater protection strategy for the state that provides guidelines for the prevention of contamination and for the conservation of groundwater and that provides for the coordination of the groundwater protection activities of the agencies represented on the committee...* (Water Code Section 26.405(2)).*"* The TGPC first established a groundwater protection strategy in 1988 and recently updated the strategy (February 2003). Implementation of the strategy is primarily through local groundwater districts, but may also be conducted through River Authorities and Regional Water Planning Groups, City ordinances, or County on-site treatment regulatory programs.

Contact Agency	Phone	Address
TCEQ – Texas Groundwater Protection Committee	512-239-4506	MC 197 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tgpc.state.tx.us

B.3.10 Dams and Reservoirs in Texas

The Texas Commission on Environmental Quality (TCEQ) regulates the construction of dams in Texas. More information on dams and reservoirs can be found in Appendix F and on-line at www.tnrcc.state.tx.us/enforcement/dam_safety/intro2.html.

The U.S. Army Corps of Engineers Regulatory Program implements Section 9 of the Rivers and Harbors Act of 1899. Under Section 9, permits are required for the construction of dams and dikes in navigable waters of the U.S. See www.swf.usace.army.mil/pubdata/environ/regulatory/jurisdiction/navlist.pdf for a list of navigable waters of the U.S. for the Fort Worth, Tulsa, and Albuquerque Districts within the State of Texas.

B.3.11 Texas Historical Commission

The Texas Historical Commission (THC) is the state agency for historic preservation. THC staff consults with citizens and organizations to preserve Texas' architectural, archeological, and cultural landmarks. The agency maintains the *Texas Historic Atlas*, a directory of historic site records, including data on Texas Historical Markers and National Register of Historic Places in Texas. Projects that include the disturbance of existing features such as buildings or other manmade structures should include a search of the THC database to screen for potential historic significance. Projects that include ground disturbance, such as new construction or pipeline installation, should include an assessment of the potential for disturbance of archeological or other culturally significant sites. The contact information for the THC is below.

Contact Agency	Phone	Address
Texas Historical Commission	512-463-6100	P.O. Box 12276 Austin, TX 78711-2276

Website: http://www.thc.state.tx.us

B.3.12 Texas General Land Office

A General Land Office (GLO) easement may be required if the project crosses or disturbs any state-owned streambeds. The ownership of any stream is determined on a case-by-case basis by the GLO.

Contact Agency	Phone	Address
Texas General Land Office	1-800-998-4456 *or* 512-463-5001	1700 N. Congress Ave. Suite 840 Austin, TX 78701-1495

Website: http://www.glo.state.tx.us

B.3.13 Sand, Gravel, Shell, and Marl Protection

The Texas Parks and Wildlife Department (TPWD) requires a permit for a project if it "disturbs or takes" streambed materials from a streambed claimed by the State. If the stream is perennial (flows most of the time), or is more than 30 feet wide between the banks (even if it is dry most of the time), the State might claim the bed and the sand and gravel in it as State-owned.

An application must be filed with the TPWD including information on the size of the stream; the nature of the banks and the bed of the stream; the amount of material requested; the adjacent landowners; and the probable effects on the stream and its other users. The TPWD evaluates the probable impacts of the activity, and grants a permit if no significant damage is anticipated. Payment is required for any material removed, in addition to the application fee. A hearing may be required before deciding whether to issue the permit.

B.3.14 Wildlife and Habitat

The Texas Parks and Wildlife Department (TPWD) Resource Protection Division is charged with protecting the state's fish, wildlife, plant, and mineral resources from degradation or depletion. The TPWD investigates environmental contamination events that may result in impacts to fish or wildlife. The agency also provides information and recommendations to other government agencies and participates in administrative and judicial proceedings concerning pollution incidents, development projects, and other actions that may affect fish and wildlife. The Department investigates fish kills, and when responsibility for fish kills can be traced, the agency recovers from the responsible party the economic value of the fish and other lost aquatic life, which by law are state properties. As a state natural resource trustee, the TPWD assesses damages to fish and wildlife resources from oil and hazardous chemical releases and seeks restoration of these resources from the responsible party.

B.4 Regional Initiatives

The ATCOG is a voluntary association of, by, and for local governments, and was established to assist local governments in planning for common needs, cooperating for mutual benefit, and coordinating for sound regional development. ATCOG's purpose is to strengthen both the individual and collective power of local governments and to help them recognize regional opportunities, eliminate unnecessary duplication, and make joint decisions.

B.4.1 Hazard Mitigation Action Planning (HazMAP)

In response to a nationally identified need to reduce our vulnerability to disasters, the North Central Texas Council of Governments is coordinating multi-jurisdictional Hazard Mitigation Action Planning (HazMAP) for the 9-county region.

Hazard mitigation is the cornerstone of the Federal Emergency Management Agency's (FEMA) approach to reducing our nation's vulnerability to disasters. Hazard mitigation is defined as the actions taken to reduce or eliminate long-term risk to people and property from hazards and their effects. This definition distinguishes actions that have a long-term impact from those that are more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage.

HazMAP is a multi-jurisdictional planning process consistent with the Disaster Mitigation Act of 2000 (DMA 2000) and the requirements of the State of Texas Division of Emergency Management (TxDEM) that is putting into place a framework for coordinated and focused hazard mitigation actions both at the local and regional levels. Important elements include:

- Identifying and prioritizing the risks of a range of natural and technological hazards, from tornadoes and flooding to nuclear power plant accidents and chemical spills, as well as civil hazards;
- Considering where improved mitigation measures could help reduce hazard risks and vulnerability; and

The Stafford Act (amended by DMA 2000) requires locally-adopted and FEMA-approved mitigation action plans by November 1, 2004, in order for local governments to participate in certain federal grant programs for disaster planning and relief. Based on federal rules, the process includes annual reporting and plan updating at least every five years.

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Appendix C

Worksheets and Checklists

TOWN OF COPPER CANYON
ENGINEERING DESIGN MANUAL

CHECKLISTS

Please make sure the plans you are submitting are in accordance with this checklist. The following checklist will be used during the Plan Review.

Plat Application: ____**Preliminary Plat** ____ **Preliminary Replat**
____**Final Plat** ____ **Final Replat**

Engineering Plan: ____**Preliminary** ___ **Final**

Storm Water Management: ____**Conceptual** ___ **Preliminary** ____ **Final**

Project Information

A. Name of Development:____________________________________ B. Date: _______________

C. Location of Development: ____

D. Type of Development: ____

E. Total area (acres):____

F. Proposed Land Uses (zoning designations):_____________________________________

G. Anticipated project schedule: ____

H. Name of Owner: ____

I. Owner Telephone No.: ______________________ J. FAX No.:__________________________

K. Owner Contact Name:____

L. Owner Address:____

M. Owner Email Address:____

N. Engineer/Surveyor’s Name: ____

O. Engineer/Surveyor’s Email Address:____

P. Engineer/Surveyor Firm: ____

Q. Telephone No.: ____

FORM CT-2

PRELIMINARY PLAT CHECKLIST:

1.	Ten (10) Sets of Final Plats submitted to the Town	Yes ____ No ____ N/A ____
2.	Preliminary plats shall be placed on maximum 24" x 36" sheets and drawn to a scale of 1" = 100' or 1" = 50' unless approved in advance by the Town.	Yes ____ No ____ N/A ____
3.	Title or name of the subdivision preceded by the words: "Preliminary Plat"	Yes ____ No ____ N/A ____
4.	Name, address and telephone number of the owner, applicant, survey, and/or engineer.	Yes ____ No ____ N/A ____
5.	Volume and page, or deed record number of the ownership deed from Denton County Deed Records.	Yes ____ No ____ N/A ____
6.	Vicinity map and key map, if multiple sheets are needed.	Yes ____ No ____ N/A ____
7.	Date of preparation, written and graphic scale, and north arrow.	Yes ____ No ____ N/A ____
8.	Boundary line of the proposed subdivision drawn with a heavy line.	Yes ____ No ____ N/A ____
9.	Computed gross acreage of the subdivision	Yes ____ No ____ N/A ____
10.	Metes and bounds description of the proposed subdivision.	Yes ____ No ____ N/A ____
11.	Location of the subdivision with respect to a corner of the survey or tract or an original corner of the survey of which it is a part.	Yes ____ No ____ N/A ____
12.	Names of adjoining subdivisions with lots and blocks shown with dashed lines and/or property owners of record for all contiguous unplatted properties.	Yes ____ No ____ N/A ____
13.	Town limits (if applicable).	Yes ____ No ____ N/A ____
14.	Location, dimension, and description and recording information for all existing rights-of-way, railroad rights-of-way, easements or other public ways on or adjacent to the property being developed.	Yes ____ No ____ N/A ____
15.	Show permanent structures or uses that will remain.	Yes ____ No ____ N/A ____
16.	Sizes and flowlines of existing drainage structures, 100-year floodplain and floodway as defined by FEMA.	Yes ____ No ____ N/A ____
17.	Location, size and type of all existing utilities within or adjacent lot the site.	Yes ____ No ____ N/A ____

18. Number each proposed lot and block. Provide the proposed number of lots. Yes ____ No ____ N/A ____

19. Existing two (2) foot interval contours referenced to NAD. Yes ____ No ____ N/A ____

20. Proposed streets, alleys, drainageways, parks, open spaces, easements, other public areas and other rights-of-way within the subdivision. Dimensions of all easements and rights-of-way. Yes ____ No ____ N/A ____

21. Dimensions for all lots. Gross acreage for all non-residential lots. Approximate acreage for areas in residential use. Approximate acreage of streets, parks, and other non-residential uses. Yes ____ No ____ N/A ____

22. Front building setback lines, side and rear building setback lines. Yes ____ No ____ N/A ____

23. Preliminary Storm Water Management Plan meeting the requirements of the Engineering Design Manual shall be submitted with the Preliminary Plat. (Checklist in App. C) Yes ____ No ____ N/A ____

24. Preliminary Plat approval block as described by the Subdivision Regulation Ordinance. Yes ____ No ____ N/A ____

25. Where the Preliminary Plat is part of a larger area owned by the Applicant that will be subsequently subdivided, provide a layout of the larger area showing the tentative layout of streets, blocks, drainage, water, sewerage, and other improvements for the larger area. Yes ____ No ____ N/A ____

26. Added the note for buildings within 1,000 feet from existing oil or gas well as described by the Subdivision Regulation Ordinance. Yes ____ No ____ N/A ____

FINAL PLAT CHECKLIST

1. Ten (10) Sets of Final Plats submitted to the Town Yes ____ No ____ N/A ____

2. Final plats shall be placed on maximum 24" x 36" sheets and drawn to a scale of 1” = 100’ or 1” = 50' unless approved in advance by the Town. Yes ____ No ____ N/A ____

3. Title or name of the subdivision preceded by the words "Final Plat" Yes ____ No ____ N/A ____

4. Name address and telephone number of the owner, applicant, survey, and/or engineer. Yes ____ No ____ N/A ____

5. Vicinity map and key map if multiple sheets are needed. Yes ____ No ____ N/A ____

6. Date, written and graphic scale, and north arrow. Yes ____ No ____ N/A ____

7. Boundary line of subdivision drawn with a heavy line and with bearings, dimensions and curve data. Yes ____ No ____ N/A ____

8. Names of adjoining subdivisions with lots and blocks shown with dashed lines and/or property owners of record for all contiguous unplatted properties. Yes ____ No ____ N/A ____

9. Town limits, if applicable. Yes ____ No ____ N/A ____

10. Proposed streets, alleys, drainageways, parks, open spaces, easements, other public areas and other rights-of-way within the subdivision including dimensions, bearings and curve data. Yes ____ No ____ N/A ____

11. Location, dimension, description and recording information for all existing rights-of-way, railroad rights-of-way, easements or other public ways on or adjacent to the property being platted. Yes ____ No ____ N/A ____

12. Location and description of all permanent monuments and control points Yes ____ No ____ N/A ____

13. Final Storm Water Management Plan meeting the requirements of the Engineering Design Manual shall be submitted with the Preliminary Plat. (Checklist in App. C) Yes ____ No ____ N/A ____

14. Floodways / Floodplains (FEMA):

    a. Show the ultimate 100-year water surface elevation. Yes ____ No ____ N/A ____

    b. Show floodplain and floodway boundaries. Yes ____ No ____ N/A ____

    c. Drainage Floodway easement limits Yes ____ No ____ N/A ____

    d. Minimum fill and floor elevations specified. Yes ____ No ____ N/A ____

15. Minimum building setback lines. Yes ____ No ____ N/A ____

16. Lot and block numbers. Yes ____ No ____ N/A ____

17. Approval block in the form prescribed by the Subdivision Regulations Ordinance. Yes ____ No ____ N/A ____

18. Abutting property owner names and recording information. Yes ____ No ____ N/A ____

19. Gross acreage of the land being subdivided Yes ____ No ____ N/A ____

27. Added the note for buildings within 1,000 feet from existing oil or gas well as described by the Subdivision Regulation Ordinance. Yes ____ No ____ N/A ____

20. Owner's certificate of deed or dedication with the following: Yes ____ No ____ N/A ____

    a. Metes and bounds description. Yes ____ No ____ N/A ____

    b. Representation that dedicators own the property. Yes ____ No ____ N/A ____

    c. Dedication statement. Yes ____ No ____ N/A ____

d. Reference and identification or name of final plat. Yes ____ No ____ N/A ____

e. Surveyor certification in the form prescribed by the Subdivision Regulation Ordinance. Yes ____ No ____ N/A ____

21. Certificate showing all taxes have been paid. Yes ____ No ____ N/A ____

22. A letter fully outlining and alterations from the approved Preliminary Plat. Yes ____ No ____ N/A ____

ENGINEERING SITE PLAN – Each Engineering Site Plan shall include:

1. Engineering Site plans shall be placed on maximum 22" x 34" sheets and drawn to a scale of 1" = 100' or 1" = 50' unless approved in advance by the Town. Yes ____ No ____ N/A ____

2. Title block in lower right hand corner including:

   a. Subdivision name with lot and block number. Yes ____ No ____ N/A ____

   b. Area in acres. Yes ____ No ____ N/A ____

   c. Metes and bounds description including survey name and abstract number. Yes ____ No ____ N/A ____

   d. Town and County. Yes ____ No ____ N/A ____

   e. Preparation Date. Yes ____ No ____ N/A ____

3. Name, address and telephone number of the owner, applicant, and surveyor/engineer. Yes ____ No ____ N/A ____

4. Vicinity map and key map, if multiple sheets are needed. Yes ____ No ____ N/A ____

5. Written scale, graphic scale and north arrow. Yes ____ No ____ N/A ____

6. Approximate distance to the nearest street. Yes ____ No ____ N/A ____

7. Site boundaries, dimensions, lot lines and lot areas. Yes ____ No ____ N/A ____

8. Legend. Yes ____ No ____ N/A ____

9. Site data summary table including:

   a. Zoning. Yes ____ No ____ N/A ____

   b. Proposed use. Yes ____ No ____ N/A ____

   c. Building area (gross square footage). Yes ____ No ____ N/A ____

   d. Building height (feet and inches). Yes ____ No ____ N/A ____

   e. Area of impervious surface. Yes ____ No ____ N/A ____

   f. Total Parking: Required and provided. Yes ____ No ____ N/A ____

g. Number of handicap parking spaces. Yes ____ No ____ N/A ____

h. Number of dwelling units and number of bedrooms (multifamily). Yes ____ No ____ N/A ____

10. Existing improvements within 75' of the subject property. Yes ____ No ____ N/A ____

11. Land use, zoning, subdivision name, recording information and adjacent owners. Yes ____ No ____ N/A ____

12. Building locations, sizes, and dimensions. Yes ____ No ____ N/A ____

13. Distance between buildings on the same lot. Yes ____ No ____ N/A ____

14. Building lines and setbacks. Yes ____ No ____ N/A ____

15. Dimensions of all drive lanes and traffic flow arrows. Yes ____ No ____ N/A ____

16. FEMA floodplains with elevations, and minimum finished floor elevations (include the floodplain note shown on the final plat). Yes ____ No ____ N/A ____

17. Public streets, private drives, and fire lanes with pavement widths and including rights-of-way, median openings, turn lanes, existing driveways, adjacent existing driveways with dimensions, radii, and surface. Yes ____ No ____ N/A ____

18. Distances between existing and proposed driveways. Yes ____ No ____ N/A ____

19. Loading and unloading areas. Yes ____ No ____ N/A ____

20. Ramps, crosswalks, sidewalks and barrier-free ramps with dimensions. Yes ____ No ____ N/A ____

21. Locations of dumpsters and trash compactors with height and material of screening. Yes ____ No ____ N/A ____

22. Size, location, dimensions and details of all signs and exterior lighting of signs, including type of standards, locations and radius of light and intensity of foot-candles. All signage are subject to approval by the Building Inspections Department. Yes ____ No ____ N/A ____

23. Location and sizes of existing and proposed water and sewer mains. Yes ____ No ____ N/A ____

24. Location of fire hydrants. Yes ____ No ____ N/A ____

25. Location and sizes of storm drains, culverts, inlets and other drainage features on or adjacent to the site. Yes ____ No ____ N/A ____

26. Locations, widths, and types of existing and proposed easements. Yes ____ No ____ N/A ____

27. Provide an elevation of all four sides of the building including materials, colors and dimensions at an architectural scale of 1”=20’. Yes ____ No ____ N/A ____

28. Landscape plan provided on separate sheet to show the following: Yes ____ No ____ N/A ____

a. Natural features including tree masses and anticipated tree loss. Yes ____ No ____ N/A ____

b. Floodplains, drainageways and creeks. Yes ____ No ____ N/A ____

c. Screening walls and fences, retaining walls, headlight screens, and service area screens including height and type of construction. Yes ____ No ____ N/A ____

d. Existing and preserved trees including location, size, and species. Yes ____ No ____ N/A ____

e. Landscaping materials including location and size. Yes ____ No ____ N/A ____

f. Proposed plant materials. Yes ____ No ____ N/A ____

g. Note to indicate type and placement of irrigation system. Yes ____ No ____ N/A ____

29. 2" x 3" blank box in lower right corner for Town use. Yes ____ No ____ N/A ____

30. Additional information as requested to clarify the proposed development. Yes ____ No ____ N/A ____

COVER SHEET * - The cover sheet shall include:

1. Project title and type of project. Yes ____ No ____ N/A ____
2. Location map. Yes ____ No ____ N/A ____
3. Disposal site for excess excavation. Yes ____ No ____ N/A ____
4. Index of Sheets (if not included on its own sheet). Yes ____ No ____ N/A ____
5. Approval blocks for Town including Town Engineer and Director of Public Works. Yes ____ No ____ N/A ____
6. Professional Engineer's seal, signature and date. Yes ____ No ____ N/A ____
7. "Release for Construction" note. Yes ____ No ____ N/A ____

* NOTE: If the Cover Sheet is not furnished, information should appear on other sheets.

GENERAL

1. North arrow clearly shown on each plan sheet. Yes ____ No ____ N/A ____
2. Bench marks shown on each sheet; located on permanent structure outside of construction limits and conveniently spaced (500' +). Yes ____ No ____ N/A ____
3. Title blocks, title, sheet number and scales shown. Yes ____ No ____ N/A ____
4. Each sheet must bear the seal of a Licensed Professional Engineer, signature, and date. Yes ____ No ____ N/A ____
5. Street names on each sheet. Yes ____ No ____ N/A ____
6. Property owners and property lines shown. Yes ____ No ____ N/A ____
7. Submit four (4) sets of plans for review on 22" x 34" sheets. Yes ____ No ____ N/A ____
8. Prepare plans on 22" x 34" sheets allowing for half size reduction to 11" x 17". Yes ____ No ____ N/A ____

9. Text shall be legible on the half size 11” x17” plans. Yes ____ No ____ N/A ____

10. Place standard general notes on plans. Yes ____ No ____ N/A ____

11. Existing, proposed and future facilities must clearly be defined. Yes ____ No ____ N/A ____

12. Project name on right end of plan sheets. Yes ____ No ____ N/A ____

<u>GRADING</u> * – Each grading plan shall include:

1. Horizontal scale for grading plans shall be at 1” = 20’ on full size drawings. Yes ____ No ____ N/A ____
2. Existing one-foot contours based on an on-the-ground survey or controlled aerial topographic map (dashed lines and labeled) to extend 20 feet from property line onto adjacent property. Yes ____ No ____ N/A ____
3. Proposed one-foot contours – solid lines and labeled. Yes ____ No ____ N/A ____
4. Show top of curb elevation every 50 feet on streets, alleys, existing and proposed parking lots. Yes ____ No ____ N/A ____
5. Slope:
   a. Back of street curb to property line: ¼” per foot. Yes ____ No ____ N/A ____
   b. Parking lot top of curb to property line: Maximum 4 (horizontal) to 1 (vertical). Yes ____ No ____ N/A ____
   c. Any unpaved area to property line: Maximum slope of 4:1. Yes ____ No ____ N/A ____
   d. Show driveways with ¼” per foot + 6” from street gutter up to property line. Yes ____ No ____ N/A ____
6. Letter of approval if grading is proposed on adjacent property. Yes ____ No ____ N/A ____
7. Utility easement from abutting property owners. Yes ____ No ____ N/A ____
8. Proposed inlets, label and size. Yes ____ No ____ N/A ____
9. Proposed pipes, label and size. Yes ____ No ____ N/A ____
10. Existing inlets and pipes. Yes ____ No ____ N/A ____

* NOTE: Add statement that grading <u>only</u> is being submitted with these plans.

PAVING PLAN – Each Paving Plan shall include:

1. Horizontal scale for paving plans shall be at 1” = 20’ on full size drawings. Yes ____ No ____ N/A ____
2. Right-of-way, street, alley, drives and sidewalks dimensioned. Yes ____ No ____ N/A ____
3. Centerline stations shown. Yes ____ No ____ N/A ____
4. Limits of work defined. Yes ____ No ____ N/A ____
5. Barrier free ramps at all intersections. Yes ____ No ____ N/A ____
6. Pavement transitions. Yes ____ No ____ N/A ____
7. Traffic control items; striping, traffic buttons, sign. Yes ____ No ____ N/A ____
8. Street lighting. Yes ____ No ____ N/A ____

9. Concrete pavement thickness. Yes ____ No ____ N/A ____

10. Minimum 3,600 psi in 28 days concrete compressive strength. Yes ____ No ____ N/A ____

11. 6” curbs. Yes ____ No ____ N/A ____

12. Minimum reinforcement with No. 4 bars 24” o.c. both ways. Yes ____ No ____ N/A ____

13. Sidewalks to be 4” thick, 3,600 psi in 28 days, reinforced with No. 3 bars 14” O.C.E.W. Yes ____ No ____ N/A ____

14. Expansion joints at intersection and at minimum 600 foot intervals for pavement. Yes ____ No ____ N/A ____

15. Saw cut at 15-, 17.5- and 20-foot intervals for 6-inch, 7-inch and 8-inch pavements respectively. Yes ____ No ____ N/A ____

16. Radius at corners conform to Table II-2. Yes ____ No ____ N/A ____

17. Gutter flow arrows. Yes ____ No ____ N/A ____

18. Roadways comply with thoroughfare plan. Yes ____ No ____ N/A ____

19. Geometrics meet design speed criteria. Yes ____ No ____ N/A ____

20. Is Superelevation required? Yes ____ No ____ N/A ____

21. Retaining Walls:

    a. Type, beginning and ending locations and wall elevations. Yes ____ No ____ N/A ____

    b. Provide design if non-standard or modified. Yes ____ No ____ N/A ____

    c. Drainage behind walls shown. Yes ____ No ____ N/A ____

22. Driveway grades shown. Yes ____ No ____ N/A ____

23. Prepare plans and necessary forms for TDLR plans review and field inspection. Yes ____ No ____ N/A ____

24. Developer to pay for all review and inspection fees. Yes ____ No ____ N/A ____

PAVING PROFILES AND GRADES – Plans shall include:

1. Vertical scale for paving profiles shall be at 1” = 4’ on full size drawings. Yes ____ No ____ N/A ____

2. Profiles plotted showing ground at proposed property line. Yes ____ No ____ N/A ____

3. Top of curb profiles must meet minimum and maximum grade requirements. Yes ____ No ____ N/A ____

4. Driveway profile grades. Yes ____ No ____ N/A ____

5. Vertical curves must be designed in accordance with Table II-5. Yes ____ No ____ N/A ____

6. Contour grading plans for major intersections. Yes ____ No ____ N/A ____

7. Spot top of curb elevations in plan view on proposed left turn lanes. Yes ____ No ____ N/A ____

8. Check carefully for any place water might pond. Are inlets located at sag points or vertical curves? Yes ____ No ____ N/A ____

9. Are grades, crossfall, slopes, etc., consistent with information shown on typical section? Yes ____ No ____ N/A ____

10. Check ends of project for drainage. If gutters drain to ditches or field type inlets, are grades and profiles shown? Yes ____ No ____ N/A ____

11. Minimum grades maintained to assure complete drainage. Yes ____ No ____ N/A ____

WATER – All water distribution and transmission facilities shall include:

1. Approval letter to connect to the waste line from Bartonville Water Supply Corporation Yes ____ No ____ N/A ____

2. Horizontal scale for plan views shall be at 1” = 20’ on full size drawings. Yes ____ No ____ N/A ____

3. Vertical scale for profile views shall be at 1” = 4’ on full size drawings. Yes ____ No ____ N/A ____

4. Loop water mains. Yes ____ No ____ N/A ____

5. Valves on fire hydrant leads. Yes ____ No ____ N/A ____

6. Valves on main lines between each fire hydrant. Yes ____ No ____ N/A ____

7. Maximum distance between each fire hydrant.

    a. Residential – 500’ c-c on street. Yes ____ No ____ N/A ____

    b. Multifamily – 400’ c-c on street. Yes ____ No ____ N/A ____

    c. Office, retail, commercial, industrial 300’ c-c on street. Yes ____ No ____ N/A ____

8. All portions of building within 300’ radius of a fire hydrant in commercial. Yes ____ No ____ N/A ____

9. All portions of building within 400’ radius of a fire hydrant in multifamily. Yes ____ No ____ N/A ____

10. All portions of buildings within 500’ radius of a fire hydrant in single family and duplex residential. Yes ____ No ____ N/A ____

11. Maximum length non-looped line serving a fire hydrant is 150 feet. Yes ____ No ____ N/A ____

12. Lateral service (min. 1” copper) from main line to two feet from ROW. Yes ____ No ____ N/A ____

13. Water main extended to opposite property line or tied to existing main. Yes ____ No ____ N/A ____

14. Profile mains 12” and larger. Yes ____ No ____ N/A ____

15. Show other utility lines crossing wastewater lines. Yes ____ No ____ N/A ____

16. Show location of water meters:

    a. Domestic. Yes ____ No ____ N/A ____

b. Irrigation. Yes ____ No ____ N/A ____

c. Fire line. Yes ____ No ____ N/A ____

17. Show size of water meters. Yes ____ No ____ N/A ____

18. Note minimum pipe covers (attach water and standard details and general notes). Yes ____ No ____ N/A ____

19. Dedicate water line easements up to and including fire hydrants and water meters for lines off ROW. Yes ____ No ____ N/A ____

WASTEWATER – All wastewater plans shall include:

1. Approval letter to connect to the wastewater collection agency (i.e. Flower Mound, Highland Village, Upper Trinity, Private) Yes ____ No ____ N/A ____

2. Horizontal scale for plan views shall be at 1" = 20' on full size drawings. Yes ____ No ____ N/A ____

3. Vertical scale for profile views shall be at 1" = 4' on full size drawings. Yes ____ No ____ N/A ____

4. 8" minimum, PVC SDR-35 (unless 6-inch approved by Town). Yes ____ No ____ N/A ____

5. Manhole at end of all lines. Yes ____ No ____ N/A ____

6. Manholes at change of pipe size, tees and bends. Yes ____ No ____ N/A ____

7. 500' maximum distance between manholes on lines 21" and smaller. 800' maximum distance between manholes on lines 24" and larger. Yes ____ No ____ N/A ____

8. Minimum slopes:

   a. 6" – 0.50% (Pipe size as approved by Town). Yes ____ No ____ N/A ____

   b. 8" – 0.33%. Yes ____ No ____ N/A ____

   c. 10" – 0.25%. Yes ____ No ____ N/A ____

   d. 12" – 0.20%. Yes ____ No ____ N/A ____

   e. 15" – 0.14%. Yes ____ No ____ N/A ____

   f. 18" – 0.12%. Yes ____ No ____ N/A ____

9. Maximum slope such that velocity is less than 10 fps. Yes ____ No ____ N/A ____

10. Sewer laterals 10' downstream from water service or to center of lot. Yes ____ No ____ N/A ____

11. Minimum lateral size:

   a. Residential, 4". Yes ____ No ____ N/A ____

   b. Apartment, retail or commercial – 6". Yes ____ No ____ N/A ____

   c. Manufacturing or industrial – 8". Yes ____ No ____ N/A ____

12. Profile all sewer lines except laterals. Yes ____ No ____ N/A ____

13. Show other utility lines crossing wastewater lines. Yes ____ No ____ N/A ____

14. Label lines to correspond to profile. Yes ____ No ____ N/A ____

15. Concrete encasement at creek crossing. Yes ____ No ____ N/A ____

16. Provide stub outs to adjacent property. Add services for Planned Development Communities. Yes ____ No ____ N/A ____

17. Note benchmark on all sheets. Yes ____ No ____ N/A ____

18. 10’ utility easement provided for lines not in ROW. Yes ____ No ____ N/A ____

UTILITIES – All plans shall show the following:

1. Existing and proposed facilities shown in plan and profiles views. Yes ____ No ____ N/A ____

2. Underground facilities close to or in conflict with proposed construction located by actual ties and elevations. Yes ____ No ____ N/A ____

3. Caution notes shown when construction operations come close to existing utilities. Telephone number of utility contact shall be shown. Yes ____ No ____ N/A ____

EROSION CONTROL – All plans shall show the following:

1. The scale for Erosion Control Plans may vary however shall be prepared on sheets no smaller than 1” = 100’ on full size drawings. Yes ____ No ____ N/A ____

2. Existing and Proposed Grading. Yes ____ No ____ N/A ____

3. Existing and Proposed Drainage Features. Yes ____ No ____ N/A ____

4. Erosion features including temporary construction entrance, silt fence, inlet protection, rock berms, seeding, etc. Yes ____ No ____ N/A ____

5. Erosion control standard details. Yes ____ No ____ N/A ____

PAVEMENT MARKINGS AND SIGNAGE

1. The scale for Pavement Marking Plans may vary however shall be prepared on sheets no smaller than 1” = 100’ on full size drawings. Yes ____ No ____ N/A ____

2. Pavement Markings and Signage Plan in accordance with MUTCD. Yes ____ No ____ N/A ____

3. Pavement Markings Standard Details. Yes ____ No ____ N/A ____

TRAFFIC CONTROL PLAN

1. The scale for Traffic Control Plans may vary however shall be prepared on sheets no smaller than 1” = 200’ on full size drawings. Yes ____ No ____ N/A ____
2. Traffic Control Plan in accordance with MUTCD. Yes ____ No ____ N/A ____
3. Traffic Control Standard Details. Yes ____ No ____ N/A ____
4. Traffic Control Phasing as necessary. Yes ____ No ____ N/A ____

LANDSCAPE AND IRRIGATION PLANS

1. The scale for Landscape and Irrigation Plans may vary however shall be prepared on sheets no smaller than 1” = 100’ on full size drawings. Yes ____ No ____ N/A ____
2. Landscape Plan showing rights-of-way and proposed back of curbs, sidewalk, existing; and proposed utilities and other features pertinent to the plan. Yes ____ No ____ N/A ____
3. Planting details. Yes ____ No ____ N/A ____
4. Irrigation Plans including metering, back flow prevention, and provision for electrical service and controllers. Yes ____ No ____ N/A ____
5. Irrigation details. Yes ____ No ____ N/A ____

STREET LIGHTING

1. The scale for Street Lighting Plans may vary however shall be prepared on sheets no smaller than 1” = 100’ on full size drawings. Yes ____ No ____ N/A ____

1. Lighting and Conduit Layout Plan. Yes ____ No ____ N/A ____
2. Lighting Standard Details. Yes ____ No ____ N/A ____

ENGINEER’S CHECKLIST FOR CONCEPTUAL STORM WATER MANAGEMENT PLAN

Please attach additional sheets as necessary for comments and descriptions.

1. Planning Concerns

A.	Have any previous drainage or watershed plans been completed in the watershed? (If yes, describe)	Yes ____ No ____ N/A ____
B.	Is there any known history of flooding downstream? (If yes, describe conditions and locations)	Yes ____ No ____ N/A ____
C.	Is there any known history of excessive erosion downstream? (If yes, describe conditions and locations)	Yes ____ No ____ N/A ____
D.	Are there any known downstream drainage constrictions such as undersized culverts or channels? Size?	Yes ____ No ____ N/A ____
E.	Are there any FEMA 100-year floodplains which will need flood studies, CLOMRs, LOMRs, etc., for this project?	Yes ____ No ____ N/A ____
F.	Are there any known or suspected wetlands areas, mitigation areas, 404 permit areas, or other natural habitat features which require special consideration?	Yes ____ No ____ N/A ____
G.	Are there any existing dams over six feet in height which are or will be subject to TCEQ regulations?	Yes ____ No ____ N/A ____
H.	Are there any existing impoundments subject to TCEQ water rights permitting? (Livestock ponds are not exempt when converted to other uses.)	Yes ____ No ____ N/A ____
I.	Are there any existing environmental concerns on the site requiring special treatment or design consideration (i.e. fuel stations, vehicle maintenance, auto recycling, illegal dump sites, outdoor material storage, loading and transfer areas, landfills, industrial facilities, etc.)?	Yes ____ No ____ N/A ____

2. Existing Conditions Map(s) showing the following information on or adjacent to the development site:

A.	Digital ortho-photography showing project boundaries	Yes ____ No ____ N/A ____
B.	Existing topography (normally 2-foot contours)	Yes ____ No ____ N/A ____
C.	Soil types from USDA soil surveys and/or soil borings	Yes ____ No ____ N/A ____
D.	Perennial or intermittent streams	Yes ____ No ____ N/A ____
E.	Boundaries of existing predominant vegetation	Yes ____ No ____ N/A ____
F.	Delineation of current FEMA floodplains and floodways	Yes ____ No ____ N/A ____
G.	Locations of steep slopes (>15%)	Yes ____ No ____ N/A ____
H.	Locations of wetlands and natural habitat areas if known.	Yes ____ No ____ N/A ____
I.	Locations of all dams and impoundments	Yes ____ No ____ N/A ____
J.	Existing paved roads, buildings, and other impervious areas	Yes ____ No ____ N/A ____
K.	Environmental concerns identified in (2.H) above	Yes ____ No ____ N/A ____
L.	Existing major utilities, pipelines, and easements	Yes ____ No ____ N/A ____

Form CT-2

3. Does this development provide opportunities for Low-Impact Design?

A. Preserve floodplains and natural valley storage?	Yes ____ No ____ N/A ____
B. Preserve natural streams and drainage patterns?	Yes ____ No ____ N/A ____
C. Preserve steep slopes?	Yes ____ No ____ N/A ____
D. Preserve trees and undisturbed natural vegetation?	Yes ____ No ____ N/A ____
E. Preserve wetlands and other natural features?	Yes ____ No ____ N/A ____
F. Drain runoff to pervious areas?	Yes ____ No ____ N/A ____
G. Utilize natural drainage vs. storm drain systems?	Yes ____ No ____ N/A ____
H. Reduce pavement and other impervious covers?	Yes ____ No ____ N/A ____

4. Conceptual analysis of hydrologic and hydraulic impacts of the proposed development:

A. Hydrologic analysis to determine conceptual rates of runoff, volumes, and velocities to support decisions related to flood control and erosion protection downstream.	Yes ____ No ____ N/A ____
B. Conceptual estimates of the three (3) storm design approach requirements.	Yes ____ No ____ N/A ____
C. Conceptual selection, location, and size of proposed storm water structural controls.	Yes ____ No ____ N/A ____
D. Conceptual limits of proposed clearing and grading.	Yes ____ No ____ N/A ____

5. Conceptual Drainage Area Map(s) showing the following information for the development site:

A. Conceptual street layout (scale 1"=200')	Yes ____ No ____ N/A ____
B. All off-site drainage areas with topography (reduced scale)	Yes ____ No ____ N/A ____
C. Delineation of watershed boundaries with flow arrows	Yes ____ No ____ N/A ____
D. Reference info (file number, etc.) for previous drainage studies or existing developments & drainage facilities	Yes ____ No ____ N/A ____
E. Approximate zone of influence for all outfalls	Yes ____ No ____ N/A ____
F. Downstream constrictions, flooding, or erosion locations	Yes ____ No ____ N/A ____
G. Location of proposed structural storm water controls, if any	Yes ____ No ____ N/A ____

(seal)	I certify that this Conceptual Storm Water Management Plan, including this checklist, required attachments, and additional comments, was prepared under my responsible supervision and that the information presented on this checklist and attachments is correct to the best of my knowledge. I also understand that an acceptance of this plan by the Town does not waive any Town standards or requirements unless a specific waiver request has been submitted and approved. Signed ________________________________ Date __________________ Print Name:_____________________________ PE No _________________

Form CT-2

ENGINEER'S CHECKLIST FOR PRELIMINARY STORM WATER MANAGEMENT PLAN

Please attach additional sheets as necessary for comments and descriptions.

1. **Changes or Modifications to Conceptual Site Plan** (May be reprinted with changes tracked or highlighted)

____

____

____

____

____

____

2. **Preliminary Project Layout Map(s) shows the following information on or adjacent to the development site:**

A.	Digital ortho-photography showing project boundaries	Yes ____ No ____ N/A ____
B.	Existing topography (normally 2-foot contours)	Yes ____ No ____ N/A ____
C.	Preliminary street and lot layout	Yes ____ No ____ N/A ____
D.	Benchmarks used for site control	Yes ____ No ____ N/A ____
E.	Construction phasing plan, if applicable	Yes ____ No ____ N/A ____
F.	Limits of proposed clearing and grading	Yes ____ No ____ N/A ____
G.	Proposed dams > 6' high (attach Dam Safety Checklist)	Yes ____ No ____ N/A ____
H.	Proposed FEMA floodplains with flood study reference info	Yes ____ No ____ N/A ____
I.	Proposed ponds subject to TCEQ water rights permits	Yes ____ No ____ N/A ____
J.	If yes, has water rights permit been applied for?	Yes ____ No ____ N/A ____

3. **Preliminary Drainage Area Map(s) shows the following information for the development site:**

A.	Preliminary street and lot layout (scale 1"=200')	Yes ____ No ____ N/A ____
B.	All off-site drainage areas with topography (reduced scale)	Yes ____ No ____ N/A ____
C.	Delineation of watershed boundaries with flow arrows	Yes ____ No ____ N/A ____
D.	Proposed modifications to watershed boundaries	Yes ____ No ____ N/A ____
E.	File numbers for existing developments & drainage facilities	Yes ____ No ____ N/A ____
F.	Zoning or Comp Plan info to document off-site land use	Yes ____ No ____ N/A ____
G.	Preliminary hydrology with supporting data & calculations for on-site existing & proposed, & off-site ultimate conditions	Yes ____ No ____ N/A ____
H.	Proposed detention ponds or other storm water controls, with summary hydrology for all applicable design storms	Yes ____ No ____ N/A ____
I.	Delineate entire zone of influence for all outfalls	Yes ____ No ____ N/A ____
J.	Downstream constrictions, flooding, or erosion locations	Yes ____ No ____ N/A ____

K. Proposed facilities with private maintenance (Maintenance Agreement and Maintenance Plan required for final) Yes ____ No ____ N/A ____

4. **Determination of Adequate Outfalls and Zones of Influence:** Describe these and provide supporting methodology:

5. **Description of Any Proposed Waiver Requests:** (for informational purposes only; all Waiver Requests must follow published procedures)

6. **Other Comments:**

(seal)	I certify that this Preliminary Storm Water Management Plan, including this checklist, required attachments, and additional comments, was prepared under my responsible supervision and that the information presented on this checklist and attachments is correct to the best of my knowledge. I also understand that an acceptance of this plan by the Town does not waive any Town standards or requirements unless a specific waiver request has been submitted and approved. Signed ________________________________ Date ______________________ Print Name:_____________________________ PE No _____________________

ENGINEER'S CHECKLIST FOR FINAL STORM WATER MANAGEMENT PLAN

Please attach additional sheets as necessary for comments and descriptions.

1. **Changes or Modifications to Preliminary Storm Water Management Plan** (May be reprinted with changes tracked or highlighted)

____

____

____

____

____

____

2. **Additional Study Attachments (include if applicable)**

A.	Dam Safety Checklist	Yes ____ No ____ N/A ____
B.	Storm Water Pollution Prevention Plan (SWPPP)	Yes ____ No ____ N/A ____
C.	Executed Maintenance Agreement (with Maintenance Plan)	Yes ____ No ____ N/A ____
D.	Landscaping Plan (for Storm Water controls)	Yes ____ No ____ N/A ____
E.	Copy of approved Waiver Request	Yes ____ No ____ N/A ____

3. **Applicable Local, State and Federal Permits** (Indicate acquired or application pending)

A.	CLOMR, LOMR or LOMA	Yes ____ No ____ N/A ____
B.	TCEQ water rights permit	Yes ____ No ____ N/A ____
C.	404 permit	Yes ____ No ____ N/A ____
D.	Other: ________________________________	Yes ____ No ____ N/A ____
E.	Other: ________________________________	Yes ____ No ____ N/A ____

4. **Hydrologic Analysis and Storm Water Management Design Plan** (separate Attachment, either A or B and C)

A.	Approved Infrastructure Plans. Attach a copy of the signed cover sheet.	Yes ____ No ____ N/A ____ Plan File No.:
B.	Site SWM Plan showing final hydrology, Identification of all storm water controls with summary calculations, delineation of adequate outfalls, zones of influence, required mitigation, and structural details and specifications as required	Yes ____ No ____ N/A ____
C.	Digital Copy of final hydrologic and hydraulic models	Yes ____ No ____ N/A ____

(seal)	I certify that this Final Storm Water Management Plan, including this checklist, required attachments, and additional comments, was prepared under my responsible supervision and that the information presented on this checklist and attachments is correct to the best of my knowledge. I also understand that an acceptance of this plan by the Town does not waive any Town standards or requirements unless a specific waiver request has been submitted and approved. Signed ______________________________ Date ___________________ Print Name:__________________________ PE No __________________

Variance Procedure – Town of Copper Canyon Storm Water Management Design Manual

Good engineering practice and practical considerations are necessary when developing storm water management plans and preparing construction drawings for specific projects. The criteria in this manual cannot cover every possibility.

The closer the criteria are followed, the more likely the plan or drawing will be approved and the construction accepted. For those situations where varying from the criteria is warranted, a variance process is described below.

Submit variance request in writing on the Request for Variance from Town of Copper Canyon – Storm Water Form (CT-7) as early as possible. The variance request must include the following:

- The specific criteria that you want to vary.
- Why the criteria needs to be varied.
- How the basis for the criteria will still be satisfied or why the criteria is not applicable.
- Indicate if there are no criteria for the proposed analysis, design, or feature in this manual.
- Appropriate technical information supporting the variance request, such as calculations, excerpts from the drainage or design plan, and/or construction drawings.

Note: Submittals with insufficient technical information to support the variance request will be returned without review.

The town will either approve or reject the variance in writing on the variance request form. If it is rejected, a written explanation will be provided.

REQUEST FOR VARIANCE FROM TOWN OF COPPER CANYON – STORM WATER – FORM CT-7

Submitted by:______________________________ Phone:_____________________ Email:_______________

Company:____Date:________________

Proposed Project Description

Name:____

Type:____

Location:____(include map)

Existing Condition (show information on map or drawing)

Existing Site: ____

Existing Right-of-Way:____

Topography:____

Other Pertinent Data Related to Variance Request:

____

____

Variance Request

Specific criteria you want to vary:____

____

Explain why the criteria needs to be varied or is not applicable:_____________________________________

____

Explain how the basis for the criteria will be satisfied:____

____

List attachments supporting variance request (preliminary design report excerpt, construction drawings, calculations, photographs, map, etc.):

Town of Copper Canyon fills in this area

Date	Reviewer	Dept./Section	Action Taken

Justification of Decision:____

____

Approval of Final Decision:_________________________________ Date:________________

CHECKLIST FOR SUBMITTAL OF APPLICATIONS FOR A BUILDING PERMIT

Thank you for choosing to build in the Town of Copper Canyon. This information is provided as a convenient checklist in submitting applications for building permits to the Town Hall. In the event of any discrepancy between the wording of this checklist and the Comprehensive Zoning Ordinance, as adopted by the Town, the Ordinance controls. Please return a copy of this checklist with your submitted application.

SINGLE FAMILY NEW CONSTRUCTION, REMODELS & ADDITIONS

- □ Three copies of the construction permit application.
- □ Three copies of a formal, scaled plot plan of the property showing all easements and dimensions to property lines. Setback distances should be marked (Zoning Ordinance 04-200, Section 2-102, pages 5, 6, & 7).
- □ Three copies of the complete plans of the project, including foundation, framing and roof plan.
- □ Three copies of erosion control plan showing location of silt fencing on plot plan.
- □ TCEQ approval letter stating authorization to construct
- □ All contractors (general, electrical, mechanical, irrigators and plumbing) must be registered with the Town before permit is issued.
- □ Porta potty must be set at property prior to 1st inspection.
- □ Trash bin showing address must be installed prior to any construction.
- □ Evidence must be submitted reflecting Residential Energy Code Compliance (Zoning Ordinance 04-185, Section 3.32-3:39)).
- □ No same residential building elevation shall exist within a 1200' radius of another residential structure. Elevations checked (Zoning Ordinance 04-200, Section 201-3(A) (1) (a)).
- □ Check maximum height allowed, per Ordinance 04-200, Section 2-102(A)(6), page 7, Maximum height for R2, R5 and R10 is 45 feet, R1 is 35 feet, and R1(A) is 42 feet.
- □ Architecture of "Residential Structures (Zoning Ordinance 04-200, Page 19, Section 2-103-A (3)).
  - a. Exterior building materials shall be of an earth tone.
  - b. Building materials not allowed include tin, material that is metal in appearance, or concrete block (except split-face block)
  - c. Building materials for exterior walls of residential structures shall consist of 80% masonry or stone.
  - d. Hardi-plank may be used without approval on a maximum of 20% of the building. Any additional use must be approved on a Concept Plan and/or Development Plan.
  - e. Two of the following design features shall be used: dormers, gables, cupolas, pillars, posts.

f. Screening awnings and similar for windows (on main or secondary structures) shall not be metal.

□ Architecture: Roofing Requirements (Zoning Ordinance 04-200, Page 19, Section 2-103(A) (3) (a)).

a. Hipped roofs shall have a minimum pitch of 6/12; gable roofs shall have a minimum pitch of 9/12; proposals for roofs of shallower runs may be approved on a Concept Plan and/or Development Plan.

b. Metal roofs, other than standing-seam metal roofs, may be approved on a

c. Concept Plan and/or Development Plan.

d. Corrugated metal shall not be allowed.

e. Shingles shall be a minimum 20 year rated dimension shingle.

□ Lot Orientation (Zoning Ordinance 04-200, page 20, section 2-103(A)).

a. The main pedestrian entry must face the front lot line and main public right- of-way unless the main entry is to face a public open space in a cluster development scheme.

b. Garage doors-may not face the main public right-of-way unless the garage door (entry) is located within the rear third of the main structure.

□ Landscaping

a. Landscaping should comply with the recommendations described in Section 6.8, Landscaping, of the 2004 Master Plan.

b. All open space on any given lot must consist of a minimum 80% ground cover of natural plantings (to include grasses).

□ Drainage: Detention/retention ponds in view from the main public right-of-way must be landscaped or aesthetically improved by other means, subject to approval by Concept Plan and/or Development Plan.

ACCESSORY BUILDINGS & STRUCTURES

□ Three copies of the construction permit application.

□ Accessory Uses shall comply with all requirements for the principal use except where specifically modified by the Zoning Ordinance.

□ Three copies of a formal, scaled plot plan of the property showing all easements and dimensions to property lines. Setback distances should be marked (Zoning Ordinance 04-200, Section 2-102, pages 5, 6, & 7).

□ Three copies of the complete plans of the project, including foundation, framing and roof plan.

□ Three copies of erosion control plan showing location of silt fencing on plot plan.

□ Accessory building shall not be located less than ten (10) feet from any dwelling or building existing or under construction on the same lot or any adjacent lot (Zoning Ordinance 98-120, Section 4-104, Page 4-1).

□ Secondary structures shall be constructed of materials similar to the main structure (not including structures whose primary use is intended for ranching for farming uses). All farming or ranching-oriented structure, if containing metal exterior walls or roofing, shall be painted or finished in those areas. All farming or ranching-oriented structures shall not contain exposed galvanized metal, unless otherwise approved in the Concept Plan and/or Development Plan (Zoning Ordinance 04-200, page 26, Section 4-104).

- □ Check maximum height (Zoning Ordinance 04-200, Section 2-102, (A) (6), page 7). Maximum height for all accessory buildings is 20 feet except for R1 and R1A, which is 15 feet.
- □ All contractors must be currently registered.

DEMOLITION OF STRUCTURES

- □ Three signed building permit applications.
- □ Plot plat showing the structures to be demolished.
- □ A list of all structures to be demolished.
- □ A list of ail utilities that will be disconnected.
- □ All contractors must be currently registered.

ELECTRICAL, MECHANICAL & PLUMBING PERMITS

- □ Three copies of the building permit application and plans.
- □ All contractors must be currently registered.

DRIVEWAYS & CULVERTS

- □ Three copies of the building permit application and plans.
- □ Plot plan showing the location of the proposed driveway and how it will connect to the street.
- □ Driveway entrances connecting to the Town's roadways or streets shall be provided culverts, sized by a Professional Engineer to carry the design flow in the roadside ditch, and reinforced concrete with concrete headwalls on each end. The driveway culvert shall have a minimum diameter of 15-inches. Property owner or his engineer shall provide enough information to the Town Engineer to justify the smaller diameter culvert.
- □ For a lot with an existing house, the property owner may install a driveway culvert that is the same size as the largest culvert upstream from the driveway with a minimum diameter of 15” or obtain a variance from the Town Engineer. Concrete Headwalls shall be installed on each end. Property owner shall provide enough information to the Town Engineer to justify the smaller diameter culvert.
- □ All contractors must be currently registered.

HOT WATER HEATER CHANGE OUTS

- □ Three copies of the building permit application.
- □ A description of the make and model of the new hot water heater.
- □ Follow guidelines listed in Ordinance #04-184, page 3-110, Section 3.401(25).
- □ All contractors must be currently registered.

MOBILE HOME MOVING PERMITS

- □ Three copies of the building permit application.
- □ A description of the mobile home to be moved out.
- □ A permit from the State of Texas to move the mobile home on the roads.
- □ Police escort required.
- □ All contractors must be currently registered.

Appendix D

Hydrologic Soils Data

APPENDIX

D

HYDROLOGIC SOIL DATA

ELECTRONIC SOIL MAPS

Electronic soil data in the Soil Survey Geographic (SSURGO) Database can be obtained free of charge from the National Resource Conservation Service (NRCS) at http://soildatamart.nrcs.usda.gov. The data is downloadable by county and includes extensive soil information, including hydrologic soil groups. The data is intended to be imported into a geographic information system (GIS) to allow for site-specific soil analysis of soil characteristics for storm design. All soil survey results can also be accessed online at http://websoilsurvey.nrcs.usda.gov/app/. Maps can be created and printed from this site without the use of a GIS.

A.1 Online Web Soil Survey

Following is a procedure for using the NRCS online Web Soil Survey.

1. Go to http://websoilsurvey.nrcs.usda.gov/app/
2. Click **Start WSS**
3. Define your Area of Interest by drawing a box around your site location.
4. Click the **Soil Map** tab.
5. Click **Save or Print** in the upper right hand corner. A pdf will open in a new window that you can either print or save. It will show the area of interest along with a legend and the appropriate map units.

A.2 Downloading Soil Surveys

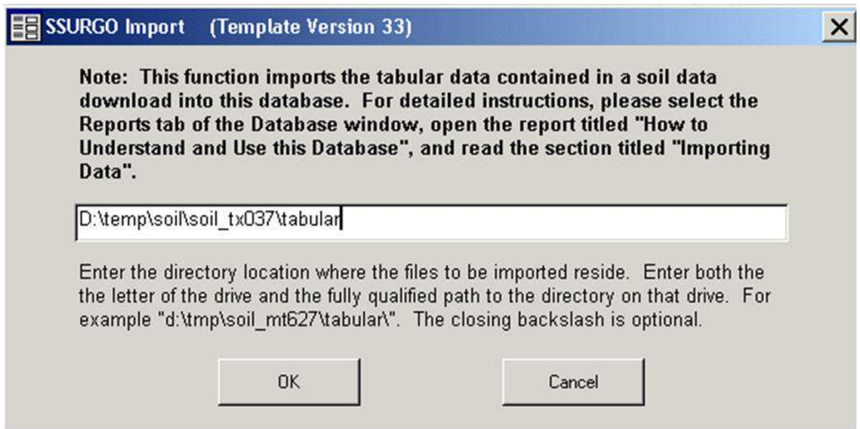
Following is a procedure for downloading data from the NRCS web site and importing in into ArcGIS.

Downloading SSURGO Soil Data into ArcInfo 9.x

1. Go to http://soildatamart.nrcs.usda.gov
2. Click **Select State**
3. Select State (**Texas)**
4. Select **County** of interest (**Denton**)
5. Click **Select Survey Area**
6. Click **Download Data**
7. Enter your e-mail address in the provided form space
8. Click **Submit Request**
9. You will receive an immediate message acknowledging your request and a follow-up e-mail once your request has been processed.
10. The file(s) will be provided in compressed ZIP format, requiring the use of WinZip to extract.
11. Extract the files to a destination directory of your choice. The extracted files contain a spatial sub-folder, a tabular sub-folder, and a zip file containing the SSURGO MS Access template file.

Importing raw tabular soil data into Microsoft Access

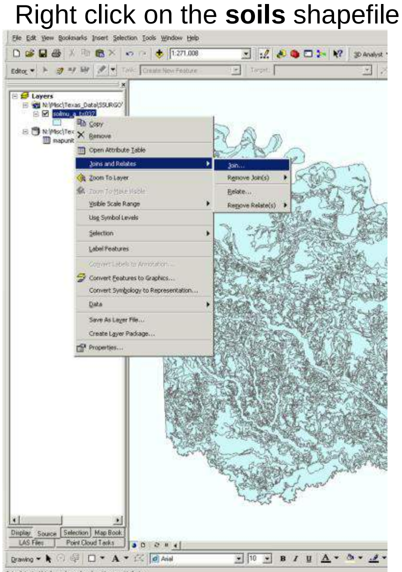
1. Extract the soildb_US_2002.zip file into the same destination folder by using the “extract to here” command in WinZip. This will extract the template database.
2. Open the template database and input the path name to the tabular data. This will build the SSURGO database and allow the creation of reports and queries.

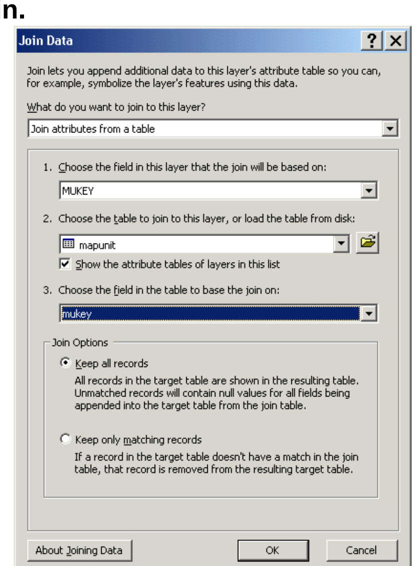


3. Once the data is imported into the database, a report can be run. With the soil reports dialog box up, press the **Select All** option and generate the report. Note: Regardless of what report you wish to run, all reports are simultaneously created. The selected report is displayed on the screen.
4. All the reports are now complete, and the tables can now be added directly into ArcGIS.

<u>Joined tables to shapefiles in ArcGIS</u>

1. Open **ArcGIS** and add the **Soils** shapefile. (soilmu_a_tx037.shp)
2. Add the "**mapunit**" report to ArcGIS by navigating directly to the MS Access database and opening it (via the add data dialog box). Note: mapunit is only a commonly used example, containing full soil names and prime farmland information.
3. Now that the table is added to the Table of Contents, it is ready to be joined to the existing soils shapefile.
4. Right click on the **soils** shapefile and select **join.**





5. Under the **Join Data** dialog box, select the **mukey** field in Dropdown Box 1 and select **mapunit** in Dropdown Box 2.
6. Now that your shapefile is joined with the appropriate information, the next step is to export the shapefile into a new shapefile with the joins saved permanently. Right click on the soils shapefile and choose **Data > Export** and **Save** your file.

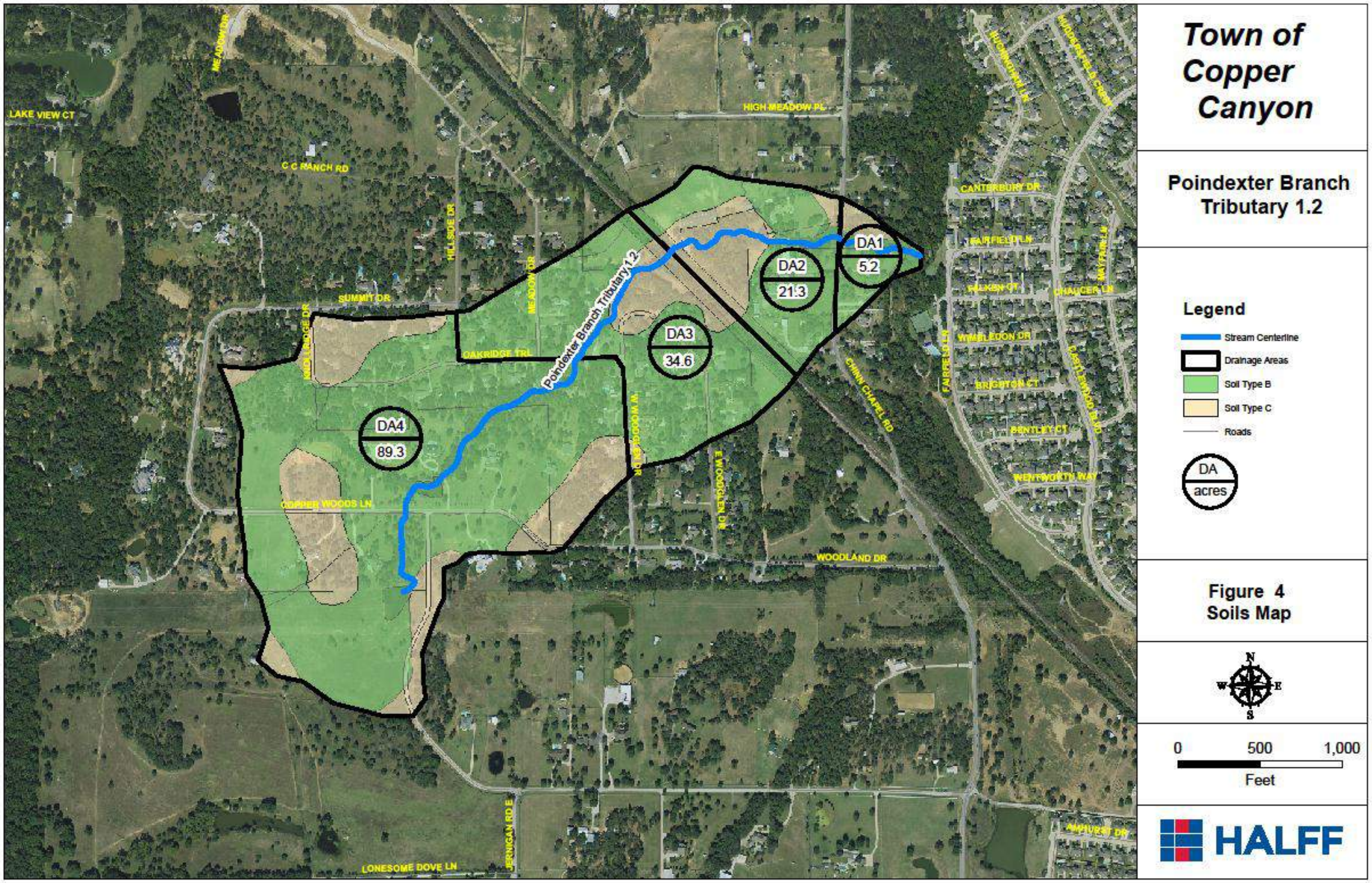


Figure A-1. Example SSURGO Soil Map – Bowie County

Appendix E

Storm Water Computer Models

APPENDIX

E

Storm Water Computer Models and Information Tools

Table of Contents

List of Tables

List of Figures

E.1 Introduction

Storm water management is becoming increasingly complex. The simple notion of collecting runoff and sending it efficiently to the nearest stream is being replaced with considerations of storm water quantity and quality control, infrastructure management, master planning and modeling, financing, complaint tracking, and more. Information needs are critical to a successful local program. North Central Texas communities need to both invest in and be aware of new and emerging technologies that can provide the ability to collect, organize, maintain and effectively use vast amounts of data and information for their community's storm water management activities.

There is a great deal of computer software that has been developed based on the intensive research effort in urban hydrology, hydraulics and storm water quality. Computer models use the computational power of computers to automate the tedious and time-consuming manual calculations. Most models also include extensive routines for data management, including input and output procedures, and possibly including graphics and statistical capabilities.

Computer modeling became an integral part of storm drainage planning and design in the mid-1970s. Several agencies undertook major software developments and these were soon supplemented by a plethora of proprietary models, many of which were simply variants on the originals. The proliferation of personal computers in the 1990s has made it possible for virtually every engineer to use state-of-the-art analytical technology for purposes ranging from analysis of individual pipes to comprehensive storm water management plans for entire cities.

In addition to the simulation of hydrologic and hydraulic processes, computer models can have other uses. They can provide a quantitative means to test alternatives and controls before implementation of expensive measures in the field. If a model has been calibrated and verified at a minimum of one site, it may be used to simulate non-monitored conditions and to extrapolate results to similar ungauged sites. Models may be used to extend time series of flows, stages and quality parameters beyond the duration of measurements, from which statistical performance measures then may be derived. They may also be used for design optimization and real-time control.

A local staff or design engineer will typically use one or more of these pieces of software in storm water facility design and review, according to the design objectives and available resources. However, it should be kept in mind that proper use of computer modeling packages requires a good knowledge of the operations of the software model and any assumptions that the model makes. The engineer should have knowledge of the hydrological, hydraulic and water quality processes simulated and knowledge of the algorithms employed by the model to perform the simulation.

E.2 Types of Models

In urban storm water management there are typically three types of computer models that are commonly used: *hydrologic*, *hydraulic* and *water quality* models. There are also a number of other specialty models to simulate ancillary issues (some of which are sub-sets of the three main categories) such as sediment transport, channel stability, lake quality, dissolved oxygen and evapotranspiration, etc.

E.2.1 Hydrologic Models

Hydrologic models attempt to simulate the rainfall-runoff process to tell us “how much water, how often.” They use rainfall information or models to provide runoff characteristics including peak flow, flood hydrograph and flow frequencies. Hydrologic models can be either:

- *Deterministic* – giving one answer for a specific input set, or
- *Stochastic* – involving random inputs giving any number of responses for a given set of parameters;
- *Continuous* – simulating many storm events over a period of time, or
- *Single Event* – simulating one storm event;

- *Lumped* – representing a large area of land use by a single set of parameters, or
- *Distributed* – land areas are broken into many small homogeneous areas each of which has a complete hydrologic calculation made on it.

E.2.2 Hydraulic Models

Hydraulic models take a known flow amount (typically the output of a hydrologic model) and provide information about flow height, location, velocity, direction, and pressure. Hydraulic models share some of the differing characteristics of hydrologic models (continuous vs. single event) and add the following:

- *One-dimensional* – calculating flow information in one direction (e.g. downstream) only, or
- *Multi-dimensional* – calculating flow information in several dimensions (e.g. in and out of the channel and downstream);

- *Steady* – having a single unchanging flow velocity value at a point in the system, or
- *Unsteady* – having changing flow velocities with time;

- *Uniform* – assuming the channel slope and energy slope are equal, or
- *Non-uniform* – solving a more complex formulation of the energy and momentum equations to account for the dynamic nature of flows.

For most problems encountered in hydraulics, a simple one-dimensional, steady model will work well. But if the volume and time distribution of flow are important (for example, in a steeper stream with storage behind a series of high culvert embankments) an unsteady model is needed. If there is a need to predict with accuracy the ebb and flow of floodwater out of a channel (for example in a wide, flat floodplain where there are relief openings under a road) then a 2-dimensional model becomes necessary. If pressure flow and the accurate computation of a hydraulic grade line are important an unsteady, non-uniform model with pressure flow calculating capabilities is needed.

E.2.3 Water Quality Models

The goal in water quality modeling is to adequately simulate the various processes and interactions of storm water pollution. Water quality models have been developed with an ability to predict loadings of various types of storm water pollutants.

Water quality models can become very complex if the complete cycle of buildup, wash-off and impact are determined. These models share the various features of hydrologic and hydraulic models in that it is the runoff flow that carries the pollutants. Therefore, a continuous hydrologic model with estimated pollution concentrations becomes a continuous water quality pollution model. Water quality models can reflect pollution from both point and nonpoint sources.

Water quality models tend to have applications that are targeted toward specific pollutants, source types or receiving waters. Some models involve biological processes as well as physical and chemical processes. Often great simplifications or gross assumptions are necessary to be able to model pollutant accumulations, transformations and eventual impacts.

Detailed short time increment predictions of “pollutographs” are seldom needed for the assessment of receiving water quality. Hence, the total storm event loads or mean concentrations are normally adequate. Simple spreadsheet-based loading models involve an estimate of the runoff volume which, when multiplied by an event mean concentration, provide an estimate of pollution loading. Because of the lack of ability to calibrate such models for variable physical parameters, such simple models tend to be more accurate the longer the time period over which the pollution load is averaged. An annual pollutant load prediction may tend toward a central estimate, while any specific storm prediction may be grossly in error when compared to actual loadings because antecedent conditions vary widely from week to week. Simulation models have the ability to adjust a number of loading parameters for calibration purposes and can simulate pollution accumulation over a long period. They can then more reliably predict loadings for any specific storm event.

While calibration data is not always needed in hydrologic or hydraulic models for an acceptably accurate answer, in water quality models the non-calibrated prediction is often off by orders of magnitude. Water quality predictions are not credible without adequate site-specific data for calibration and verification. However, even without specifically accurate loading values relative effects of pollution abatement controls can be tested using uncalibrated models.

E.2.4 Computer Model Applications

Storm water computer models can also be categorized by their use or application:

Screening-level models are typically equations or spreadsheet models that give a first estimate of the magnitude of urban runoff quality or quantity. At times this is the only level that is necessary to provide answers. This is true either because the answer needs to be only approximate or because there is no data to justify a more refined procedure.

Planning-level models are used to perform "what if" analysis comparing in a general way design alternatives or control options. They are used to establish flow frequencies, floodplain boundaries, and general pollution loading values.

Design-level models are oriented toward the detailed simulation of a single storm event for the purposes of urban storm water design. They provide a more complete description of flow or pollution values anywhere in the system of concern and allow for adjustment of various input and output variables in some detail. They can be more exact in the impact of control options, and tend to have a better ability to be calibrated to fit observed data.

Operational models are used to produce actual control decisions during a storm event. They are often linked with SCADA systems. They are often developed from modified or strongly calibrated design models, or can be developed on a site-specific basis to appropriately link with the system of concern and accurately model the important physical phenomena.

E.3 The Modeling Process

E.3.1 Basic Computer Modeling Principles

The following basic principles apply to all forms of computer modeling:

1. All computer models require site-specific information to be supplied by the user. Inputs are the measured or estimated parameters the model needs to make calculations. For example, for basic hydrologic models it might include: area, slope, land use, channel forms and roughness, connectivity, and rainfall. A basic hydraulic model would include: channel slope, discharge, roughness, shape, obstructions or constrictions, and connectivity. Water quality models may add pollution loading or build-up-washoff factors and fate and transport information. All models, for planning and design, allow the modeler to try different combinations of variables to see what happens (called a "what if" analysis).
2. While modeling generally yields more information, simpler methods may provide sufficient information for design or solving management issues. In general, the simplest method that provides the desired analysis should be used. The risk of using a more complex (and presumably "better") model is that it requires more expertise, data, support, etc. to use and understand, with a consequent higher probability of misapplication.
3. If water quality problems are being considered, it still may not be necessary to simulate quality processes since most control strategies are based on hydrologic or hydraulic considerations. Quality

processes are very difficult to simulate accurately. If abatement strategies can be developed without the simulation of water quality parameters, the overall modeling program will be greatly simplified.

Models sometimes may be used to extrapolate beyond the measured data record. It is important to recognize, however, that models do not extend data, but rather generate simulated numbers that should never be assumed to be the same as data collected in the field. Careful consideration should be given when using models to provide input to receiving water quality analyses. The quality response of most receiving waters is relatively insensitive to such short-term variations. In many instances, the total storm load will suffice to determine the receiving water response. Simulation of short time increment changes in concentrations and loads is generally necessary only for analysis of control options, such as storage or high-rate treatment, whose efficiency may depend on the transient behavior of the quality constituents.

The overall modeling process involves: (1) development of study or model objectives, (2) identification of resources and constraints, and finally, (3) the selection and implementation of the model itself.

E.3.2 Model Objectives

It is important to know specifically what answers are needed, to what accuracy, and in what format. Requiring a simple peak flow is far different from needing to know the timing of peaks from several different intersecting watersheds. Estimating future floodplain elevations along a reach is a fundamentally different problem than finding the probability of roadway overtopping.

A review of the problem begins the process of determining the model objectives. These objectives also establish a performance or design criteria for the model. Must the system handle the 25-year storm? Are future conditions important? Which ones? Are annual loadings of pollution adequate? Which pollutants?

Those aspects of the system to be modeled will dictate what models are appropriate for use. For example, if storm sewers are present then an open channel model can be ruled out as an appropriate model for the entire system. If a specific type of hydraulic structure is present that a standard model cannot handle, an alternate way to simulate that structure will be necessary.

Model objectives also explain how the numbers generated from the model will relate to the needs of the study. For example, if a cost-benefit analysis is required, the model results must be interpreted in terms of overall life-cycle cost and not simply in terms of discharge rate.

E.3.3 Model Constraints

Availability of data, funds, time and user ability can potentially constrain modeling solutions. The goal of any modeling effort is to develop an approach that stays within the constraints dictated while addressing the needs of the study identified in the previous step. Data collection/availability and cost are usually the chief constraints.

Sources of existing available data should be researched. Look for data that tends to “ground truth” model outputs. Even partial data can be useful if it helps to validate the model or modeling results. After existing data sources have been identified, the need to gather additional data is assessed. Automated processes and systems such as GIS and GPS can reduce both cost and human error. A consideration of the long-term use of data and its maintenance is necessary. For example, if the model is to eventually become an operational model, the ability to maintain the data in a cost effective way becomes of paramount importance.

Accuracy and the corresponding necessary level of detail are of overriding importance. Accuracy depends on both the accuracy of the input data and the degree to which the model adequately represents the hydrologic, hydraulic or water quality processes being modeled. For example, if lumped hydrologic parameters are adequate, then the cost of the modeling effort can be reduced. However, the ability to determine information within the sub-basin represented by a single parameter is lost. Changing model needs from an average 500-acre sub-basin size to a 50-acre size can increase the cost of a model almost ten fold. Is the information derived worth the cost?

Both risk and uncertainty affect the modeler's ability to predict results accurately. Risk is an estimated chance of an occurrence, such as flooding. Uncertainty is the error associated with measuring or estimating key parameters or functions. Uncertainty arises due to errors in sampling, measurement, estimation and forecasting, and modeling. For hydrologic and hydraulic analysis, stage and discharge are of prime importance. Uncertainty in discharge is due to short or nonexistent flood records, inaccurate rainfall-runoff modeling, and inaccuracy in known flood flow regulation where it exists. Stage uncertainty comes from errors and unknowns in roughness, geometry, debris accumulation, sediment effects and others factors.

Accuracy developed in one area can be impacted by rough estimates in another, and the technological gains lost. For example, the gains in accuracy from very precise field surveys of cross sections can be lost if the estimates of roughness coefficients or discharge rates are very approximate.

Sensitivity analysis involves holding all parameters constant except one and assessing the change in output variable of concern with a certain percent change in the input variable. Those variables that are amplified in the output should be estimated with higher accuracy and with a more detailed consideration of the potential range of values and the need for conservative design. The modeler must try to assess how accurate estimates are and to account for risk and uncertainty through estimating the range of potential error and choosing values that balance conservative engineering with cost consciousness. The designer typically develops a "most likely" estimate of a certain design parameter (for example, 10-year storm rainfall or Manning's roughness coefficient) and then uses sensitivity analysis to test the impact of variability in the parameter estimate on the final solution

E.3.4 Selection and Implementation

Once the model objectives and constraints have been evaluated, the model (or models) is selected and the study or design is implemented. Typical steps in model implementation include *validation*, *calibration*, *verification* and *production*.

Validation involves a determination that the model is structured and coded as intended for the range of variables to be encountered in the study. Validation tests key algorithms for accuracy. For example, if a hydrologic model cannot handle short time steps or long time periods it cannot be used without modification. If a certain model begins to lose accuracy at high or low imperviousness or cannot accurately handle backwater situations, and these will be encountered in practice the model cannot be used. Often validation is a one-time effort, after which the modeler is comfortable with the model's "quirks" and knows how to deal with them. Validation often involves pushing parameters to the limit of reasonable extent to test an algorithm. For example, in a hydrologic model infiltration can be reduced to zero to test if the input and output hydrographs are equal. Or the model can be run with small rainfalls using porous soils to determine if no runoff is generated, or only runoff from directly connected impervious areas.

Calibration is the comparison of a model to field measurements, other known estimates of output (e.g. regression equations), or another model known to be accurate, and the subsequent adjustment of the model to best fit those measurements. *Verification* then tests the calibrated model against another set of data not used in the calibration. This step is not always possible due to the general shortage of data of any sort in storm water management. Goodness of prediction is done through a simple comparison of the difference in observed and predicted peaks, pollution loads, flood elevations or volumes divided by the observed values and expressed as a percentage, or as simple ratio. Assessing the goodness of fit of a hydrograph is done by calculating the sum of the squares of the difference between observed and predicted values at discreet time steps.

Once the model is prepared for use, attention shifts to efficient *production* methods that minimize the potential for errors while maximizing efficiency. Often "production line"-type efforts are used for large modeling projects. However, constant attention must be paid to ensure the execution of correct procedures, detailed documentation of efforts and input/output data sets, and recognition of anomalies that would invalidate a particular model run.

While there is much to be gained from simple user interfaces and black box approaches that simplify the input and output processes, there is an inherent danger that the modeler will not be aware of errors or problems in the modeling process. For example, in hydraulic modeling, shifts from super- to sub-critical flow happen at sharp break points and are reflected in a jump in water surface. If not caught, a model will under predict flow elevation. Numeric instability in mathematical algorithms may give oscillating answers that have nothing to do with reality. A structured review process must be established to insure reasonableness of output and accuracy of input values has been used. Labeling of data sets should be systematic and exact.

E.4 Summary of Commonly-Used Models

Computer models can be simple, representing only a very few measured or estimated input parameters or can be very complex involving twenty times the number of input parameters. The “right” model is the one that: (1) the user thoroughly understands, (2) gives adequately accurate and clearly displayed answers to the key questions, (3) minimizes time and cost, and (4) uses readily available or collected information. Complex models used to answer simple questions are not an advantage. However, simple models that do not model key necessary physical processes are useless.

There is no one engineering model or software that addresses all hydrologic, hydraulic and water quality situations. Design needs and troubleshooting for watershed and storm water management occur on several different scales and can be either system-wide (i.e., watershed) or localized. System-wide issues can occur on both large and small drainage systems, but generally require detailed, and often expensive, watershed models and/or design tools. The program(s) chosen to address these issues should handle both major and minor drainage systems. Localized issues also exist on both major and minor drainage systems, but unlike system-wide problems, flood and water quality solution alternatives can usually be developed quickly and cheaply using simpler engineering methods and design tools.

Table E.4-1 lists several widely used computer programs and modeling packages. The programs were examined for their applicability to both system-wide and localized issues, the methodologies used for computations, and ease-of-use.

For the purposes of this table, major drainage systems are defined as those draining to larger receiving waters. These are typically FEMA-regulated streams, or lakes or reservoirs. Minor drainage systems are smaller natural and man-made systems that drain to the more major streams. Minor drainage systems can have both closed and open-channel components and can include, but are not limited to, neighborhood storm sewers, culverts, ditches, and tributaries.

A brief description of program capabilities and methodologies are presented in a short discussion of each program.

Table E.4-1 Storm Water Modeling Programs and Design Tools					
	Major System Modeling	**Minor System Modeling**	**Hydrologic Features**	**Hydraulic Features**	**Water Quality Features**
Hydrology Software					
HEC-1	**X**		**X**		
HEC-HMS	**X**		**X**		
TR-55			**X**		
PondPack		**X**	**X**	**X**	
WMS	**X**		**X**		
Watershed Modeling	**X**		**X**		
Hydraulics Software					
HEC-RAS	**X**			**X**	
WSPRO	**X**			**X**	
EPA SWMM	**X**	**X**	**X**	**X**	**X**
CulvertMaster		**X**		**X**	
FlowMaster		**X**		**X**	
Water Quality Software					
HSPF	**X**		**X**		**X**
BASINS	**X**		**X**	**X**	**X**
QUAL2E	**X**			**X**	**X**
WASP5	**X**			**X**	**X**
SLAMM	**X**		**X**		**X**

E.4.1 Hydrology Programs

HEC-1 - Flood Hydrograph Package

HEC-1 was developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers to simulate the surface runoff response of a watershed to rainfall events. Although it is a DOS-based program, it is still considered by many in the engineering and regulatory communities to be the leading model for major drainage system applications such as Flood Insurance Studies and watershed master planning. HEC-1 is accepted by the Federal Emergency Management Agency; therefore it is the most widely used model for major drainage system analyses.

In a HEC-1 model, the watershed is represented in the model as an interconnected system of hydrologic (e.g., sub-basins, reservoirs, ponds) and hydraulic (e.g., channels, closed conduits, pumps) components. The model computes a runoff hydrograph at each component, combining two or more hydrographs as it moves downstream in the watershed. The model has a variety of rainfall-runoff simulation methods, including the popular SCS Curve Number methodology. The user can define rainfall events using gage or historical data, or HEC-1 can generate synthetic storms. Hydrograph generation is performed using the unit hydrograph technique. Clark, SCS Dimensionless, and Snyder Unit Hydrographs are the available methodologies. Several common channel and storage routing techniques are available as well.

HEC-1 is not considered a "design tool." The program has limited hydraulic capabilities. It does not account for tailwater effects and cannot adequately simulate many urban hydraulic structures such as pipe networks, culverts and multi-stage detention pond outlet structures. However, there are other hydrologic applications developed within HEC-1 that have been utilized with much success. Multiplan-multiflood analyses allow the user to simulate a number of flood events for different watershed situations (or plans). The dam safety option enables the user to analyze the impact dam overtopping or structural failure on downstream areas. Flood damage analyses assess the economic impact of flood damage.

Because it is not a Windows-based program, HEC-1 does not have easy-to-use input and output report generation and graphical capabilities, and therefore is generally not considered a user-friendly program. Because of its wide acceptance, several software development companies have incorporated the source code into enhanced "shells" to provide a user-friendly interface and graphical input and output capabilities. Examples of these programs include Graphical HEC-1 developed by Haested Methods and WMS developed by the Environmental Modeling Research Laboratory.

HEC-HMS
The Corps of Engineers has developed a user-friendly, Windows-based Hydrologic Modeling System (HEC-HMS) intended to replace the DOS-based HEC-1 model. The Town of Copper Canyon recommends submitting the HEC-HMS. The new program has all the components of HEC-1, with more user-friendly input and output processors and graphical capabilities. HEC-1 files can be imported into HEC-HMS.

TR-55 - Technical Release 55
The TR-55 model is a DOS-based software package used for estimating runoff hydrographs and peak discharges for small urban watersheds. The model was developed by the NRCS (formally SCS), and therefore uses SCS hydrograph methodology to estimate runoff. No other methodology is available in the program. Four 24-hour regional rainfall distributions are available for use. Rainfall durations less than 24-hours cannot be simulated. Using detailed input data entered by the user, the TR-55 model can calculate the area-weighted CN, time of concentration and travel time. Detention pond (i.e., storage) analysis is also available in the TR-55 model, and is intended for initial pond sizing. Final design requires a more detailed analysis.

TR-55 is easy-to-use, however because it is DOS-based it does not have the useful editing and graphical capabilities of a Windows-based program. Haestad Methods, Inc., included most of the TR-55 capabilities in its PondPack program described below.

PONDPACK
PondPack, by Haestad Methods, Inc., is Windows-based software developed for modeling general hydrology and runoff from site development. The program analyzes pre- and post-developed watershed conditions and sizes detention ponds. It also computes outlet rating-curves with consideration of tailwater effects, accounts for pond infiltration, calculates detention times and analyzes channels.

Rainfall options are unlimited. The user can model any duration or distribution, for synthetic or real storm events. Several peak discharge and hydrograph computation methods are available, including SCS, the Rational Method and the Santa Barbara Unit Hydrograph procedure. Infiltration can be considered, and pond and channel routing options are available as well. Like TR-55, PondPack allows the user to calculate hydrologic parameters, such as the time of concentration, within the program.

PondPack has limited, but useful hydraulic features, using Manning's equation to model natural and man-made channels and pipes. A wide variety of detention pond outlet structure configurations can be modeled, including low flow culverts, weirs, riser pipes, and even user-defined structures.

WMS - Watershed Modeling System
WMS was developed by the Engineer Computer Graphics Laboratory of Brigham Young University. WMS is a Windows-based user interface that provides a link between terrain models and GIS software, with industry standard lumped parameter hydrologic models, including HEC-1, TR-55, TR-20 and others. The hydrologic models can be run from the WMS interface. The link between the spatial terrain data and the hydrologic model(s) gives the user the ability to develop hydrologic data that is typically gathered using manual methods from within the program. For example, when using SCS methodologies, the user can delineate watersheds and sub-basins, determine areas and curve numbers, and calculate the time of concentration at the computer. Typically, these computations are done manually, and are laborious and time-consuming. WMS attempts to utilize digital spatial data to make these tasks more efficient.

Watershed Modeling
The Watershed Modeling program was developed to compute runoff and design flood control structures. The program can run inside the MicroStation CAD system. Like WMS, this feature enables the program to delineate and analyze the drainage area of interest. Area, curve number, land use and other hydrologic parameters can be computed and/or catalogued for the user, removing much of the manual calculation typically performed by the hydrologic modeler.

Watershed Modeling contains a variety of methods to calculate flood hydrographs, including SCS, Snyder and Rational methods. Rainfall can be synthetic or user-defined, with any duration and return period. Rainfall maps for the entire U.S. are provided to help the user calculate IDF relationships. Several techniques are available for channel and storage routing. The user also has a wide variety of outlet structure options for detention pond analysis and design.

E.4.2 Hydraulics Programs

HEC-RAS - River Analysis System
HEC-RAS is a Windows-based hydraulic model developed by the Corps of Engineers to replace the popular, DOS-based HEC-2 model. RAS has the ability to import and convert HEC-2 input files and expounds upon the capabilities of HEC-2. Since its introduction several years ago, the user-friendly HEC-RAS has become known as an excellent model for simulation of major systems (i.e., open channel flow) and has become the chief model for calculating floodplain elevations and determining floodway encroachments for Flood Insurance Studies. Like HEC-2, HEC-RAS has been accepted for FIS analysis by the FEMA. However, RAS is a much easier model to use than HEC-2 as it has an extremely useful interface that provides the immediate capability to view model input and output data in graphical, tabular, and report formats.

HEC-RAS performs one-dimensional analysis for steady flow water surface profiles, using the energy equation. Energy losses are calculated using Manning's equation and contraction and expansion changes. Rapidly varied flow (e.g., hydraulic jumps) is modeled using the momentum equation. The effects of in-stream structures, such as bridges, culverts, weirs and floodplain obstructions and in-stream changes such as levees and channel improvements can be simulated. The model allows the user to define the geometry of the channel or structure to the level of detail required by the application. One popular and useful feature of the HEC-RAS model is the capability to easily facilitate floodway encroachment analysis. Five encroachment methods are available to the user.

The Corps of Engineers has stated that future versions of the HEC-RAS model will have components for unsteady flow and sediment transport simulations. In the model's original form, RAS does not provide a tie to GIS information. However, the model was designed with GIS applications in mind and future ties between RAS and GIS platforms are anticipated. Several software developers have already released enhanced versions of RAS that provide the capability to import GIS data for channel geometry and export RAS output for floodplain and floodway delineation. Examples of such software include BOSS RMS, developed by BOSS International and SMS (Surface Water Modeling System), distributed by the Scientific Software Group.

WSPRO
WSPRO was developed by the USGS to compute water surface profiles for one-dimensional, gradually varied, steady flow. Like HEC-RAS, WSPRO can develop profiles in subcritical, critical and supercritical flow regimes. WSPRO is designated HY-7 in the Federal Highway

Administration (FHWA) computer program series and its original objective was analysis and design of bridge openings and embankment configurations. Since then, the model has been expanded to model open channels and culverts.

Open channel computations use standard step-backwater techniques. Flow through bridges is simulated using an energy-balancing technique that uses a coefficient of discharge and estimates an effective flow length. Pressure flow under bridges using orifice-type flow equations developed by the FHWA. Culvert flow is simulated using FHWA techniques for inlet control and energy balance for outlet control.

WSPRO is considered a fairly easy-to-use DOS-based model, applicable to water surface profile analysis for highway design, flood insurance studies, and establishing stage-discharge relationships. However, the model in its original form is not Windows based and therefore does not have the useful editing and graphical features found in HEC-RAS. Like HEC-RAS, a third party software developer has designed SMS (Surface Water Modeling Software) to support both pre- and post-processing of WSPRO data.

EPA SWMM - Storm Water Management Model

EPA SWMM was developed by the Environmental Protection Agency (EPA) to analyze storm water quantity and quality problems associated with runoff from urban areas. EPA SWMM has become the model of choice for simulation of minor drainage systems primarily composed of closed conduits. The model can simulate both single-event and continuous events and has the capability to model both wet and dry weather flow. The basic output from SWMM consists of runoff hydrographs, pollutographs, storage volumes and flow stages and depths.

SWMM's hydraulic computations are link-node based, and are performed in separate modules, called blocks. The EXTRAN computational block solves complete dynamic flow routing equations to simulate backwater, looped pipe connections, manhole surcharging and pressure flow. It is the most comprehensive model in its capabilities to simulate urban storm flow and many cities have used successfully for storm water, sanitary, or combined sewer system modeling. Open channel flow can be simulated using the TRANSPORT block, which solves the kinematic wave equations for natural channel cross-sections.

Although evaluated for this study as a hydraulic model, SWMM has both hydrologic and water quality components. Hydrologic processes are simulated using the RUNOFF block, which computes the quantity and quality of runoff from drainage areas and routes the flow to the major sewer system lines. Pollutant transport is simulated in tandem with hydrologic and hydraulic computations and consists of calculation of pollutant buildup and washoff from land surfaces and pollutant routing, scour and in-conduit suspension in flow conduits and channels.

EPA SWMM is a public domain, DOS-based model. For large watersheds with extensive pipe networks, input and output processing can be tedious and confusing. Because of the popularity of the model commercial, third-party enhancements to SWMM have become more common, making the model a strong choice for minor system drainage modeling. Examples of commercially enhanced versions of EPA SWMM include MIKE SWMM, distributed by BOSS International, XPSWMM by XP-Software, and PCSWMM by Computational Hydraulics Inc (CHI). CHI also developed PCSWMM GIS, which ties the SWMM model to a GIS platform.

CULVERTMASTER

CulvertMaster, developed by Haestad Methods, Inc., is an easy-to-use, Windows-based culvert simulation and design program. The program can analyze pressure or free surface flow conditions and in subcritical, critical and supercritical flow conditions, based on drawdown and backwater. A variety of common culvert shapes and section types are available. Tailwater effects are considered and user can enter a constant tailwater elevation, a rating curve, or specify an outlet channel section. Culvert hydraulics are solved using FHWA methodology for inlet and outlet control computations. Roadway and weir overtopping are checked in the solution of the culvert.

CulvertMaster does have a hydrologic analysis component to determine peak flow using the Rational Method, SCS Graphical Peak Methods. The user also has the option of entering a known peak flow rate. The user must enter all rainfall and runoff information (e.g., IDF data, rainfall depths, curve numbers, C coefficients, etc).

FLOWMASTER

FlowMaster, also developed by Haestad Methods, Inc., is a Windows-based hydraulic pipe and channel design program. The user enters known information on the channel section or pipe, and allows the program to solve for the unknown parameter(s), such as diameter, depth, slope, roughness, capacity, velocity, etc. Solution methods include Manning's equation, the Darcy-Weisbach formula, Hazen-Williams formula, and Kutter's Formula. The program also features calculations for weirs, orifices, gutter flow, ditch and median flow and discharge into curb, grated, and slot inlets.

Other Hydraulics Programs

In addition to the Hydraulics Software listed in Table G.4-1, appropriately applied versions of the following computer models are also available for use.

- *CULVERT* – by TxDOT for hydraulic analysis and design of culverts.
- *WINSTORM* – by TxDOT for analysis and design of storm sewer.
- *HY8* – by the Federal Highway Association (FHWA) for hydraulic analysis and design of culverts.
- *HY8Energy* – by FHWA for the selection and analysis of energy dissipation structures.
- *CHANLPRO* – by U.S. Army Corps of Engineers for analysis and design of streambank protection.

E.4.3 Water Quality Programs

HSPF - Hydrologic Simulation Program FORTRAN

The HSPF model was developed by the EPA for the continuous or single-event simulation of runoff quantity and quality from a watershed. The original model was developed from the Stanford Watershed Model, which simulated runoff quantity only. It was expanded to include quality components, and has since become a popular model for continuous non-point source water quality simulations. Non-point source conventional and toxic organic pollutants from urban and agricultural land uses can be simulated, on pervious and impervious land surfaces and in streams and well-mixed impoundments. The various hydrologic processes are represented mathematically as flows and storages. The watershed is divided into land segments, channel reaches and reservoirs. Water, sediment and pollutants leaving a land segment move laterally to a downstream land segment, a stream or river reach, or reservoir. Infiltration is considered for pervious land segments.

HSPF model output includes time series information for water quality and quantity, flow rates, sediment loads, and nutrient and pesticide concentrations. To manage the large amounts of data associated with the model, HSPF includes a database management system. To date, HSPF is still a DOS-based model and therefore does not have the useful graphical and editing options of a Windows-based program. Input data requirements for the model are extensive and the model takes some time to learn. However the EPA continues to expand and develop HSPF, and still recommends it for the continuous simulation of hydrology and water quality in watersheds.

BASINS - Better Assessment Science Integrating Point and Non-Point Sources

The BASINS watershed analysis system was developed by the EPA for use by regional, state and local pollution control agencies to analyze water quality on a watershed-wide basis. BASINS integrates the ArcView GIS environment, national databases containing watershed data, and modeling programs and water quality assessment tools into one stand-alone program. The program will analyze both point and non-point sources and supports the development of the total maximum daily loads (TMDLs). The assessment tools and models utilized in BASINS include TARGET, ASSESS, Data Mining, HSPF, TOXIROUTE and QUAL2E. The databases, assessment tools and models are directly tied to the ArcView GIS environment.

QUAL2EU - Enhanced Stream Water Quality Model

QUAL2EU was developed by the EPA and intended for use as a water quality planning tool. The model actually consists of four modules: QUAL2E - the original water quality model, QUAL2EU - the water quality model with uncertainty analysis, and pre and post processing modules. QUAL2EU simulates steady state or dynamic conditions in branching streams and well-mixed lakes, and can evaluate the impact of waste loads on water quality. It also can enhance a field sampling program by helping to identify the magnitude and quality characteristics of non-point waste loads. Up to 15 water quality constituents can be modeled. Dynamic simulation allows the user to study the effects of diurnal variations in water quality (primarily DO and temperature). The steady state option allows the user to perform uncertainty analyses.

QUAL2EU is a DOS-based program, and the user will require some length of time to develop a QUAL2EU model, mainly due to the complexity of the model and data requirements for a simulation. However, to ease user interaction with the model an interactive preprocessor (AQUAL2) has been developed to help the user build input data files. A postprocessor (Q2PLOT) also exists that displays model output in textual or graphical formats.

WASP5 - Water Quality Analysis Simulation Program
The WASP5 model was developed by the EPA to simulate contaminant fate in surface waters. Both chemical and toxic pollution can be simulated in one, two, or three dimensions. Problems studied using WASP5 include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination. WASP5 has an associated stand alone hydrodynamic model, called DYNHYD5, that simulates variable tidal cycles, wind and unsteady flows. DYNHYD4 supplies flows and volumes to the water quality model. The model is DOS-based, however WASP packages can be obtained from outside vendors that include interactive tabular and graphical pre- and post-processors.

SLAMM - Source Loading and Management Model
The SLAMM model was originally developed as a planning tool to model runoff water quality changes resulting from urban runoff pollutants. The model has been expanded to included simulation of common water quality best management practices such as infiltration BMPs, wet detention ponds, porous pavement, street cleaning, catchbasin cleaning and grass swales. Unlike other water quality models, SLAMM focuses on small storm hydrology and pollutant washoff, which is large contributor to urban stream water quality problems. SLAMM computations are based on field observations, as opposed to theoretical processes. SLAMM can be used in conjunction with more commonly used hydrologic models to predict pollutant sources and flows.

E.5 Information Tools

E.5.1 Geographic Information Systems (GIS)

A Geographic Information System (GIS) is a computer-based database system designed to spatially analyze and display data. A GIS stores information about a given area as a collection of thematic layers that can be linked together by geography or geo-referencing. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world storm water problems from tracking complaints, to master planning applications and infrastructure management.

GIS Components

A functional GIS integrates four key components: hardware, software, data, and trained users:

- *Hardware* – Desktop computers and digitizing equipment are the primary hardware components of a typical local GIS system.
- *Software* – GIS software provides the functionality and tools needed to capture or input, store, analyze, display, and output geographic information.
- *Data* – Generally, the most costly part of a GIS is data development. Some geographic data and related tabular data can be collected in-house or purchased from commercial data providers. A

GIS can also integrate tabular data or electronic drafting (CAD) data to build information into the GIS database.

- *Users* – GIS technology is of limited value without trained operators who understand the data, system, organization and how to apply the resources to achieve the desired results.

GIS Functions

General purpose geographic information systems essentially perform four processes or tasks:

1. Data Input – Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology can sometimes automate this process fully for projects using scanning technology; some jobs may require some manual digitizing using a digitizing table. Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from a number of different sources including the North Central Texas GIS Data Clearinghouse at *http://gis.dfwinfo.com/geodata/.*

2. Data Conversion – It is likely that some needed data may not be in the correct format or proper map projection to use with your system. Most GIS software has the ability to do this conversion, but in some cases this is better done by a contractor who specializes in data conversion. Be careful with third party data; it is imperative that you understand the source, quality, age, accuracy and limitations of a dataset. This and other information about a dataset is often provided in (FGDG) metadata that accompanies the dataset.

3. Query and Analysis – Once there is a functioning GIS containing geographic information, it can be used to answer questions such as:

- Who owns the land parcel being flooded?
- What is the distance between two stream locations?
- Which homes are located in the updated floodplain?
- How will the new development impact downstream properties?
- What types of infrastructure give us the most complaints and where are they located?

GIS provides both simple point-and-click query capabilities and sophisticated spatial analysis tools to provide timely information to storm water managers and analysts alike. GIS technology can also be used to analyze geographic data to look for patterns and trends and to undertake "what if" scenarios. Most modern GIS's have many powerful analytical tools including:

- *Size Analysis* – Provides specific information about a feature. (e.g. What is the area and perimeter of a parcel?)
- *Proximity Analysis* – Determines relationships between objects and areas. (e.g. Who is located within 100 feet of the streambank?)
- *Overlay Analysis* – Performs integration of different data layers. (e.g. What is the SCS curve number for this sub-watershed considering soils, and land use?) Figure G.3-1 illustrates the overlay concept.
- *Network Analysis* – Analyzes the connectivity of linear features and establishes routes or direction of flow. (e.g. Which pipes feed into this junction box?)
- *Raster Analysis* – Utilizes a raster model to address a number of hydrologic issues. (e.g. What does the 3-D model of this watershed look like? Where does the water flow?)

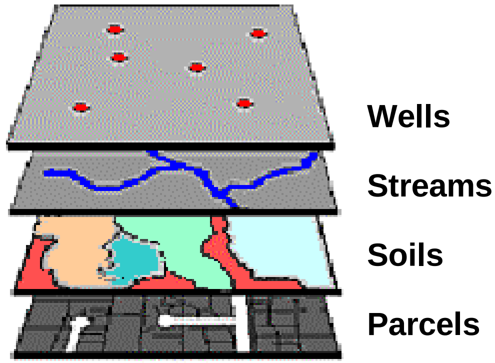


Figure E.5-1 Example of Overlay Analysis
Source: ESRI

4. Data Display, Output and Visualization – Geographic information systems excel at being able to create rich and detailed maps, graphs and other types of output which allow local staff, elected officials and the general public to be able to visualize and understand complex problems and large amounts of information. These maps and charts can be integrated with reports, three-dimensional views, photographic images, and multimedia presentations.

Use of GIS in Storm Water Management

GIS can be useful to a community in a wide variety of storm water-related applications:

- GIS can be used for the mapping of surface features, land uses, soils, rainfall amounts, watershed boundaries, slopes, land cover, etc.
- A GIS can manage a storm water system inventory and information about facility conditions, storm sewer networks, maintenance scheduling, and problem areas.
- GIS can be used to automate certain tasks such as measuring the areas of subwatersheds, plotting floodplain boundaries, or assessing storm water utility fees. Figure G.3-2 shows an example of automated hydrologic mapping.
- A GIS can be used to evaluate water quality impacts and answer cause and effect questions, such as the relationship between various land uses and in-stream pollution monitoring results.
- “What if” analyses can be undertaken with GIS. For example, various land use scenarios and their impacts on pollution or flooding can be tried in various combinations to determine the best management solutions or to determine the outcome of current decisions. When tied to hydrology, hydraulics and/or water quality models this type of analysis becomes a powerful tool to assess the impacts of new development on downstream properties. For example, Figure G.3-3 shows the flooding impacts on a small tributary for a proposed new development approved during a rezoning.
- GIS databases can provide staff, elected officials, and citizens with immediate answers and ready information. For example, inventory, complaints and other information about storm water infrastructure (including pictures) can be placed in a database tied to geographic location.
- Complex problems or changes over time, such as water quality improvements, can be easily visualized in maps and graphs generated by GIS systems.

- GIS maps can be used to educate or convince citizens and political leadership concerning a course of action or a project's viability.

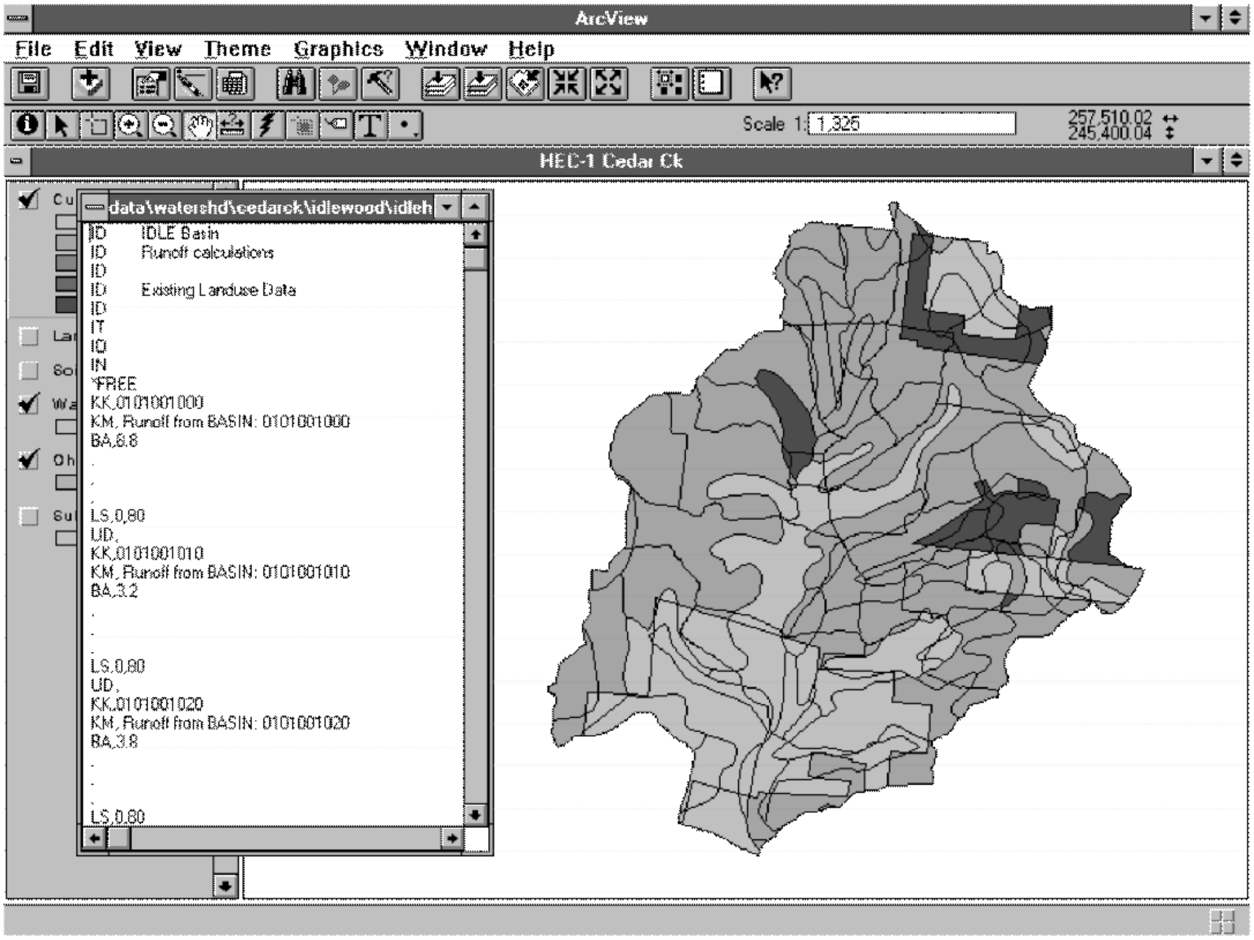


Figure E.5-2 Automated Hydrologic Modeling

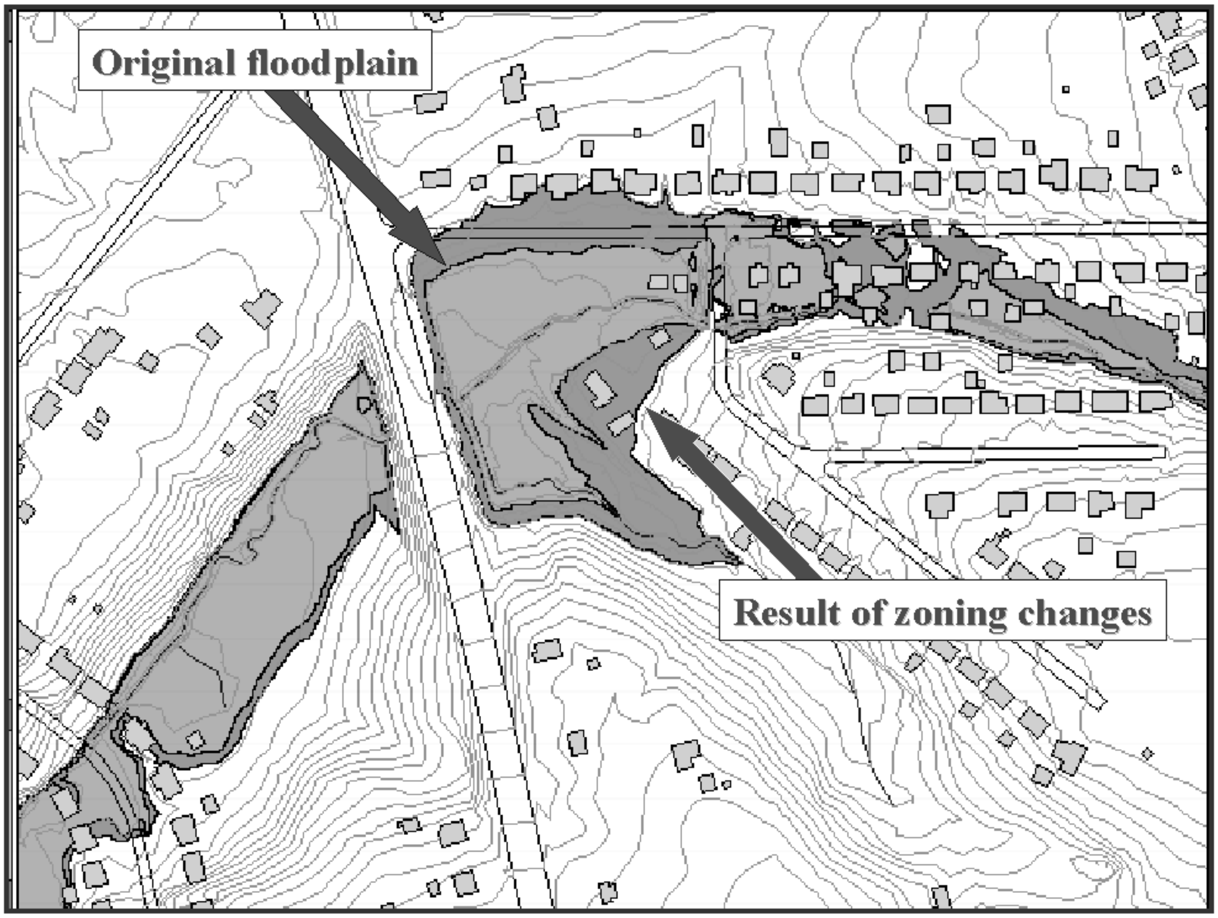


Figure E.5-3 Use of a GIS to Map Current and Potential Floodplains

Communities often make the mistake of making enormous expenditures on data, hardware and software and databases but little on planning, staff familiarization, training and graphical user interface (GUI) and applications development. The end result is often an unusable system accessible by only a few who have the resources to learn the system, hire competent staff, and develop applications. It is often better to target the GIS implementation to certain needs and quickly roll-out applications that work for these needs even prior to the complete development of the database and overall system.

Proper implementation of GIS applications for storm water management involves planning for both storm water only applications and to integrate these applications with other potential users within the municipality.

Other Related Technologies

GIS is closely related to several other types of information systems, and can be used with these other information tools, including:

- *Computer-Assisted Design (CAD)* – CAD systems evolved to create designs and plans of buildings and infrastructure. The systems are designed to do very detailed drafting and drawing but have only limited capability to attach data fields to the electronic drawing. As a result these systems do not have the capability to perform spatial analysis. Fortunately these drawings can be input to a GIS saving significant digitizing efforts. Once in a GIS, attribute data can then be added to the graphic features.

- *Database Management Systems (DBMS)* – These systems specialize in the storage and management of all types of data including geographic data. DBMS's are optimized to store and retrieve data and many GIS's rely on them for this purpose. They do not typically have the analytic and visualization tools common to GIS.

- *Supervisory Control and Data Acquisition System (SCADA)* –These systems combine the ability to monitor information (e.g. rainfall, stream flow, flood level, etc.) remotely through telemetry. SCADA systems can also execute commands to do such things as open gates or close valves from a distance. Examples of the use of SCADA include automating storm water pump station operation, automated alarms for flood warning and automated lowering of traffic control barrier arms during high water periods. SCADA systems can be combined with GIS to create comprehensive tracking systems.

E.5.2 Global Positioning Systems (GPS)

The Global Positioning System (GPS) is a space satellite based radio positioning system for obtaining accurate positional information for mapping or navigational purposes. GPS is made up of three distinct parts:

- *Satellites* – A constellation of 24 satellites orbiting the earth continuously emit a timing signal, provided by an on-board atomic clock, which is used to calculate the distance from each satellite to the receiver.
- *Receiver* – A GPS receiver located on the ground converts satellite signals into position, velocity, and time estimates.
- *Ground Control* – The U.S. Department of Defense (DOD) developed and currently manages the maintenance of the satellite system. The DOD uses tracking antennas to constantly monitor the precise position of the NAVSTAR satellites. These positions can be used to correct for errors in the calculated positions of the roving receivers.

The GPS was built and is maintained by the U.S. government. The satellites orbit at an altitude of approximately 12,000 miles in a 12-hour pattern that provides coverage to the entire earth. The system is capable of serving an unlimited number of users free of charge.

A GPS receiver uses information from at least 4 of the 24 satellites to precisely triangulate its position on the earth with about one meter accuracy. If a receiver cannot "see" four satellites, it can calculate a less-accurate estimate based on three satellites. Virtually all GPS receivers display basic positional information including latitude, longitude, elevation and speed (if moving). Most receivers also display time, heading, the number of satellites in view, where those satellites are positioned in the sky, and signal quality. GPS receivers for data collection can collect both the location (coordinates) and the attribute data of a given geographical feature.

GPS Applications to Storm Water

Storm water infrastructure inventories can be conducted more easily and in far less time using GPS. In the past, traditional geodetic surveying was used to locate and map storm water system components. A transit survey requires traversing between a known point to the point of interest, which may take half to one day per point. GPS surveying is much more efficient, possibly taking as little as a few seconds to map each point. Using bicycle or car-mounted equipment, a community may be able to survey up to 500 points per day. Obviously, the users must be trained and knowledgeable of the GPS devices and the objectives of the inventory to insure accuracy of the data.

GPS inventory work can be integrated with GIS application software. For example, a GIS layer of structural control locations can be created using GPS data and linked to a maintenance database. GPS data can also be used in computer modeling activities for storm water management. For instance, GPS data can be used to create a ground surface for automated stream floodplain modeling and mapping.

E.5.3 Remote Sensing

Remote Sensing is a technique for collecting observations of the earth using airborne platforms (airplanes and satellites) which have on-board instruments, or sensors. These sensors record physical images based on light, temperature or other reflected electromagnetic energy. This sensor data may be recorded as either analog data, such as photos or digital image data. Figure E.5-1 gives an example of low (25-meter), medium (5-meter) and high (1-meter) resolution satellite imagery.

Figure E.5-4 Low, Medium and High Resolution Satellite Imagery
Source: Space Imaging, Inc.

Ground reference data is then applied to aid in the analysis and interpretation of the sensor data, to calibrate the sensor, and to verify the information extracted from the sensor data. Remotely sensed images have a number of advantages to on-the-ground observation, including:

- Remote sensing can provide a regional view.
- Remote sensing can provide repetitive looks at the same area over time.
- Remote sensors "see" over a broader portion of the electromagnetic spectrum than the human eye.
- Sensors can focus on specific bandwidths in an image and can also look at a number of bandwidths simultaneously.
- Remote sensors often record signals electronically and provide geographically referenced data in digital format.
- Remote sensors operate in all seasons, at night, and in bad weather.

The airborne platforms that carry remote sensing instruments can be any kind of aircraft or satellite observing the Earth at altitudes anywhere from a few thousand feet to orbits of hundreds of kilometers. Satellites may employ a variety of sensors for numerous of applications. Currently, no single sensor is sensitive to all wavelengths. All sensors have fixed limits of spectral sensitivity and spatial sensitivity, the limit on how small an object on the earth's surface can be seen. The common types of sensors aboard satellites include:

- *Multispectral Scanner (MSS) Sensors* – Data are sensed in four spectral bands simultaneously: green, red, and two in near-infrared. (Steve – these can sense as many as six bands including UV, visible, near-IR, mid-IR and thermal)
- *Thematic Mapper (TM) Sensors* – Data are sensed in seven spectral bands simultaneously: blue, green, red, near-infrared, and two in mid-infrared. The seventh band detects only the thermal portion of the spectrum.
- *Radio Detection and Ranging (RADAR)* – Examples are Doppler radar systems used in weather and cloud cover predictions.

The appropriate band or combination of MSS bands should be selected for each interpretive use. For example bands 4 (green) and 5 (red) are usually best for detecting cultural features such as urban areas, roads, new subdivisions, gravel pits, and quarries. The TM bands are more finely tuned for vegetation discrimination than those of the MSS due in part to the narrower width of the green and red bands.

Examples of the growing number of remote sensing satellites include the U.S. Landsat satellites, the Indian Remote Sensing (IRS) satellites, Canada's RADARSAT, and the European Space Agency's Radar Satellite. Images from these satellites have spatial resolutions ranging from approximately 100 meters to 15 meters or better. The first commercial satellite capable of resolving objects on the ground as small as one meter in diameter was recently launched. Several competing companies have similar offerings. For example, the IKONOS-2 features high spatial resolutions of 1-meter panchromatic (black and white) and 4-meter multispectral (color). Panchromatic data has a higher resolution, while multispectral data provides better interpretation. Additionally, the 1-meter panchromatic spatial content can be combined with the spectral content of the 4-meter multispectral data. This 1-meter accuracy allows for a wide range of applications in storm water management at a price typically less than $500 per square mile (with some minimum order restrictions).

Digital Orthophoto Quarter Quadrangles (DOQQ's)

Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. Unlike standard aerial photography, relief displacement in orthophotos has been removed displaying ground features in their true ground position, thus allowing for direct measurement of distance, area, angles, and positions.

The National Aerial Photography Program (NAPP) is the primary source of aerial photography used in the production of 1-meter digital orthophotos. The North Central Texas Council of Governments (NCTCOG) maintains a database of digital aerial photography known as digital orthophoto quarter quadrangles (DOQQ's).

Figure E.5-2 illustrates a section of a DOQQ. Local government organizations that do not have access to their own digital aerial photography can acquire this data. The details concerning DOQQ's are:

- A standard DOQQ image covers an area of 3.75' x 3.75', or ¼ of a USGS quadrangle with some overlap
- 1-meter pixel resolution (1-meter resolution provides the minimum resolution needed for capturing smaller impervious features within the 200 sq. ft. to 100 sq. ft. range)
- Projected in Universal Transverse Mercator (UTM) with units in meters
- Available in TIFF format
- Coverage for the entire state of Texas
- Images were captured between 1994 and 1997
- DOQQ images for all of North Central Texas can be obtained at the www.tnris.state.tx.us/digitaldata/doq.htm.

Figure E.5-5 Example DOQQ

<u>Remote Sensing Applications for Storm Water</u>

Satellite imagery offers a diverse set of mapping products for projects ranging from land use/land cover evaluation to urban and regional planning, tax assessment and collection, and growth monitoring. In the case of storm water runoff, multispectral imagery can be used to measure impervious surfaces, such as rooftops, streets, and parking lots. Pervious surfaces, such as tree- and grass-covered areas can also be measured or delineated. Applying runoff coefficients to the area of each surface type can provide the best available estimates for nonpoint source water pollution. By adding parcel boundaries, it is possible to provide estimates of runoff per parcel in order to calculate storm water user fees. Similarly, designated land use categories can be applied to the area of each surface type and in combination with the known soil coverage can be used to calculate hydrologic curve numbers. Flood boundaries can be measured within a few meters accuracy in areas without tree cover using submeter multispectral fused imagery. Individual buildings and parcel boundaries can also be identified in order to assess flood vulnerability.

E.6 Additional Models

In addition to Storm Water Computer Models listed in Appendix E of this Manual, the Town of Copper Canyon accepts appropriately applied versions of the following computer models.

1. STORMCAD and GeoPac by Bentley for analysis and design of storm sewer.
2. Gabion Design Programs by Maccaferri:
    a. Macra 1 for Channel Design
    b. GawacWIN for Retaining Wall Design
3. SWFHYD (formerly NUDALLAS) by Fort Worth District, U.S. Army Corps of Engineers for hydrologic routing studies (use only where model currently exists).
4. AdICPR (Advanced Interconnected Pond Routing) by Streamline Technologies, Inc. for complex hydrograph routing particularly detention ponds in series.
5. InforWorks by MWHSoft (formerly Wallingford) for complex dynamic routing applications.

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Appendix F

Dams and Reservoirs in Texas

Dams and Reservoirs in Texas

The Texas Commission on Environmental Quality (TCEQ) regulates the construction of dams in Texas as per the Texas Administrative Code (Title 30, Part 1, Chapter 299 – Dams and Reservoirs). Approval from the TCEQ of plans and specifications is required for construction of a dam. The TCEQ also has the authority to inspect existing dams, and if necessary, require unsafe dams to be upgraded or removed. The Dam Safety Program is administered under the Field Operations Division of the Office of Compliance and Enforcement. Forms, Guidelines, Rules, Regulations, and many other resources can be found on-line at www.tnrcc.state.tx.us/enforcement/dam_safety/intro2.html.

F.1 Overview

Structures constructed for the purpose of the impounding water either on a temporary or permanent basis, which meet specific height, storage or hazard criteria are regulated by the State. The Texas Commission on Environmental Quality (TCEQ) is the regulatory agency responsible for administration of the State dam safety laws in Texas. Dams are classified according to size, and the potential for loss of human life and/or property damage within the area downstream of the dam. According to 30 TAC 299.1(a) dams fall under the jurisdiction of the TCEQ Dam Safety Program if the meet one or more of the following criteria:

(1) they have a height greater than or equal to 25 feet and a maximum storage capacity greater than or equal to 15 actre-feet;
(2) they have a height greater than 6 feet and a maximum storage capacity greater than or equal to 50 acre-feet;
(3) they are a high or significant hazard dam as defined by 30 TAC 299.14 (relating to Hazard Classification Criteria), regardless of height or maximum storage capacity; or
(4) they are used as a pumped storage or terminal storage facility.

The State regulates the design, construction, operation and maintenance of dams and this chapter provides an overview of some of the pertinent criteria.

F.2 Symbols and Definitions

The following words and terms, when used in this chapter, shall have the following meanings, unless the context clearly indicates otherwise:

Dam--Any barrier, including one for flood detention, designed to impound liquid volumes and which is defined as described in the previous section. This does not include highway, railroad, or other roadway embankments, including low water crossings that may temporarily detain floodwater, levees designed to prevent inundation by floodwater, closed dikes designed to temporarily impound liquids in the event of emergencies, or off-channel impoundments authorized by the commission in accordance with the Texas Water Code, Chapter 26, or the Texas Solid Waste Disposal Act, Texas Civil Statutes, Article 4477-7.

Effective crest of the dam--The elevation of the lowest point on the crest of the dam excluding spillways.

Existing dam--

(A) any dam constructed in accordance with necessary authorizations of the TCEQ;

(B) any existing dam exempt under the Texas Water Code, §11.142.

Height of dam--The vertical distance from the effective crest of the dam to the lowest elevation on the centerline or downstream toe of the dam, including the natural stream channel.

Maximum storage capacity--The volume of the impoundment created by the dam at the effective crest of the dam, usually expressed in acre-feet.

Normal storage capacity--The volume of the impoundment created by the dam, at the lowest uncontrolled spillway crest, usually expressed in acre-feet.

Probable maximum flood (PMF)--The flood magnitude that may be expected from the most critical combination of meteorologic and hydrologic conditions that are reasonably possible for a given watershed.

Probable maximum precipitation (PMP)--Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year.

Proposed dam--Any dam, constructed or to be constructed, which is not included in the definition of existing dam.

Spillway design flood (SDF)--The flood criteria that needs to be considered in the design of a proposed project.

Spillway evaluation flood (SEF)--The flood criteria that needs to be considered in the hydrologic evaluation of an existing structure.

F.3 Dam Classifications

Texas Administrative Code, Chapter 299 - DAMS

In accordance with the Texas Administrative Code, Chapter 299, the State of Texas considers a dam any barrier designed to impound liquid volumes that meets the criteria described in Section F.1. Dams in Texas are classified based on their size (height), hazard potential (failure consequences), and hydrologic criteria (spillway capacity).

F.3.1 Size

The Texas Administrative Code classifies the size of a dam as small, intermediate or large depending upon the height of the dam and the storage volume of the reservoir or pond created by the dam. The height of a dam is the vertical distance from the lowest point on the dam crest, excluding the spillway, to the lowest elevation on the centerline or downstream toe of the dam, including the natural stream channel. The storage capacity in acre-feet is the volume of the pond when the water level is at the crest of the service spillway. A “rule of thumb” is that the storage capacity of a pond in acre-feet is equal to the surface area of the pond in acres times 40 percent of the maximum depth of the pond in feet. Once the dam height and pond volume are know, the size classification of the dam is determined by the following table:

SIZE CLASSIFICATION		
Category	**Storage (Ac-Ft) Impoundment**	**Height (Ft.)**
Small	Equal to or Greater than 15 & Less than 1,000 Equal to or Greater than 50 & Less than 1,000	Equal to or Greater than 25 & Less than 40 Greater than 6 & Less than 40
Intermediate	Equal to or Greater than 1,000 & less than 50,000	Equal or Greater than 40 & less than 100
Large	Equal to or Greater than 50,000	Equal or Greater than 100

F.3.2 Hazard Potential

Hazard classification pertains to potential loss of human life and/or property damage within either existing or potential developments in the area downstream of the dam in event of failure or malfunction of the dam or appurtenant facilities. Hazard classification does not indicate any condition of the dam itself. Dams in the low hazard potential category are normally those in rural areas where failure may damage farm buildings, limited agricultural improvements, and county roads. Significant hazard potential category dams are usually those in predominantly rural areas where failure would not be expected to cause loss of human life, but may cause damage to isolated homes, secondary highways, minor railroads, or cause interruption of service or use (including the design purpose of the facility) of relatively important public utilities. Dams in the high hazard potential category are usually those in or near urban areas where failure would be expected to cause loss of human life, extensive damage to agricultural, industrial, or commercial facilities, important public utilities (including the design purpose of the facility), main highways, or railroads.

The Texas Administrative Code's hazard classifications for dams include the classifications of *low, significant or high* according to the criteria listed in the following table:

HAZARD POTENTIAL CLASSIFICATION		
Category	**Loss of Human Life**	**Economic Loss**
Low	None expected (No Permanent structures for human habitation)	Minimal (Underdeveloped to occasional structures or agricultural improvements)
Significant	Possible, (one to six lives or one or two habitable structures)	Appreciable (Notable agricultural, industrial or commercial development)
High	Expected (seven or more lives or three or more habitable structures)	Excessive (Extensive public, industrial, commercial or agricultural development)

F.3.3 Hydrologic Criteria

Uncontrolled floodwaters are one of the most powerful and destructive forces in nature. Dams that are not designed to withstand major storms may be destroyed by them, increasing flood damage downstream. This damage is too often catastrophic. In order to protect lives and property downstream, the Texas Administrative Code requires that dams be constructed to safely handle an appropriate percentage of the Probable Maximum Flood (PMF). This percentage varies according to the height of the dam, size of the impoundment, and extent and severity of damage possible upon failure. The requirements established in Texas are similar to those used in other states, and historical records of significant storms and dam failures this century verify that the design criteria are reasonable.

F.3.4 Development of the PMP

Scientists use both meteorological methods and historical records to determine the greatest amount of precipitation that is theoretically possible within a region. The historical data consists of point precipitation amounts measured at rain gages throughout the region being studied, or a region with very similar meteorologic and topographic characteristics. These rainfall data are subsequently maximized through "moisture maximization" and other numerical methods. Moisture maximization is a process in which the maximum possible atmospheric moisture for a region is applied to rainfall data from a historic storm. This process increases the rainfall depths, bringing them closer to their potential maximum.

Probable maximum precipitation amounts vary slightly throughout Texas because of variations in topography and meteorology. The PMP is greatest in the eastern portion of the state. Furthermore, not all storms have the same duration. Using the methods mentioned above, the PMP has been determined for different storm periods, generally ranging from six to seventy two hours.

F.3.5 Development of the PMF

The Probable Maximum Flood is the flood that is a direct result of the Probable Maximum Precipitation. However, drainage areas with the same PMP may have different PMFs. This is possible because the amount of flooding which results from a given rainfall amount depends upon the characteristics of the drainage basin. For this reason, the PMF, not the PMP, must be used as a design criterion for a dam. Some important characteristics include soil type, land use, size and shape of the watershed, and average watershed slope. Both the volume and rate of runoff are affected. For example, water will run off of steep slopes more quickly than gentle ones. More water will infiltrate sandy soils than clay.

F.3.6 Application of the PMF

The percentage of the PMF that a dam must be designed to withstand depends upon its classification. The Texas Administrative Code's hydrologic criteria for dams is as shown in the table below.

HYDROLOGIC CRITERIA FOR DAMS		
Classification		-
Hazard	Size	Minimum Design Flood Hydrograph
Low (No. 3)	Small	1/4 PMF
	Intermediate	1/4 PMF to 1/2 PMF
	Large	PMF
Significant (No. 2)	Small	1/2 PMF
	Intermediate	1/2 PMF to 3/4 PMF
	Large	PMF
High (No. 1)	Small	3/4 PMF
	Intermediate	3/4 PMF to PMF
	Large	PMF

The exact percent of the PMF to be passed is determined by a straight-line interpolation of the dam height in the range. For example, a small, significant hazard dam would be between 6 to 40 feet high. If the dam has a height of 20 feet, the hydrologic criteria would be that the dam spillway should pass 20' x (50%-25%) / (40'-6') + 25% or 39.7% of the PMF.

There are some exemptions to minimum hydrologic criteria. Proposed low hazard dams exempt under the Texas Water Code, §11.142, (see below) are exempt from the minimum criteria. Any other proposed structure may be exempt from the minimum criteria if properly prepared dam breach analyses show that existing downstream improvements or known or planned future improvements will not be adversely affected. A properly prepared breach analysis should include at least three events, the normal storage capacity nonflood event, the barely overtopping event, and the PMF event. Data on additional flood magnitudes may be provided as necessary to document other conditions or conclusions. Downstream flooding differentials of one-foot or less between breach and nonbreach simulations are not considered to be adverse.

F.3.7 Water Rights

The Texas Water Code requires anyone appropriating State Water or beginning work to store or divert State Water to obtain a permit from the Texas Commission on Environmental Quality (TCEQ). Private developments with ponds that contain 200 acre-feet or less of storage and that are used exclusively for domestic and livestock purposes are exempt from this requirement (11.142–Permit Exemptions). This exemption is based in part on the premise that all such ponds would by their nature of construction and due to their location on ranches or farms, be *low* hazard dams. However, as soon as the purpose for and use of these ponds change, there is a requirement to inform the TCEQ and obtain water rights permit. Usually the downstream water rights holders do not challenge these new storage permits for existing small ponds; however notifications are sent out and public hearings could be held if there are objections to the permit. All dams that are classified as *significant* or *high* hazard must have a permit.

If any other use of the stored water were contemplated, such as using the pond water for irrigation purposes, then another water right authorization would be required. Authorization for a permit to divert State Water for other than domestic and livestock uses on a reservoir permitted for storage only, should be requested pursuant to Texas Water Code, 11.143.

F.4 Design Criteria

Preparation of all plans and specifications, and the construction, enlargement, alteration, repair, or removal of dams subject to TCEQ review shall be under the supervision of an engineer registered in Texas. Construction of a dam or the enlargement, repair, or alteration of an existing dam requiring TCEQ authorization shall not be commenced prior to the executive director's written approval of final construction plans and specifications. Construction plans and specifications shall be submitted to the executive director and shall be as completely detailed as necessary for submission to the contractors bidding on the proposal. The proper design of a dam involves a complex combination of engineering applications.

Failure of an impoundment structure and the sudden release of water is referred to as a dam breach. A breach may occur during flooding or in fair weather due to effects of erosion or seepage. The hydrologic and hydraulic design determines what the potential impacts of a dam breach might be and what volume and flow rate a structure must withstand.

The geotechnical and structural design must consider that the structure can safely withstand the hydraulic forces imposed by the estimated hydrologic and hydraulic design. The following steps are necessary for the design of an embankment or concrete dam and each step must be thoroughly evaluated and documented.

1. Hydrologic and Hydraulic Design

   Determination of controlling design conditions and associated storm runoff.

   Setting of spillway and stilling basin widths and elevations, top of dam elevation, and normal pool elevation if necessary.

2. Structural and geotechnical design of embankments, concrete structure, spillways, and drawdown structures.
3. Development of operation and maintenance procedures.

F.4.1 Hydrologic and Hydraulic Design

The height of the dam, the amount of freeboard, the size and capacity of the spillways must be designed to balance the hydrologic and hydraulic properties. The structure must be designed based on the size and classification of the dam. The hydrologic and hydraulic modeling is discussed elsewhere in the manual. General considerations include the sizing of the capacity of the outlet works and spillway.

F.4.2 Geotechnical Considerations

Information concerning geology, seismicity, foundation conditions, and construction materials is essential for any size structure. It is necessary for the stability of the structure that the material used in the embankment, as well as the foundation and adjacent earth have the necessary structural properties to withstand the hydrostatic forces required by the design. The foundation for these structures may vary significantly, and will affect the general shape and configuration of the embankment. In addition, the potential for seepage should be identified and provided for in the design. The embankment should also be adequately protected from surface erosion.

Field investigations to determine the soils and groundwater conditions for stability and seepage control must be considered. Stability analysis should consider after construction conditions, based on shear strength parameters as determined by laboratory tests.

F.4.3 Structural Considerations

Structural designs should be prepared in accordance with generally accepted structural engineering practices. Components of the dam, spillway or outlet structures should resist the most critical loading considering buoyancy, sliding, hydrostatic uplift, overturning, soil and water pressure forces, impact forces, and other loads.

Embankment dams are the most common type of dam constructed today. They generally have a trapezoidal shape with side slopes of two horizontal to one vertical or flatter. The ability of an embankment dam to resist the hydrostatic pressure caused by the water in the reservoir or detention pond is primarily the result of the weight of the materials and the strength of the materials which are used.

The embankment must be stable and resistant to movement under all operating conditions including rapid drawdown. Seepage through the embankment, abutments, and foundation should be controlled so that piping or surface slides do not occur. The embankment must be safe form overtopping by flow and surface erosion, or protected to allow these flows. The embankment must be safe from damage due to wave action or rain.

Concrete structures use many of the same considerations in the design. Concrete dams generally use their own weight as the primary resistance to sliding. Other considerations include the strength of the concrete, the hydrostatic uplift on the structure, silt load which may accumulate on the upstream toe, as well as overturning and impact forces.

F.4.4 Seepage Considerations

Embankment materials vary with the site. Their water retention capability is due to the low permeability of the embankment material whether it is a homogeneous mass of material or a zone of low permeability material in the structure. Materials used for the construction of embankment dams can include soil or rock. If the difference between the permeability of the core section of the embankment and the downstream shell is great, an internal drainage system is probably not needed. If the variation in permeability is not great, then the entire embankment section can become saturated and that condition reduces the stability of the structure. The drainage system could consist of a chimney drain, a toe drain, a blanket drain, finger drains, or a combination of these items.

Concrete structures are also subject to seepage. Seepage can be present at the dam foundation interface reducing the sliding resistance. A line of drain holes away from the upstream face can relieve seepage pressure under the structure.

F.4.5 Other Considerations

Slopes for most embankment sections can be as steep as two horizontal to one vertical, however if the slope is designed with grass and will need to be mowed, a three horizontal to one vertical is about as steep as can be maintained without special equipment. The higher the plasticity index of the material in the embankment section, the more possibility for slope failures and therefore flatter slopes should be used. Compaction of materials in the construction process is another critical item for consideration. The need for rock riprap or other type of slope protection is usually evaluated on a case specific need depending on the potential for wave or water erosion. Grass on the slopes particularly the downstream slope generally provides adequate protection for structures where overtopping is not an issue.

Slopes for concrete structures especially if they are designed for overtopping, need to consider the difference between headwater and tailwater, the potential for a hydraulic jump, and overturning stability.

There are many resources available for the design of dams. Design of Small Dams by the Bureau of Reclamation is a good resource for both embankment structures and concrete dams.

The attached forms for submittal of a dam for approval to TCEQ are needed.

F.5 Operation and Maintenance

Once completed, the structure must be kept in good condition by regular maintenance. This includes periodic inspection of the structure. Evaluating the structural condition of an existing dam includes, but is not limited to, visual inspections and evaluations of potential problems such as seepage, cracks, slides, conduit and control malfunctions, erosion, rodent damage, spillway blockage, and other structural and maintenance deficiencies which could lead to failure of a structure. In addition, existing dams may need to be re-evaluated in consideration of continuing downstream development. The Texas Water Commission has prepared Guidelines for Operation and Maintenance of Dams in Texas, which covers many of the considerations for dam safety.

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Appendix F Submittal Forms

Information Sheet: Existing Dam (Form TCEQ-20344)

Information Sheet: Proposed New Construction, Modification,
Repair, Alteration, or Removal of a Dam (Form TCEQ-20345)

Hydrologic and Hydraulic (H&H) Evaluation Summary (Form TCEQ-20346)

Engineer's Notification of Completion (Form TCEQ-20347)

Texas Commission on Environmental Quality

INFORMATION SHEET: EXISTING DAM

(PLEASE PRINT OR TYPE)

Reference 30 Texas Administrative Code, Chapter 299, Dams and Reservoirs

SECTION 1: OWNER INFORMATION

Owner's Name ____________________________________ Title ___________________________________
Organization ____

____
(Signature of Owner) *(Date)*

Owner's Address ____
City ______________________________ State ___________________________ Zip Code ________________
Phone Number ( ) ______________________________ Emergency Contact Phone ( ) _______________________
Fax Number ( ) ____________________ E-mail ____
Owner Code *(Please check one)*: ❑ Federal (F) ❑ Local Government (L) ❑ Utility (U) ❑ Private (P) ❑ State (S)

❑ Other (O) please specify: ____
Year Built _________________________ Year Modified ____________________
Dam and Reservoir Use *(Please check one)*: ❑ Augmentation ❑ Diversion ❑ Domestic ❑ Erosion Control

❑ Evaporation ❑ Flood Control ❑ Fire Control ❑ Fish ❑ Hydroelectric ❑ Industrial ❑ Irrigation ❑ Mining

❑ Municipal ❑ Pollution Control ❑ Recreation ❑ Stock Water ❑ Settling Ponds ❑ Tailings ❑ Waste Disposal

❑ Other, please specify: _______________________________________
Engineering Firm ____
Project Engineer ______________________________________ Texas P.E. License Number ________________
Engineering Firm Address ____
City ______________________________ State ___________________________ Zip Code ________________
Phone ( ) ______________________ Fax ( ) _____________________
E-mail ____

SECTION 2: GENERAL INFORMATION

Name of Dam ____
Other Name(s) of Dam ____
Reservoir Name ____
Location ___________________________ Latitude ________________________ Longitude ________________
County_____________________________ Stream Name ____
River Basin _________________________ Topographic Map No.____
Distance & Direction from Nearest City or Town ____
Last Inspection Date ___________________ Inspected by (name of company or agency) _____________________
TX Number ________________________ Water Rights Number ____
Date of Emergency Action Plan (EAP), if one exists ____
Describe the current operating condition of dam ____

If you have questions on how to fill out this form or about the Dam Safety Program, please contact us at 512-239-5195. Individuals are entitled to request and review their personal information that the agency gathers on its forms. They may also have any errors in their information corrected. To review such information, contact us at 512-239-3282.

TCEQ-20344 (1/07)

SECTION 3: INFORMATION ON DAM

Classification

Size Classification: ❑ Large ❑ Medium ❑ Small

Hazard Classification: ❑ High ❑ Significant ❑ Low

Number of People at Risk _______________ Study Year ___________________

Type of Dam: ❑ Concrete ❑ Gravity ❑ Earthfill ❑ Rockfill ❑ Masonry ❑ Other (specify) _________________

Dam Structure (dimensions to nearest tenth of foot, volume to nearest acre-foot or cubic yard, areas to nearest acre):
Spillway Height ___________ ft *(natural surface of ground to bottom of emergency spillway at longitudinal centerline)*
Embankment Height _______ ft *(natural surface of ground to crest of dam at centerline)*
Structural Height ______________ ft *(bottom of cutoff trench to crest of dam at centerline)*
Length of Dam ________________ ft Crest Width __________________________________ ft
Normal Pool Elevation _____________________ ft-MSL Principal Spillway Elevation __________________ ft-MSL
Emergency Spillway Elevation ________________ ft-MSL Top of Dam Elevation ______________________ ft-MSL
Embankment Volume _____________________________ cu yd
Maximum Impoundment Capacity ___________________ ac-ft *(at top of dam)*
Normal Reservoir Capacity _________________________ ac-ft *(at normal or conservation pool)*
Reservoir Surface Area _____________________________ acres *(at normal or conservation pool)*

Outlet

Outlet Diameter: __________________ ❑in ❑ft *(check one)*
Type: ___________________________

Principal Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other
Width (Diam.): ___________________ ft Capacity: ____________________ cfs

Emergency Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other
Width (Diam.): ___________________ ft Capacity: ____________________ cfs
Total Spillway Capacity: ____cfs (crest of the dam)

SECTION 4: HYDROLOGIC INFORMATION

Required Hydrologic Criteria (% PMF) _____________% PMF Passing ______________________________
PMF Study Year ______________________________
Drainage Area: _______________________________acres, or ________________________________ sq mi
Curve Number (AMC III condition) _______________
Time of Concentration _________________________hr
Peak Discharge _______________________________cfs
Peak Stage __________________________________ft-MSL
Storm Duration Causing Peak Stage _______________hr

Texas Commission on Environmental Quality

INFORMATION SHEET: PROPOSED NEW CONSTRUCTION, MODIFICATION, REPAIR, ALTERATION, OR REMOVAL OF A DAM

(PLEASE PRINT OR TYPE)

Reference 30 Texas Administrative Code, Chapter 299, Dams and Reservoirs

PLEASE CHECK ONE: ❑ New ❑ Modification ❑ Repair ❑ Removal ❑ Alteration

SECTION 1: OWNER INFORMATION

Owner's Name ____________________________________ Title ____
Organization____
I have authorized the submittal of the final construction plans and specifications to the TCEQ Dam Safety Program according to 30 TAC Chapter 299.

____
(Signature of Owner) *(Date)*

Owner's Address ____
City _____________________________ State ________________ Zip Code ______________________________
Phone Number ( ) __________________________ Emergency Contact Phone ( ) ________________________
Fax Number ( ) _________________ E-mail ____

Owner Code *(Please check one)*: ❑ Federal (F) ❑ Local Government (L) ❑ Utility (U) ❑ Private (P) ❑ State (S)

❑ Other (O) please specify: ____

Dam and Reservoir Use *(Please check one)*: ❑ Augmentation ❑ Diversion ❑ Domestic ❑ Erosion Control ❑ Evaporation

❑ Flood Control ❑ Fire Control ❑ Fish ❑ Hydroelectric ❑ Industrial ❑ Irrigation ❑ Mining ❑ Municipal ❑ Pollution Control ❑

Recreation ❑ Stock Water ❑ Settling Ponds ❑ Tailings ❑ Waste Disposal ❑ Other, please specify: ______

Engineering Firm ____
Project Engineer ________________________________ Texas P.E. License Number ______________________
Engineering Firm Address ____
City ____ State ______________________ Zip Code _________
Phone ( ) ______________________ Fax ( ) _____________________
E-mail ____

SECTION 2: GENERAL INFORMATION

Name of Dam ____
Other Name(s) of Dam____
Reservoir Name ____
Location ___________________________ Latitude _________________ Longitude ____________________________
County____________________________ Stream Name ____
River Basin _________________________ Topographic Map No.____________________________________
Distance and Direction from Nearest City or Town ____
TX Number ________________________ Water Rights Number _____________________________________

If you have questions on how to fill out this form or about the Dam Safety Program, please contact us at 512-239-5195. *Individuals are entitled to request and review their personal information that the agency gathers on its forms. They may also have any errors in their information corrected. To review such information, contact us at 512-239-3282.*

TCEQ-20345 (1/07)

SECTION 3: INFORMATION ON DAM

Classification

Size Classification: ❑ Large ❑ Medium ❑ Small

Hazard Classification: ❑ High ❑ Significant ❑ Low

Number of People at Risk _______________ Study Year ___________________

Type of Dam: ❑ Concrete ❑ Gravity ❑ Earthfill ❑ Rockfill ❑ Masonry ❑ Other (specify) ________________________

Dam Structure (dimensions to nearest tenth of foot, volume to nearest acre-foot or cubic yard, areas to nearest acre):

Spillway Height _______________ ft *(natural surface of ground to bottom of emergency spillway at longitudinal centerline)*
Embankment Height ___________ ft *(natural surface of ground to crest of dam at centerline)*
Structural Height ______________ ft *(bottom of cutoff trench to crest of dam at centerline)*
Length of Dam ________________ ft Crest Width __________________________________ ft
Normal Pool Elevation _____________________ ft-MSL Principal Spillway Elevation __________________ ft-MSL
Emergency Spillway Elevation ________________ ft-MSL Top of Dam Elevation ______________________ ft-MSL
Embankment Volume _____________________________ cu yd
Maximum Impoundment Capacity ___________________ ac-ft *(at top of dam)*
Normal Reservoir Capacity _________________________ ac-ft *(at normal or conservation pool)*
Reservoir Surface Area _____________________________ acres *(at normal or conservation pool)*

Outlet

Outlet Diameter: __________________ ❑in ❑ft *(check one)*
Type: ___________________________

Principal Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other
Width (Diam.): ___________________ ft Capacity: ____________________ cfs

Emergency Spillway

Type: ❑ Natural ❑ Riprap ❑ Concrete ❑ CMP ❑ RCP ❑ Other
Width (Diam.): ___________________ ft Capacity: ____________________ cfs
Total Spillway Capacity: ____cfs (crest of the dam)

SECTION 4: HYDROLOGIC INFORMATION

Required Hydrologic Criteria (% PMF) _____________% PMF Passing ______________________________
PMF Study Year ______________________________
Drainage Area: _______________________________acres, or ________________________________ sq mi
Curve Number (AMC III condition) _______________
Time of Concentration _________________________hr
Peak Discharge _______________________________cfs
Peak Stage __________________________________ft-MSL
Storm Duration Causing Peak Stage _______________hr

Texas Commission on Environmental Quality

HYDROLOGIC AND HYDRAULIC (H&H) EVALUATION SUMMARY

(Please complete **all** sections, unless otherwise specified)

Name of Dam: ______________________________

TCEQ Dam Safety Project No.: ______________________________

County: ______________________________

Year to Build: ______________________________

Maximum Record Precipitation (in): ______________________________

Record Area (county or city): ______________________________

Duration (hr): ______________________________

Date of Record (MM/DD/YY): ______________________________

Source Ref. (FEMA, National Weather Service, etc.): ______________________________

Downstream Dam Toe ___________ (ft-MSL) Normal Reservoir Capacity ___________ (ac-ft)

Normal Pool ___________________ (ft-MSL) Maximum Reservoir Capacity _________ (ac-ft)

Principal Spillway ______________ (ft-MSL) Reservoir Surface Area ________________ (ac)

Emergency Spillway ____________ (ft-MSL) Drainage Area _______________________ (ac)

Top of Dam ____________________ (ft-MSL) Outlet Diameter or Cross-Section _________(in)

Storm Duration	Peak Inflow (cfs)	Peak Outflow (cfs)	Peak Stage (ft-MSL)	% PMF Passing	Comments (if needed)
1 hr					
2 hr					
3hr					
6 hr					
12 hr					
24 hr					
48 hr					
72 hr					

To the best of my knowledge, I certify the above data are correct. I will supply the hydrologic and hydraulic reports to the Texas Commission on Environmental Quality upon request.

____
(Signature)

(P. E. Seal)

____
(Date)

TCEQ-20346 (1/07)

Texas Commission on Environmental Quality

ENGINEER'S NOTIFICATION OF COMPLETION
(PLEASE PRINT OR TYPE)

PLEASE CHECK ONE: ❑ New ❑ Modification ❑ Repair ❑ Removal ❑ Alteration

TX Number __________________ County ____

Adjudication Number __________ Permit Number _____________________________________

Name of Dam/Project ____

Owner:

Name ____

Address ____

City ________________________ State _________________ Zip Code ____________________

Phone ( ) _______________________ Emergency Contact Phone ( ) ______________________

Fax ( ) _________________________ E-mail ____

Engineering Firm:

Firm Name ____

Project Engineer __________________________ TX P.E. License No _____________________

Firm Address ____

City _________________________ State ________________ Zip Code ____________________

Phone ( ) ________________________ Fax ( ) _______________________________________

E-mail ____

The project was completed on ____________, 20_____. To the best of my knowledge, the project was constructed in substantial conformance with plans, specifications, and change orders filed with and approved by the Texas Commission on Environmental Quality.

____
(Signature)

(P. E. Seal)

____
(Date)

If you have questions on how to fill out this form or about the Dam Safety Program, please contact us at 512-239-5195. Individuals are entitled to request and review their personal information that the agency gathers on its forms. They may also have any errors in their information corrected. To review such information, contact us at 512-239-3282.

TCEQ-20347 (1/07)

Appendix G

Storm Water Controls (iSWM Chapter 5)

CHAPTER

5

Table of Contents

Chapter 5 – Storm Water Controls

5.1 Storm Water Controls Overview

5.2 Storm Water Controls

List of Tables

Chapter 5

List of Figures

Chapter 5

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CHAPTER

5

STORM WATER CONTROLS

Section 5.1
Storm Water Controls Overview

5.1.1 Storm Water Controls - Categories and Applicability

5.1.1.1 Introduction

Structural storm water controls are engineered facilities intended to treat storm water runoff and/or mitigate the effects of increased storm water runoff peak rate, volume, and velocity due to urbanization. This section provides an overview of structural storm water controls that can be used to address the minimum storm water management standards outlined in Section 1.2.

In terms of the *Integrated* Design Approach, a structural storm water control, or set of structural controls, must:

- **Water Quality:** Remove pollutants in storm water runoff to protect water quality;
- **Streambank Protection:** Regulate discharge from the site to minimize downstream bank and channel erosion; and
- **Flood Control:** Control conveyance of runoff within and from the site to minimize flood risk to people and properties.

5.1.1.2 Control Categories

The storm water control practices recommended in this Manual vary in their applicability and ability to meet storm water management goals:

Primary Controls

Primary Structural Storm Water Controls have the ability to fully address one or more of the Steps in the *integrated* Design Approach if designed appropriately. Structural controls are recommended for use with a wide variety of land uses and development types. These structural controls have a demonstrated ability to effectively treat the Water Quality Volume (WQ_v) and have been shown to be able to remove 70% to 80% of the annual average total suspended solids (TSS) load in typical post-development urban runoff when designed, constructed, and maintained in accordance with recommended specifications. Several of these structural controls can also be designed to provide primary control for downstream streambank protection (SP_v) and flood control (Q_f). These structural controls are recommended storm water management facilities for a site wherever feasible and practical.

Secondary Controls

However, a number of structural controls are recommended <u>only</u> for limited use or for special site or design conditions. Generally, these practices either: (1) do not have the ability on their own to fully address one or more of the Steps in the *integrated* Design Approach, (2) are intended to address hotspot or specific land use constraints or conditions, and/or (3) may have high or special maintenance requirements that may preclude their use. These types of structural controls are typically used for *water quality treatment only*. Some of these controls can be used as a pretreatment measure or in series with other structural controls to meet pollutant removal goals. Such structural controls should be considered mostly for commercial, industrial, or institutional developments.

Table 5.1.1-1 lists the structural storm water control practices. These structural controls are recommended for use in a wide variety of applications. A detailed discussion of each of the controls, as well as design criteria and procedures can be found in Section 5.2.

Table 5.1.1-1 Structural Controls

Structural Control	Description
Bioretention Areas	*Bioretention areas* are shallow storm water basins or landscaped areas which utilize engineered soils and vegetation to capture and treat storm water runoff. Runoff may be returned to the conveyance system, or allowed to partially exfiltrate into the soil.
Channels • Enhanced Swale (Dry, Wet, or Wetland) • Grass Channel (biofilter)	• *Enhanced swales* are vegetated open channels that are explicitly designed and constructed to capture and treat storm water runoff within dry or wet cells formed by check dams or other means • *Grass channels* provide "biofiltering" of storm water runoff as it flows across the grass surface. However, a grass channel alone cannot meet the 70% TSS removal performance goal. Consequently, grass channels should only be used as pretreatment measure or as part of a treatment train approach.
Chemical Treatment • Alum Treatment	*Alum treatment* provides for the removal of suspended solids from storm water runoff entering a wet pond by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events. Alum treatment should only be considered for large-scale projects where high water quality is desired.
Conveyance Components • Culvert • Inlet • Pipe Systems • Energy Dissipators • Open Conveyance Channel	• A *culvert* is a short, closed (covered) conduit that conveys storm water runoff under an embankment, usually a roadway. • *Inlets* are drainage structures used to collect surface water through grate or curb openings and convey it to storm drains or direct outlet to culverts. • *Pipe systems* are used for transporting runoff from roadway and other inlets to outfalls at structural storm water controls and receiving waters. Culverts, inlets, and pipe systems alone do not provide water quality treatment.
Detention • Dry Detention / Dry Extended Detention Basins • Multi-Purpose Detention Areas • Underground Detention	• *Dry detention basins and dry extended detention (ED) basins* are surface facilities intended to provide for the temporary storage of storm water runoff to reduce downstream water quantity impacts. • *Multi-purpose detention areas* are site areas used for one or more specific activities, such as parking lots and rooftops, which are also designed for the temporary storage of runoff. • *Underground detention tanks and vaults* are an alternative to surface dry detention for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area.

Table 5.1.1-1 Structural Controls

Structural Control	Description
Filtration • Filter Strip • Organic Filter • Planter Boxes • Surface Sand Filter/ Perimeter Sand Filter • Underground Sand Filter	• *Filter strips* provide "biofiltering" of storm water runoff as it flows across the grass surface. However, filter strips alone cannot meet the 70% TSS removal performance goal. Consequently, filter strips should only be used as pretreatment measure or as part of a treatment train approach. • *Organic filters* are surface sand filters where organic materials such as a leaf compost or peat/sand mixture are used as the filter media. These media may be able to provide enhanced removal of some contaminants, such as heavy metals. Given their potentially high maintenance requirements, they should only be used in environments that warrant their use. • *Planter boxes* are used on impervious surfaces in highly urbanized areas to collect and detain / infiltrate rainfall and runoff. The boxes may be prefabricated or constructed in place and contain growing medium, plants, and a reservoir. • *Sand filters* are multi-chamber structures designed to treat storm water runoff through filtration, using a sand bed as its primary filter media. Filtered runoff may be returned to the conveyance system, or allowed to partially exfiltrate into the soil. • *Underground sand filters* are sand filter systems located in an underground vault. These systems should only be considered for extremely high density or space-limited sites.
Hydrodynamic Devices • Gravity (Oil-Grit) Separator	*Hydrodynamic controls* use the movement of storm water runoff through a specially designed structure to remove target pollutants. They are typically used on smaller impervious commercial sites and urban hotspots. These controls typically do not meet the Primary TSS removal performance goal and therefore should only be used as a pretreatment measure and as part of a treatment train approach.
Infiltration • Downspout Dry Wells • Infiltration Trench • Soakage Trenches	• *Downspout dry wells* are essentially perforated manholes, but they can be manufactured in various sizes. Located underground, they allow storm water infiltration even in highly urbanized areas. They should be used in conjunction with some type of pretreatment devices where there are minimal risks of groundwater contamination. • An *infiltration trench* is an excavated trench filled with stone aggregate used to capture and allow infiltration of storm water runoff into the surrounding soils from the bottom and sides of the trench. • *Soakage trenches* are a variation of infiltration trenches. Soakage trenches drain through a perforated pipe buried in gravel. They are used in highly impervious areas where conditions do not allow surface infiltration and where pollutant concentrations in runoff are minimal (i.e. non-industrial rooftops). They may be used in conjunction with other storm water devices, such as draining downspouts or planter boxes.

Table 5.1.1-1 Structural Controls	
Structural Control	**Description**
Storm Water Ponds • Micropool Extended Detention Pond • Multiple Pond Systems • Wet Extended Detention Pond • Wet Pond	*Storm water ponds* are constructed storm water retention basins that have a permanent pool (or micropool) of water. Runoff from each rain event is detained and treated in the pool.
Porous Surfaces • Green Roofs • Modular Porous Paver Systems • Porous Concrete	• A *green roof* uses a small amount of substrate over an impermeable membrane to support a covering of plants. The green roof slows down runoff from the otherwise impervious roof surface as well as moderating rooftop temperatures. With the right plants, a green roof will also provide aesthetic or habitat benefits. • *Modular porous paver systems* consist of open void paver units laid on a gravel subgrade. Both porous concrete and porous paver systems provide water quality and quantity benefits, but have high workmanship and maintenance requirements, as well as high failure rates. • *Porous surfaces* are permeable pavement surfaces with an underlying stone reservoir to temporarily store surface runoff before it infiltrates into the subsoil. *Porous concrete* is the term for a mixture of course aggregate, Portland cement, and water that allows for rapid infiltration of water.
Proprietary Systems • Commercial Storm Water Controls	*Proprietary controls* are manufactured structural control systems available from commercial vendors designed to treat storm water runoff and/or provide water quantity control. Proprietary systems often can be used on small sites and in space-limited areas, as well as in pretreatment applications. However, proprietary systems are often more costly than other alternatives, may have high maintenance requirements, and often lack adequate independent performance data.
Re-Use • Rain Harvesting (tanks/barrels)	*Rain harvesting* is a container or system designed to capture and store rainwater discharged from a roof. The rain harvesting system consists of a storage container, a downspout diversion, a sealed lid, and an overflow system. Typical rain harvesting systems hold between 50 and 500 gallons of water and may work in series to provide larger volumes of storage.
Storm Water Wetlands • Extended Detention Shallow Wetland • Pocket Wetland • Pond/Wetland Systems • Shallow Wetland • Submerged Gravel Wetlands	• *Storm water wetlands* are constructed wetland systems used for storm water management. Storm water wetlands consist of a combination of shallow marsh areas, open water, and semi-wet areas above the permanent water surface. • *Submerged gravel wetland systems* use wetland plants in submerged gravel or crushed rock media to remove storm water pollutants. These systems should only be used in mid- to high-density environments where the use of other structural controls may be precluded. The long-term maintenance burden of these systems is uncertain.

5.1.1.3 Using Other or New Structural Storm Water Controls

Innovative technologies should be allowed and encouraged providing there is sufficient documentation as to their effectiveness and reliability. Communities can allow controls not included in this Manual at their discretion, but should not do so without independently derived information concerning performance, maintenance, application requirements, and limitations.

More specifically, new structural storm water control designs will not be accepted for inclusion in the manual until independent performance data shows that the structural control conforms to local and/or State criteria for treatment, conveyance, maintenance, and environmental impact.

5.1.2 Suitability of Storm Water Controls

Some structural storm water controls are intended to provide water quality treatment for storm water runoff. Though most of these structural controls provides pollutant removal capabilities, the relative capabilities vary between structural control practices and for different pollutant types.

5.1.2.1 Water Quality

Pollutant removal capabilities for a given structural storm water control practice are based on a number of factors including the physical, chemical, and/or biological processes that take place in the structural control and the design and sizing of the facility. In addition, pollutant removal efficiencies for the same structural control type and facility design can vary widely depending on the tributary land use and area, incoming pollutant concentration, flow rate, volume, pollutant loads, rainfall pattern, time of year, maintenance frequency, and numerous other factors.

To assist the designer in evaluating the relative pollutant removal performance of the various structural control options, Table 5.1.2-1 provides design removal efficiencies for each of the control practices. It should be noted that these values are *conservative* average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. A structural control design may be capable of exceeding these performances, however the values in the table are minimum reasonable values that can be assumed to be achieved when the structural control is sized, designed, constructed, and maintained in accordance with recommended specifications in this Manual.

Where the pollutant removal capabilities of an individual structural storm water control are not deemed sufficient for a given site application, additional controls may be used in series in a "treatment train" approach. More detail on using structural storm water controls in series is provided in subsection 5.1.6.

For additional information and data on the range of pollutant removal capabilities for various structural storm water controls, the reader is referred to the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the International Storm Water Best Management Practices (BMP) Database at www.bmpdatabase.org

Table 5.1.2-1 Design Pollutant Removal Efficiencies for Storm Water Controls (Percentage)

Structural Control	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Fecal Coliform	Metals
Bioretention Areas	80	60	50	---	80
Grass Channel	50	25	20	---	30
Enhanced Dry Swale	80	50	50	---	40
Enhanced Wet Swale	80	25	40	---	20
Alum Treatment	80	80	60	90	75

Table 5.1.2-1 Design Pollutant Removal Efficiencies for Storm Water Controls (Percentage)					
Structural Control	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Fecal Coliform	Metals
Filter Strip	50	20	20	---	40
Dry Detention	65	50	30	70	---
Organic Filter	80	60	40	50	75
Planter Boxes	80	60	40	50	60
Sand Filters	80	50	25	40	50
Underground Sand Filter	80	50	25	40	50
Gravity (Oil-Grit) Separator	40	5	5	---	---
Downspout Drywell	80	60	60	90	90
Infiltration Trench	80	60	60	90	90
Soakage Trench	80	60	60	90	90
Storm Water Ponds	80	50	30	70*	50
Green Roof	85	---	25	---	95
Modular Porous Paver Systems with infiltration	**	80	80	---	90
Porous Concrete with infiltration	**	50	65	---	60
Proprietary Systems	***	***	***	***	***
Rain Harvesting	---	---	---	---	---
Storm Water Wetlands	80	40	30	70*	50
Submerged Gravel Wetland	80	50	20	70	50

* If no resident waterfowl population present

** Due to the potential for clogging, porous concrete and modular block paver systems should not be used for the removal of sediment or other coarse particulate pollutants

*** The performance of specific proprietary commercial devices and systems must be provided by the manufacturer and should be verified by independent third-party sources and data

--- Insufficient data to provide design removal efficiency

5.1.2.2 Streambank Protection

These controls have the ability to detain the volume and regulate the discharge of the 1-year, 24-hour storm event to protect natural waterways downstream of the development. Controls that provide streambank protection include detention, energy dissipation, storm water ponds, storm water wetlands, and pipe systems.

5.1.2.3 Flood Control

- **On-Site:** These controls have the ability to safely convey storm water through a development to minimize the flood risk to persons and property on-site. On-site flood control structures include channels, culverts, detentions, enhanced swales, open conveyance channels, storm water ponds, conveyance components (inlets and pipe systems), and storm water wetlands.
- **Downstream:** These controls have the ability to detain the volume and regulate the discharge from the controlling storm event, as determined by downstream assessment, and to minimize flood risk to persons and property downstream of the development. Downstream flood controls include open channels, pipe systems, detention, storm water ponds, and storm water wetlands.

5.1.3 Storm Water Control Selection

5.1.3.1 Control Screening Process

Outlined below is a screening process for structural storm water controls which can effectively treat the water quality volume as well as provide water quantity control. This process is intended to assist the site designer and design engineer in the selection of the most appropriate structural controls for a development site, and provides guidance on factors to consider in their location.

In general the following four criteria should be evaluated in order to select the appropriate structural control(s) or group of controls for a development:

- Storm Water Treatment Suitability
- Water Quality Performance
- Site Applicability
- Implementation Considerations

In addition, for a given site, the following factors should be considered and any specific design criteria or restrictions need to be evaluated:

- Physiographic Factors
- Soils
- Special Watershed or Stream Considerations

Finally, environmental regulations should be considered as they may influence the location of a structural control on site, or may require a permit.

The following pages provide a selection process for comparing and evaluating various structural storm water controls using a screening matrix and a list of location and permitting factors. These tools are provided to assist the design engineer in selecting the subset of structural controls that will meet the storm water management and design objectives for a development site or project.

Step 1 Overall Applicability

Through the use of the first four screening categories in Table 5.1.3-1, the site designer evaluates and screens the overall applicability of the full set of structural controls as well as the constraints of the site in question. The following are the details of the various screening categories and individual characteristics used to evaluate the structural controls.

<u>Storm Water Management Suitability</u>

The first category in the Matrix examines the capability of each structural control option to provide water quality treatment, downstream streambank protection, and flood control. A blank entry means that the structural control cannot or is not typically used to meet an *integrated* Design Approach. This does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one structural control may be needed at a site (e.g., a bioretention area used in conjunction with dry detention storage).

Ability to treat the Water Quality Volume (WQ_v). This indicates whether a structural control provides treatment of the water quality volume (WQ_v). The presence of a "P" or an "S" indicates whether the control is a Primary or Secondary control for meeting the TSS reduction goal.

Ability to provide Streambank Protection (SP_v). This indicates whether the structural control can be used to provide the extended detention of the streambank protection volume (SP_v). The presence of a "P" indicates that the structural control can be used to meet SP_v requirements. An "S" indicates that the structural control may be sized to provide streambank protection in certain situations, for instance on small sites.

Ability to provide Flood Control (Q_f). This indicates whether a structural control can be used to meet the flood control criteria. The presence of a "P" indicates that the structural control can be used to provide peak reduction of the 100-year storm event.

Relative Water Quality Performance

The second category of the Matrix provides an overview of the pollutant removal performance of each structural control option, when designed, constructed, and maintained according to the criteria and specifications in this Manual.

Ability to provide TSS and Sediment Removal. This column indicates the capability of a structural control to remove sediment in runoff. All of the Primary structural controls are presumed to remove 70% to 80% of the average annual total suspended solids (TSS) load in typical urban post-development runoff (and a proportional removal of other pollutants).

Ability to provide Nutrient Treatment. This column indicates the capability of a structural control to remove the nutrients nitrogen and phosphorus in runoff, which may be of particular concern with certain downstream receiving waters.

Ability to provide Bacteria Removal. This column indicates the capability of a structural control to remove bacteria in runoff. This capability may be of particular focus in areas with public beaches, shellfish beds, or to meet water regulatory quality criteria under the Total Maximum Daily Load (TMDL) program.

Ability to accept Hotspot Runoff. This last column indicates the capability of a structural control to treat runoff from designated hotspots. Hotspots are land uses or activities which produce higher concentrations of trace metals, hydrocarbons, or other priority pollutants. Examples of hotspots might include: gas stations, convenience stores, marinas, public works storage areas, garbage transfer facilities, material storage sites, vehicle service and maintenance areas, commercial nurseries, vehicle washing/steam cleaning, landfills, construction sites, industrial sites, industrial rooftops, and auto salvage or recycling facilities. A check mark indicates that the structural control may be used on hotspot site; however, it may have specific design restrictions. Please see the specific design criteria of the structural control for more details. Local jurisdictions may have other site uses which they designate as Hotspots, so their criteria should be checked as well.

Site Applicability

The third category of the Matrix provides an overview of the specific site conditions or criteria that must be met for a particular structural control to be suitable. In some cases, these values are recommended values or limits and can be exceeded or reduced with proper design or depending on specific circumstances. Please see the specific criteria section of the structural control for more details.

Drainage Area. This column indicates the approximate minimum or maximum drainage area considered suitable for the structural control practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway can be permitted if more than one practice can be installed. The minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), the mechanisms employed to prevent outlet clogging, or design variations used to maintain a permanent pool (e.g., liners).

Space Required (Space Consumed). This comparative index expresses how much space a structural control typically consumes at a site in terms of the approximate area required as a percentage of the impervious area draining to the control.

Slope. This column evaluates the effect of slope on the structural control practice. Specifically, the slope restrictions refer to how flat the area where the facility is installed must be and/or how steep the contributing drainage area or flow length can be.

Minimum Head. This column provides an estimate of the minimum elevation difference needed at a site (from the inflow to the outflow) to allow for gravity operation within the structural control.

Water Table. This column indicates the minimum depth to the seasonally high water table from the bottom or floor of a structural control.

Implementation Considerations

The fourth category in the Matrix provides additional considerations for the applicability of each structural control option.

Residential Subdivision Use. This column identifies whether or not a structural control is suitable for typical residential subdivision development (not including high-density or ultra-urban areas).

Ultra-Urban. This column identifies those structural controls appropriate for use in very high-density (ultra-urban) areas, or areas where space is a premium.

Construction Cost. The structural controls are ranked according to their relative construction cost per impervious acre treated, as determined from cost surveys.

Maintenance. This column assesses the relative maintenance effort needed for a structural storm water control, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging), and reported failure rates. It should be noted that **all structural controls** require routine inspection and maintenance.

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Table 5.1.3-1 Structural Control Screening Matrix

Category	On-Site Storm Water Controls	STORM WATER TREATMENT SUITABILITY				WATER QUALITY PERFORMANCE				SITE APPLICABILITY					IMPLEMENTATION CONSIDERATIONS			
		Water Quality Protection	Streambank Protection	On-Site Flood Control	Downstream Flood Control	TSS/ Sediment Removal Rate	Nutrient Removal Rate (TP/TN)	Bacteria Removal Rate	Hotspot Application	Drainage Area (acres)	Space Req'd (% of tributary Imp. Area)	Site Slope	Minimum Head Required	Depth to Water Table	Residential Subdivision Use	High Density/Ultra Urban	Capital Cost	Maintenance Burden
Bioretention Areas	Bioretention Areas	P	S	S	-	80%	60%/50%	-	✓	5 max***	5-7%	6% max	5 ft	2 feet	✓	✓	Moderate	Low
Channels	Enhanced Swales	P	S	S	S	80%	25%/40%	-	✓	5 max	10-20%	4% max	1 ft	below WT	✓		High	Low
	Channels, Grass	S	S	P	S	50%	25%/20%	-							✓		Low	Moderate
	Channels, Open	-	-	P	S	-	-	-							✓		Low	Low
Chemical Treatment	Alum Treatment System	P	-	-	-	90%	80%/60%	90%	✓	25 min	None				✓	✓	High	High
Conveyance Components	Culverts	-	-	P	P	-	-	-							✓	✓	Low	Low
	Energy Dissipation	-	P	S	S	-	-	-							✓	✓	Low	Low
	Inlets/Street Gutters	-	-	P	-	-	-	-							✓	✓	Low	Low
	Pipe Systems	-	P	P	P	-	-	-							✓	✓	Low	Low
Detention	Detention, Dry	S	P	P	P	65%	50%/30%	70%	✓		2 - 3%	15% across pond	6 to 8 ft	2 feet	✓		Low	Moderate to High
	Detention, Extended Dry	S	P	P	P	65%	50%/30%	70%	✓		2 - 3%	15% across pond	6 to 8 ft	2 feet	✓		Low	Moderate to High
	Detention, Multi-purpose Areas	-	P	P	P	-	-	-		200 max		1% for Parking Lot; 0.25 in/ft for Rooftop			✓	✓	Low	Low
	Detention, Underground	-	P	P	P	-	-	-		200 max						✓	High	Moderate
Filtration	Filter Strips	S	-	-	-	50%	20%/20%	-		2 max***	20-25%	2-6%			✓		Low	Moderate
	Organic Filters	P	-	-	-	80%	60%/40%	50%	✓	10 max***	2-3%		5 to 8 ft			✓	High	High
	Planter Boxes	P	-	-	-	80%	60%/40%	-			6%					✓	Low	Moderate
	Sand Filters, Surface/ Perimeter	P	S	-	-	80%	50%/25%	40%	✓	10 max***/ 2 max***	2-3%	6% max	5 ft/ 2 to 3 ft	2 feet		✓	High	High
	Sand Filters, Underground	P	-	-	-	80%	50%/25%	40%	✓	5 max	None					✓	High	High
Hydrodynamic Devices	Gravity (Oil-Grit) Separator	S	-	-	-	40%	5%/5%	-		1 max***	None					✓	High	High
Infiltration	Downspout Drywell	P	-	-	-	80%	60%/60%	90%							✓	✓	Low	Moderate
	Infiltration Trenches	P	S	-	-	80%	60%/60%	90%		5 max	2-3%	6% max	1 ft	4 feet	✓	✓	High	High
	Soakage Trenches	P	S	-	-	80%	60%/60%	90%		5 max	27' per 1000 ft^2 impervious area	6% max	1 ft	4 feet	✓	✓	High	High
Ponds	Wet Pond	P	P	P	P	80%	50%/30%	70%*	✓		2-3%	15% max	6 to 8 ft	2 feet, if hotspot or aquifer	✓		Low	Low
	Wet ED Pond	P	P	P	P	80%	50%/30%	70%*	✓	25 min**					✓		Low	Low
	Micropool ED Pond	P	P	P	P	80%	50%/30%	70%*	✓	10 min**					✓		Low	Moderate
	Multiple ponds	P	P	P	P	80%	50%/30%	70%*	✓	25 min**					✓		Low	Low
Porous Surfaces	Green Roof	P	S	-	-	85%	95%/16%	-	✓							✓	High	High
	Modular Porous Paver Systems	S	S	-	-	**	80%/80%	-		5 max	Varies					✓	Moderate	High
	Porous Concrete	S	S	-	-	**	50%/65%	-		5 max	Varies					✓	High	High
Proprietary Systems	Proprietary Systems ****	S	S	S	S	****	****	****		****	****				****	✓	High	High
Re-Use	Rain Harvesting	P	-	-	-	-	-	-							✓	✓	Low	High
Wetlands	Wetlands, Storm Water	P	P	P	P	80%	40%/30%	70%*	✓	25 min	3-5%	8% max	3 to 5 ft (shallow) 6 to 8 ft (pond)	2 feet, if hotspot or aquifer	✓		Moderate	Moderate
	Wetlands, Submerged Gravel	P	P	S	-	80%	50%/20%	70%	✓	5 min			2 to 3 ft	below WT	✓	✓	Moderate	High

✓ - Meets suitability criteria

P - Primary Control, meets suitability criteria

S - Secondary Control, can be incorporated into the structural control in certain situations

* Provides less than 80% TSS removal efficiency. May be used in pretreatment and as part of a "treatment train"

** Smaller area acceptable with adequate water balance and anti-clogging device

*** Drainage area can be larger in some instances

**** The application and performance of specific commercial devices and systems must be provided by the manufacturer and should be verified by independent third-party sources and data

1 Porous surfaces provide water quantity benefits by reducing the effective impervious area

2 Due to the potential for clogging, porous surfaces should not be used for the removal of sediment or other coarse particulate pollutants

Table 5.1.3-1 Structural Control Screening Matrix

Category	On-Site Storm Water Controls	PHYSIOGRAPHIC FACTORS			Soils	SPECIAL WATERSHED CONSIDERATIONS		
		Low Relief	High Relief	Karst		High Quality Stream	Aquifer Protection	Reservior Protection
Bioretention Areas	Bioretention Areas	Several design variations will likely be limited by low head		Use poly-liner or impermeable membrane to seal bottom	Clay or silty soils may require pretreatment	Evaluate for stream warming	Needs to be designed with no exfiltration (i.e. outflow to groundwater)	
Channels	Enhanced Swales	Generally feasible however slope <1% may lead to standing water in dry swales	Often infeasible if slopes are 4% or greater				Hotspot runoff must be adequately treated	Hotspot runoff must be adequately treated
	Channels, Grass							
	Channels, Open							
Chemical Treatment	Alum Treatment System							
Conveyance Components	Culverts							
	Energy Dissipation							
	Inlets/Street Gutters							
	Pipe Systems							
Detention	Detention, Dry		Embankment heights restricted	Require poly or clay liner, Max ponding depth, Geotechnical tests	Underlying soils of hydrologic group "C" or "D" should be adequate to maintain a permanent pool. Most group "A" soils and some group "B" soils will require a pond liner.			
	Detention, Extended Dry							
	Detention, Multi-purpose Areas							
	Detention, Underground			GENERALLY NOT ALLOWED				
Filtration	Filter Strips							
	Organic Filters							
	Planter Boxes				Type A or B			
	Sand Filters, Surface/ Perimeter	Several design variations will likely be limited by low head		Use poly-liner or impermeable membrane to seal bottom	Clay or silty soils may require pretreatment	Evaluate for stream warming	Needs to be designed with no exfiltration (i.e. outflow to groundwater)	
	Sand Filters, Underground							
Hydrodynamic Devices	Gravity (Oil-Grit) Separator							
Infiltration	Downspout Drywell	Minimum distance to water table of 4 feet		GENERALLY NOT ALLOWED	Infiltration rate > 0.5 inch/hr			
	Infiltration Trenches	Minimum distance to water table of 2 feet	Maximum slope of 6% Trenches must have flat bottom	GENERALLY NOT ALLOWED	Infiltration rate > 0.5 inch/hr		Maintain safe distance from wells and water table. No hotspot runoff	Maintain safe distance from bedrock and water table. Pretreat runoff
	Soakage Trenches	Minimum distance to water table of 4 feet	Maximum slope of 6% Trenches must have flat bottom	GENERALLY NOT ALLOWED	Infiltration rate > 0.5 inch/hr			
Ponds	Wet Pond	Limit maximum normal pool depth to about 4 feet (dugout) Providing pond drain can be problematic	Embankment heights restricted	Require poly or clay liner Max ponding depth Geotechnical tests	"A" soils may require pond liner "B" soils may require infiltration testing	Evaluate for stream warming	May require liner if "A" soils are present Pretreat hotspots 2 to 4 ft separation distance from water table	
	Wet ED Pond							
	Micropool ED Pond							
	Multiple ponds							
Porous Surfaces	Green Roof							
	Modular Porous Paver Systems							
	Porous Concrete							
Proprietary Systems	Proprietary Systems *							
Re-Use	Rain Harvesting							
Wetlands	Wetlands, Storm Water		Embankment heights restricted	Require poly-liner Geotechnical tests	"A" soils may require pond liner	Evaluate for stream warming	May require liner if "A" soils are present Pretreat hotspots 2 to 4 ft separation distance from water table	
	Wetlands, Submerged Gravel							

✓ - Meets suitability criteria

P - Primary Control, meets suitability criteria

S - Secondary Control, can be incorporated into the structural control in certain situations

* Provides less than 80% TSS removal efficiency. May be used in pretreatment and as part of a "treatment train"

** Smaller area acceptable with adequate water balance and anti-clogging device

*** Drainage area can be larger in some instances

**** The application and performance of specific commercial devices and systems must be provided by the manufacturer and should be verified by independent third-party sources and data

1 Porous surfaces provide water quantity benefits by reducing the effective impervious area

2 Due to the potential for clogging, porous surfaces should not be used for the removal of sediment or other coarse particulate pollutants

Step 2 Specific Criteria

The last three categories in the Structural Control Screening matrix (Table 5.1.3-1) provides an overview of various specific design criteria and specifications, or exclusions for a structural control that may be present due to a site's general physiographic character, soils, or location in a watershed with special water resources considerations.

Physiographic Factors

Three key factors to consider are low-relief, high-relief, and karst terrain. In the North Central Texas, low relief (very flat) areas are primarily located east of the Dallas metropolitan area. High relief (steep and hilly) areas are primarily located west of the Fort Worth metropolitan area. Karst and major carbonaceous rock areas are limited to portions of Palo Pinto, Erath, Hood, Johnson, and Somerveil counties. Special geotechnical testing requirements may be needed in karst areas. The local reviewing authority should be consulted to determine if a project is subject to terrain constraints.

- Low relief areas need special consideration because many structural controls require a hydraulic head to move storm water runoff through the facility.
- High relief may limit the use of some structural controls that need flat or gently sloping areas to settle out sediment or to reduce velocities. In other cases, high relief may impact dam heights to the point that a structural control becomes infeasible.
- Karst terrain can limit the use of some structural controls as the infiltration of polluted waters directly into underground streams found in karst areas may be prohibited. In addition, ponding areas may not reliably hold water in karst areas.

Soils

The key evaluation factors are based on an initial investigation of the NRCS hydrologic soils groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Special Watershed or Stream Considerations

The design of structural storm water controls is fundamentally influenced by the nature of the downstream water body that will be receiving the storm water discharge. In addition, the designer should consult with the appropriate review authority to determine if their development project is subject to additional structural control criteria as a result of an adopted local watershed plan or special provision.

In some cases, higher pollutant removal or environmental performance is needed to fully protect aquatic resources and/or human health and safety within a particular watershed or receiving water. Therefore, special design criteria for a particular structural control or the exclusion of one or more controls may need to be considered within these watersheds or areas. Examples of important watershed factors to consider include:

High Quality Streams (Streams with a watershed impervious cover less than approximately 15%). These streams may also possess high quality cool water or warm water aquatic resources or endangered species. The design objectives are to maintain habitat quality through the same techniques used for cold-water streams, with the exception that stream warming is not as severe of a design constraint. These streams may also be specially designated by local authorities.

Wellhead Protection. Areas that recharge existing public water supply wells present a unique management challenge. The key design constraint is to prevent possible groundwater contamination by preventing infiltration of hotspot runoff. At the same time, recharge of unpolluted storm water is encouraged to maintain flow in streams and wells during dry weather.

Reservoir or Drinking Water Protection. Watersheds that deliver surface runoff to a public water supply reservoir or impoundment are a special concern. Depending on the treatment available, it may be necessary to achieve a greater level of pollutant removal for the pollutants of concern, such as bacteria pathogens, nutrients, sediment, or metals. One particular management concern for reservoirs is ensuring storm water hotspots are adequately treated so they do not contaminate drinking water.

Step 3 Location and Permitting Considerations

In the last step, a site designer assesses the physical and environmental features at the site to determine the optimal location for the selected structural control or group of controls. The checklist below (Table 5.1.3-2) provides a condensed summary of current restrictions as they relate to common site features that may be regulated under local, state, or federal law. These restrictions fall into one of three general categories:

- Locating a structural control within an area when expressly prohibited by law.
- Locating a structural control within an area that is strongly discouraged, and is only allowed on a case by case basis. Local, state, and/or federal permits shall be obtained, and the applicant will need to supply additional documentation to justify locating the storm water control within the regulated area.
- Structural storm water controls must be setback a fixed distance from a site feature.

This checklist is only intended as a general guide to location and permitting requirements as they relate to siting of storm water structural controls. Consultation with the appropriate regulatory agency is the best strategy.

Table 5.1.3-2 Location and Permitting Checklist

Site Feature	Location and Permitting Guidance
Jurisdictional Wetland **(Waters of the U.S)** U.S. Army Corps of Engineers Regulattory Permit	• Jurisdictional wetlands should be delineated prior to siting structural control. • Use of natural wetlands for storm water quality treatment is contrary to the goals of the Clean Water Act and should be avoided. • Storm water should be treated prior to discharge into a natural wetland. • Structural controls may also be *restricted* in local buffer zones. Buffer zones may be utilized as a non-structural filter strip (i.e., accept sheet flow). • Should justify that no practical upland treatment alternatives exist. • Where practical, excess storm water flows should be conveyed away from jurisdictional wetlands.
Stream Channel (Waters of the U.S) U.S. Army Corps of Engineers Section 404 Permit	• All Waters of the U.S. (streams, ponds, lakes, etc.) should be delineated prior to design. • Use of any Waters of the U.S. for storm water quality treatment is contrary to the goals of the Clean Water Act and should be avoided. • Storm water should be treated prior to discharge into Waters of the U.S. • In-stream ponds for storm water quality treatment are highly discouraged. • Must justify that no practical upland treatment alternatives exist. • Temporary runoff storage preferred over permanent pools. • Implement measures that reduce downstream warming.

Table 5.1.3-2 Location and Permitting Checklist

Site Feature	Location and Permitting Guidance
Texas Commission on Environmental Quality Groundwater Management Areas	• Conserve, preserve, protect, recharge, and prevent waste of groundwater resources through Groundwater Conservation Districts • Groundwater Conservation District pending for Middle Trinity. • Detailed mapping available from Texas Alliance of Groundwater Districts.
Texas Commission on Environmental Quality Surface Water Quality Standards	• Specific stream and reservoir buffer requirements. • May be imperviousness limitations • May be specific structural control requirements. • TCEQ provides water quality certification – in conjunction with 404 permit • Mitigation will be required for imparts to existing aquatic and terrestrial habitat.
100 Year Floodplain Local Storm water review Authority	• Grading and fill for structural control construction is generally discouraged within the 100 year floodplain, as delineated by FEMA flood insurance rate maps, FEMA flood boundary and floodway maps, or more stringent local floodplain maps. • Floodplain fill cannot raise the floodplain water surface elevation by more than limits set by the appropriate jurisdiction.
Stream Buffer Check with appropriate review authority whether stream buffers are required	• Consult local authority for storm water policy. • Structural controls are discouraged in the streamside zone (within 25 feet or more of streambank, depending on the specific regulations).
Utilities Local Review Authority	• Call appropriate agency to locate existing utilities prior to design. • Note the location of proposed utilities to serve development. • Structural controls are discouraged within utility easements or rights of way for public or private utilities.
Roads TxDOT or DPW	• Consult TxDOT for any setback requirement from local roads. • Consult DOT for setbacks from State maintained roads. • Approval must also be obtained for any storm water discharges to a local or state-owned conveyance channel.
Structures Local Review Authority	• Consult local review authority for structural control setbacks from structures. • Recommended setbacks for each structural control group are provided in the performance criteria in this manual.
Septic Drain fields Local Health Authority	• Consult local health authority. • Recommended setback is a minimum of 50 feet from drain field edge or spray area.
Water Wells Local Health Authority	• 100-foot setback for storm water infiltration. • 50-foot setback for all other structural controls.

5.1.3.2 Example Application

A 20-acre institutional area (e.g., church and associated buildings) is being constructed in a dense urban area within Dallas/Fort Worth metropolitan area. The impervious coverage of the site is 40%. The site drains to an urban stream that is highly impacted from hydrologic alterations (accelerated channel erosion). The stream channel is deeply incised; consequently, flooding is not a problem. The channel drains to an urban river that is tributary to a phosphorus limited drinking water reservoir. Low permeability soils limit infiltration practices.

Objective: Avoid additional disruptions to receiving channel and reduce pollutant loads for sediment and phosphorus to receiving waters.

Target Removals: Provide storm water management to mitigate for accelerated channel incision and reduce loadings of key pollutants by the following:

- Sediment: 70% to 80%
- Phosphorus: 40%

Activity/Runoff Characteristics: The proposed site is to have large areas of impervious surface in the form of parking and structures. However, there will be a large contiguous portion of turf grass proposed for the front of the parcel that will have a relatively steep slope (approximately 10%) and will drain to the storm drain system associated with the entrance drive. Storm water runoff from the site is expected to exhibit fairly high sediment levels and seasonally high phosphorus levels (due to turf grass management).

Table 5.1.3-3 lists the results of the selection analysis using the screening matrix described previously. The highlighted rows indicate the controls selected for this example. The **X**'s indicate inadequacies in the control for this site. The ✓'s indicate adequate control capabilities for this site.

While there is a downstream reservoir to consider, there are no special watershed factors or physiographic factors to preclude the use of any of the practices from the structural control list. However, due to the size of the drainage area, most storm water ponds and wetlands are removed from consideration. In addition, the site's impermeable soils remove an infiltration trench from being considered. Due to the need to provide flood control as well as streambank protection storage, an extended detention micropool pond will likely be needed, unless some downstream regional storage is available to control flood waters.

To provide additional pollutant removal capabilities in an attempt to better meet the target removals, bioretention, surface sand filters, and/or perimeter sand filters can be used to treat the parking lot and driveway runoff. The bioretention will provide some removal of phosphorus while improving the aesthetics of the site. Surface sand filters provide higher phosphorus removal at a comparable unit cost to bioretention, but are not as aesthetically pleasing. The perimeter sand filter, is a flexible, easy to access practice (but at higher cost) that provides good phosphorus removal and additionally high oil and grease trapping ability.

The site drainage system can be designed so the bioretention and/or sand filters drain to the extended detention micropool pond for redundant treatment. Vegetated dry swales could also be used to convey runoff to the pond, which would provide pretreatment. Pocket wetlands and wet swales were eliminated from consideration due to potential for nuisance conditions. Underground sand filters could also be used at the site; however, cost and aesthetic considerations were significant enough to eliminate from consideration.

Structural Control Alternative	Storm Water Treatment Suitability	Site Applicability	Implementation Considerations	Physiographic Factors/Soils	Special Watershed Considerations	Other Issues
Bioretention	✓[1]	✓[2]	✓	✓	none	
Dry Swale	✓[1]	✓[2]	✓	✓	none	
Wet Swale	✓[1]	✓[2]	✓	✓	none	Odor / mosquitoes
Perimeter Sand Filter	✓[1]	✓[2]	✓	✓	none	Higher cost
Surface Sand Filter	✓[1]	✓[2]	✓	✓	none	Aesthetics
Infiltration Trench	✓[1]	✓	✓	X		
Extended Detention Micropool Pond	✓	✓	✓	✓	none	
Multiple Ponds	✓	X				
Wet Extended Detention Pond	✓	X				
Wet Pond	✓	X				
Extended Detention Shallow Wetland	✓	X				
Pocket Wetland	✓	✓	✓	✓	none	Odor / mosquitoes
Shallow Wetland	✓	X				

Table 5.1.3-3 Sample Structural Control Selection Matrix

Notes:
1. Only when used with another structural control that provides water quantity control
2. Can treat a portion of the site

5.1.4 On-Line Versus Off-Line Structural Controls

5.1.4.1 Introduction

Structural storm water controls are designed to be either "on-line" or "off-line." On-line facilities are designed to receive, but not necessarily control or treat, the entire runoff volume above the Q_f up to the peak 100-year discharge (Q_{p100}). On-line structural controls must be able to handle the entire range of storm flows.

Off-line facilities on the other hand are designed to receive only a specified flow rate or volume through the use of a flow regulator (i.e. diversion structure, flow splitter, etc). Flow regulators are typically used to divert the water quality volume (WQ_v) to an off-line structural control sized and designed to treat and control the WQ_v. After the design runoff flow has been treated and/or controlled, it is returned to the conveyance system. Figure 5.1.4.1 shows an example of an off-line sand filter and an on-line enhanced dry swale.

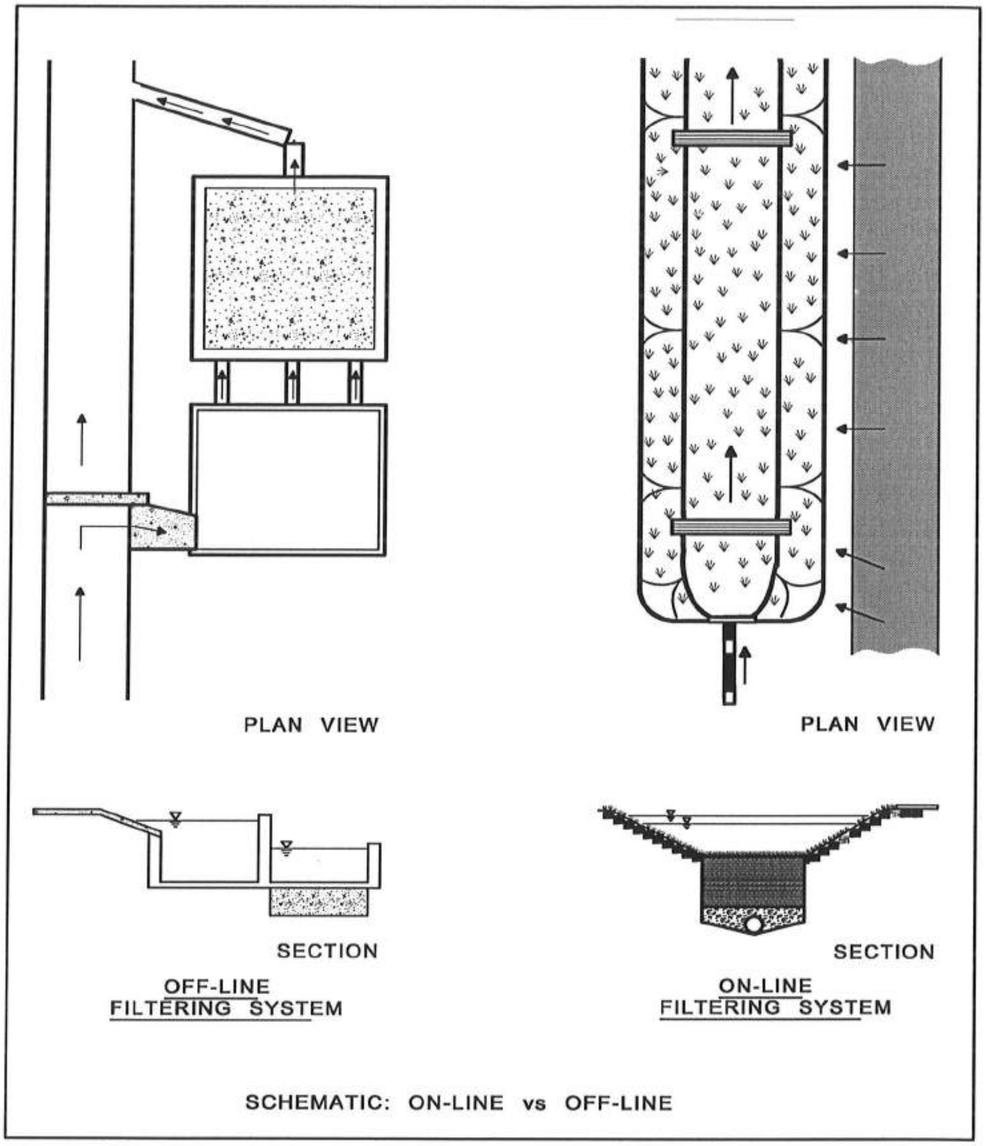


Figure 5.1.4-1 Example of On-Line versus Off-Line Structural Controls
(Source: CWP, 1996)

5.1.4.2 Flow Regulators

Flow regulation to off-line structural storm water controls can be achieved by either:

- Diverting the water quality volume or other specific maximum flow rate to an off-line structural storm water control, or
- Bypassing flows in excess of the design flow rate

The peak water quality flow rate (Q_{wq}) can be calculated using the procedure found in Section 2.1.10.2.

Flow regulators can be flow splitter devices, diversion structures, or overflow structures. A number of examples are shown below.

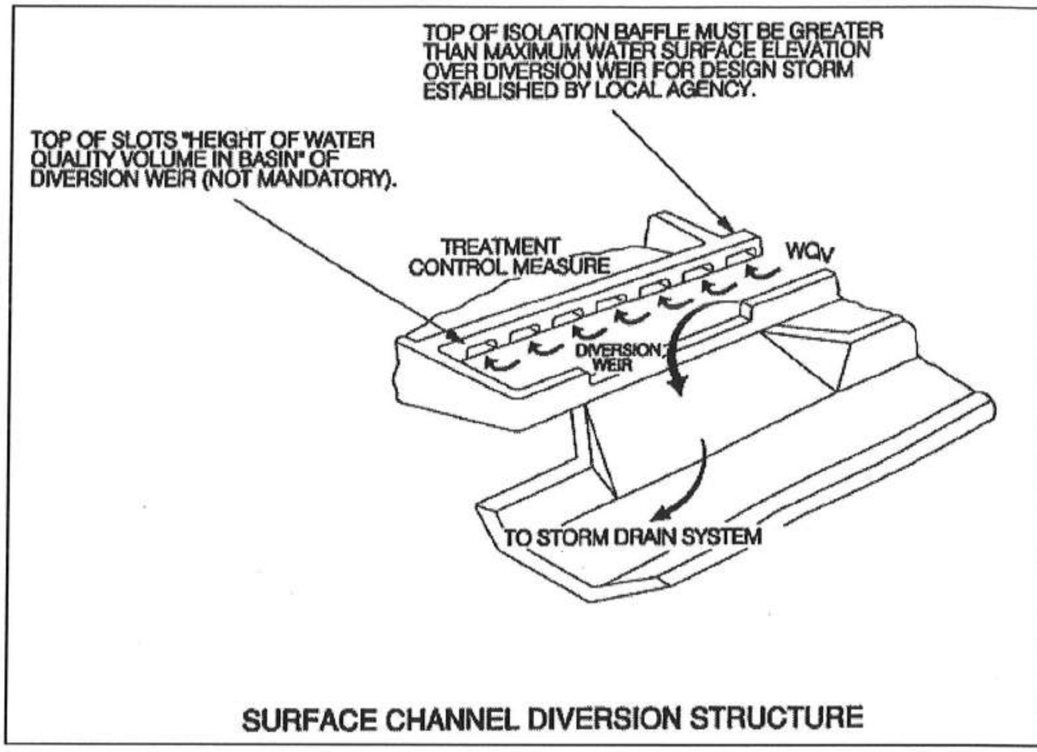


Figure 5.1.4-2 Pipe Interceptor Diversion Structure
(Source: City of Sacramento, 2000)

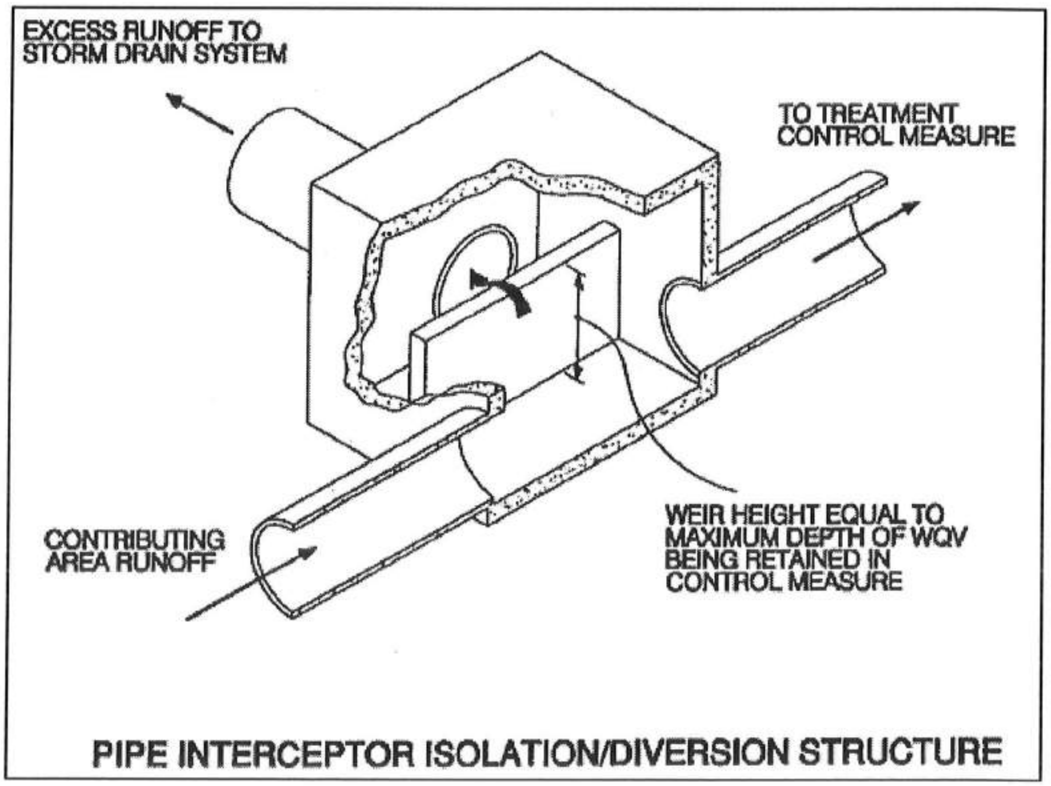


Figure 5.1.4-3 Surface Channel Diversion Structure
(Source: City of Sacramento, 2000)

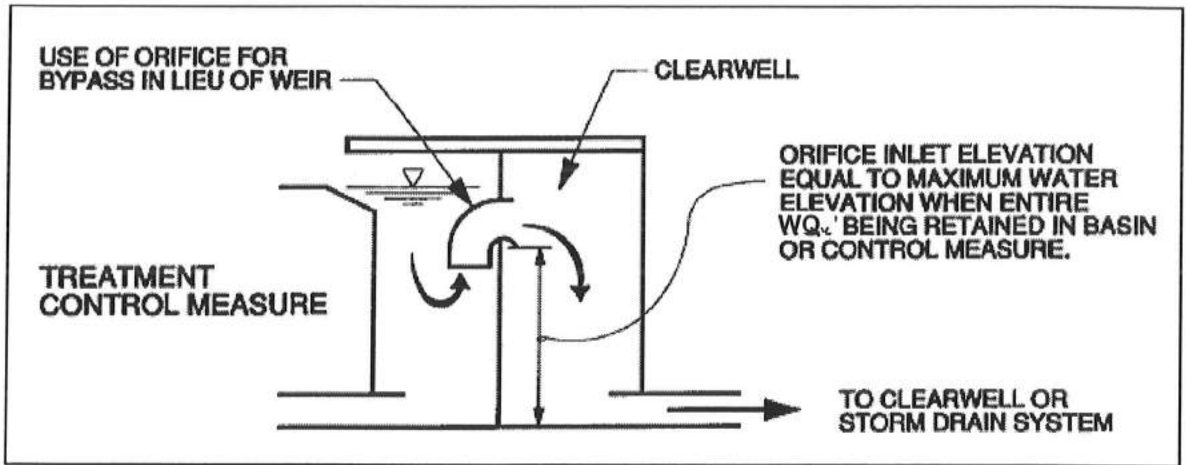


Figure 5.1.4-4 Outlet Flow Regulator
(Source: City of Sacramento, 2000)

5.1.5 Regional Versus On-Site Storm Water Management

5.1.5.1 Introduction

Using individual, on-site structural storm water controls for each development is the typical approach for controlling storm water quantity and quality. The developer finances the design and construction of these controls and, initially, is responsible for all operation and maintenance.

A potential alternative approach is for a community to install a few strategically located regional storm water controls in a subwatershed rather than require on-site controls (see Figure 5.1.5-1). For this Manual, regional storm water controls are defined as facilities designed to manage storm water runoff from multiple projects and/or properties through a local jurisdiction-sponsored program, where the individual properties may assist in the financing of the facility, and the requirement for on-site controls is either eliminated or reduced.

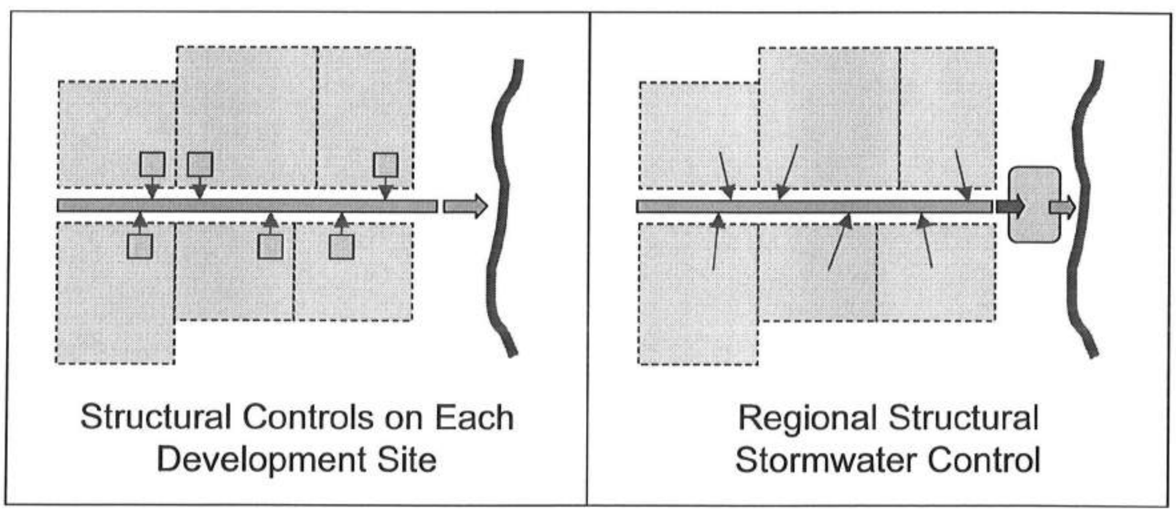


Figure 5.1.5-1 On-Site versus Regional Storm Water Management

5.1.5.2 Advantages and Disadvantages of Regional Storm Water Controls

Regional storm water facilities are significantly more cost-effective because it is easier and less expensive to build, operate, and maintain one large facility than several small ones. Regional storm water controls are generally better maintained than individual site controls because they are large, highly visible, and typically the responsibility of the local government. In addition, a larger facility poses less of a safety hazard than numerous small ones because it is more visible and is easier to secure.

There are also several disadvantages to regional storm water controls. In many cases, a community must provide capital construction funds for a regional facility, including the costs of land acquisition. However, if a downstream developer is the first to build, that person could be required to construct the facility and later be compensated by upstream developers for the capital construction costs and annual maintenance expenditures. Conversely, an upstream developer may have to establish temporary control structures if the regional facility is not in place before construction. Maintenance responsibilities generally shift from the homeowner or developer to the local government when a regional approach is selected. The local government would need to establish a storm water utility or some other program to fund and implement storm water control. Finally, a large in-stream facility can pose a greater disruption to the natural flow network and is more likely to affect wetlands within the watershed.

Below are summarized some of the "pros" and "cons" of regional storm water controls.

Advantages of Regional Storm Water Controls

- **Reduced Construction Costs** – Design and construction of a single regional storm water control facility can be far more cost-effective than numerous individual on-site structural controls.
- **Reduced Operation and Maintenance Costs** – Rather than multiple owners and associations being responsible for the maintenance of several storm water facilities on their developments, it is simpler and more cost effective to establish scheduled maintenance of a single regional facility.
- **Higher Assurance of Maintenance** – Regional storm water facilities are far more likely to be adequately maintained as they are large and have a higher visibility, and are typically the responsibility of the local government.
- **Maximum Utilization of Developable Land** – Developers would be able to maximize the utilization of the proposed development for the purpose intended by minimizing the land normally set aside for the construction of storm water structural controls.
- **Retrofit Potential** – Regional facilities can be used by a community to mitigate existing developed areas that have insufficient or no structural controls for water quality and/or quantity, as well as provide for future development.
- **Other Benefits** – Well-sited regional storm water facilities can serve as a recreational and aesthetic amenity for a community.

Disadvantages of Regional Storm Water Controls

- **Location and Siting** – Regional storm water facilities may be difficult to site, particularly for large facilities or in areas with existing development.
- **Capital Costs** – The community must typically provide capital construction funds for a regional facility, including the costs of land acquisition.
- **Maintenance** – The local government is typically responsible for the operation and maintenance of a regional storm water facility.
- **Need for Planning** – The implementation of regional storm water controls requires substantial planning, financing, and permitting. Land acquisition must be in place ahead of future projected growth.

For in-stream regional facilities:

- **Water Quality and Streambank Protection** – Without on-site water quality and streambank protection, regional controls do not protect smaller streams upstream from the facility from degradation and streambank erosion.
- **Ponding Impacts** – Upstream inundation from a regional facility impoundment can eliminate floodplains, wetlands, and other habitat.

5.1.5.3 Important Considerations for the Use of Regional Storm Water Controls

If a community decides to implement a regional storm water control, then it must ensure that the conveyances between the individual upstream developments and the regional facility can handle the design peak flows and volumes without causing adverse impact or property damage. Fully developed conditions in the regional facility drainage area should be used in the analysis.

Furthermore, unless the system consists of completely man-made conveyances (i.e. storm drains, pipes, concrete channels, etc) the on-site structural controls for water quality and downstream streambank protection will likely be required for all developments within the regional facility's drainage area. Federal water quality provisions do not allow the degradation of water bodies from untreated storm water discharges, and it is U.S. EPA policy to not allow regional storm water controls that would degrade stream quality between the upstream development and the regional facility. Further, without adequate streambank protection, aquatic habitats and water quality in the channel network upstream of a regional facility may be degraded by streambank erosion if they are not protected from bankfull flows and high velocities.

Based on these concerns, both the EPA and the U.S. Army Corps of Engineers have expressed opposition to *in-stream* regional storm water control facilities. In-stream facilities should be avoided if possible and will likely be permitted on a case-by-case basis only.

It is important to note that siting and designing regional facilities should ideally be done within a context of storm water master planning or watershed planning to be effective.

5.1.6 Using Structural Storm Water Controls in Series

5.1.6.1 Storm Water Treatment Trains

The minimum storm water management standards are an integrated planning and design approach whose components work together to limit the adverse impacts of urban development on downstream waters and riparian areas. This approach is sometimes called a storm water "treatment train." When considered comprehensively, a treatment train consists of all the design concepts and nonstructural and structural controls that work to attain water quality and quantity goals. This is illustrated in Figure 5.1.6-1.

Figure 5.1.6-1 Generalized Storm Water Treatment Train

Runoff and Load Generation – The initial part of the "train" is located at the source of runoff and pollutant load generation, and consists of *integrated* site design and pollution prevention practices that reduce runoff and storm water pollutants from the source.

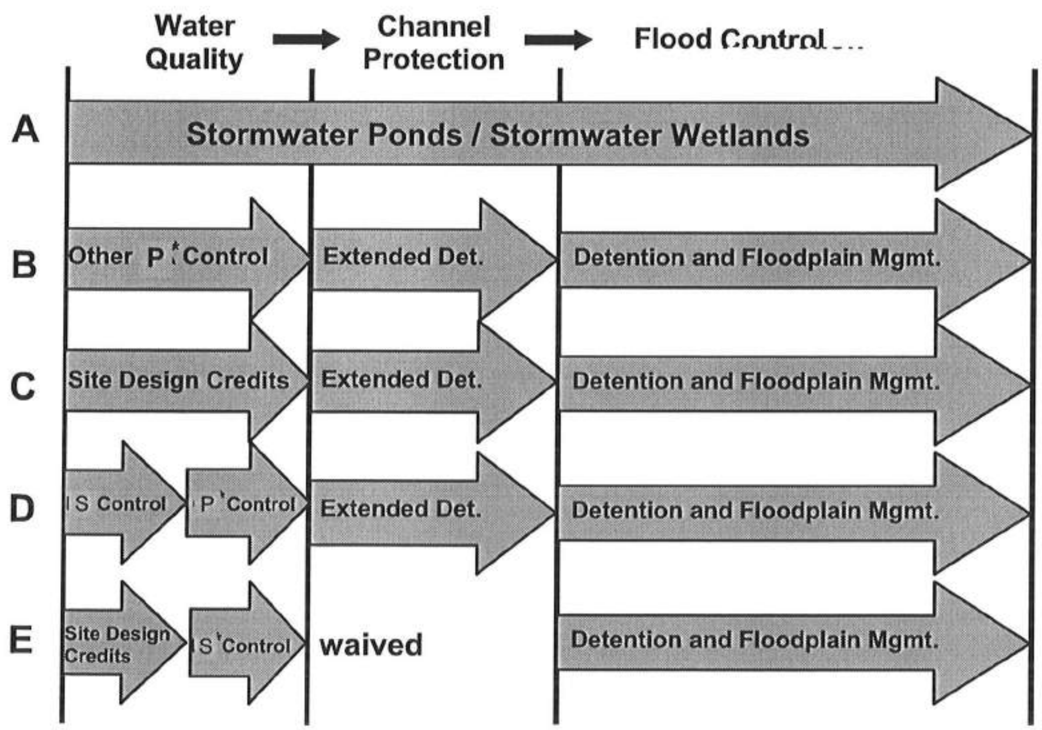
Pretreatment – The next step in the treatment train consists of pretreatment measures. These measures typically do not provide sufficient pollutant removal to meet the Primary TSS reduction goal, but do provide calculable water quality benefits that may be applied towards meeting the WQ_v treatment requirement. These measures include:

- The use of storm water *integrated* site design practices and site design credits to reduce the water quality volume (WQ_v)
- Structural controls that achieve less than the Primary TSS removal rate, but provide pretreatment
- Pretreatment facilities such as sediment forebays

Primary Treatment and/or Quantity Control – The last step is primary water quality treatment and/or quantity (streambank protection and/or flood control) control. This is achieved through the use of either a structural control to achieve both water quality and quantity benefits or a structural control to achieve water quality benefits only.

5.1.6.2 Use of Multiple Structural Controls in Series

Many combinations of structural controls in series may exist for a site. Figure 5.1.6-2 provides a number of hypothetical examples of how the *integrated* Design Approach may be addressed by using structural storm water controls.



***P - Primary Control and S - Secondary Control Limited Application.**

Figure 5.1.6-2 Examples of Structural Controls Used in Series

Referring to Figure 5.1.6-2 by line letter:

A. Two structural controls achieving Primary TSS removal each, *storm water ponds* and *storm water wetlands*, can be used to meet all of the requirements of the *integrated* Design Approach in a single facility.

B. The other structural controls achieving Primary TSS removal each (*bioretention, sand filters, infiltration trench and enhanced swale*) are typically used in combination with detention controls to meet the *integrated* Design Approach. The detention facilities are located downstream from the water quality controls either on-site or combined into a regional or neighborhood facility.

C. Line C indicates the condition where an environmentally sensitive large lot subdivision has been developed that can be designed so as to waive the water quality treatment requirement altogether. However, detention controls may still be required for downstream streambank protection and flood control.

D. Where a structural control does not meet the Primary TSS removal criteria, another downstream structural control must be added. For example, urban hotspot land may be fit or retrofit with devices adjacent to parking or service areas designed to remove petroleum hydrocarbons. These devices may also serve as pretreatment devices removing the coarser fraction of sediment. One or more downstream structural controls are then used to meet the full Primary TSS removal goal, and well as water quantity control.

E. In line E, site design credits have been employed to reduce partially the water quality volume requirement. In this case, for a smaller site, a well designed and tested structural control provides limited TSS removal while a dry detention pond handles the flooding criteria. For this location, direct discharge to a large stream and local downstream floodplain management practices have eliminated the need for streambank protection and flood control storage on site.

The combinations of structural storm water controls are limited only by the need to employ measures of proven effectiveness and meet local regulatory and physical site requirements. Figures 5.1.6-3 through 5.1.6-5 illustrate the application of the treatment train concept for: a moderate density residential neighborhood, a small commercial site, and a large shopping mall site.

In Figure 5.1.6-3 rooftop runoff drains over grassed yards to backyard grass channels. Runoff from front yards and driveways reaches roadside grass channels. Finally, all storm water flows to a extended detention micropool storm water pond.

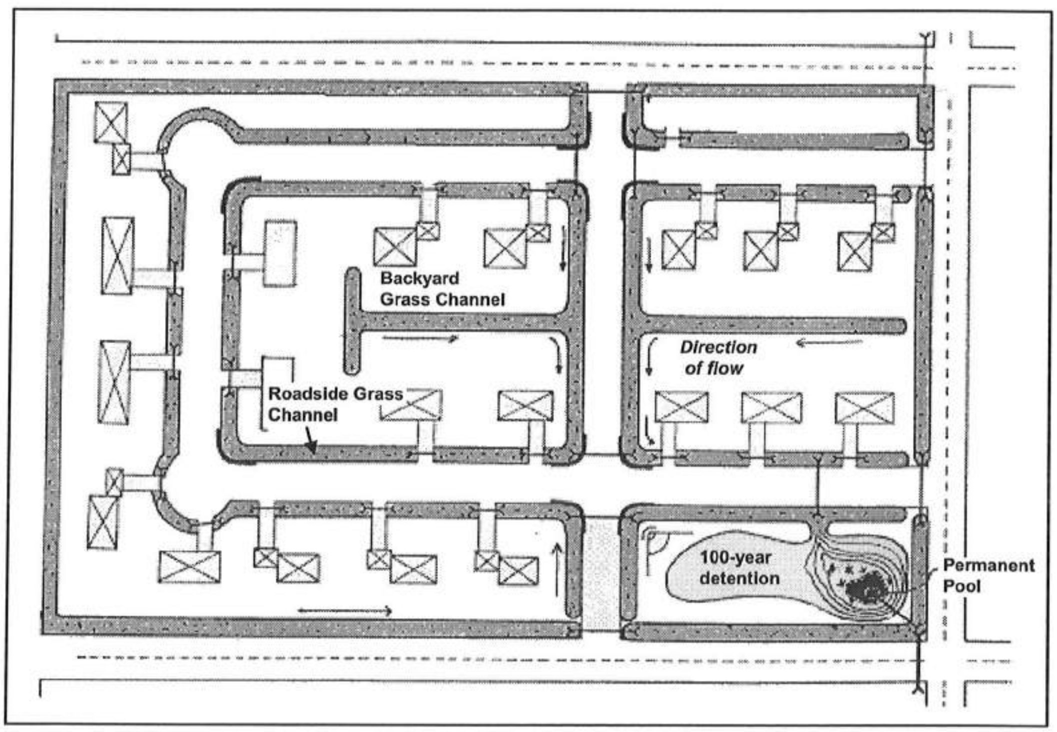


Figure 5.1.6-3 Example Treatment Train – Residential Subdivision
(Adapted from: NIPC, 2000)

A gas station and convenience store is depicted in Figure 5.1.6-4. In this case, the decision was made to intercept hydrocarbons and oils using a commercial gravity (oil-grit) separator located on the site prior to draining to perimeter sand filter for removal of finer particles and TSS. No storm water control for streambank protection is required as the system drains to the municipal storm drain pipe system. Flood control is provided by a regional storm water control downstream.

Figure 5.1.6-5 shows an example treatment train for a commercial shopping center. In this case, runoff from rooftops and parking lots drains to depressed parking lot islands, perimeter grass channels, and bioretention areas. Slotted curbs are used at the entrances to these swales to better distribute the flow and to settle out the very coarse particles at the parking lot edge for sweepers to remove. Runoff is then conveyed to an extended detention wet pond for additional pollutant removal and streambank protection. Flood control is provided through parking lot detention.

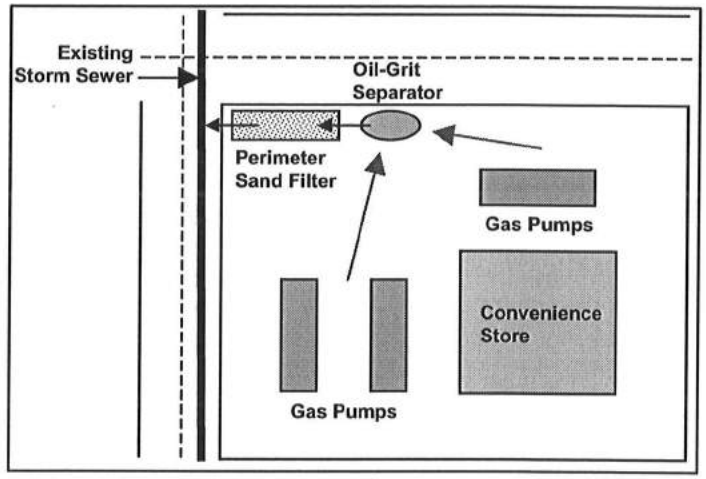


Figure 5.1.6-4 Example Treatment Train – Small Commercial Site

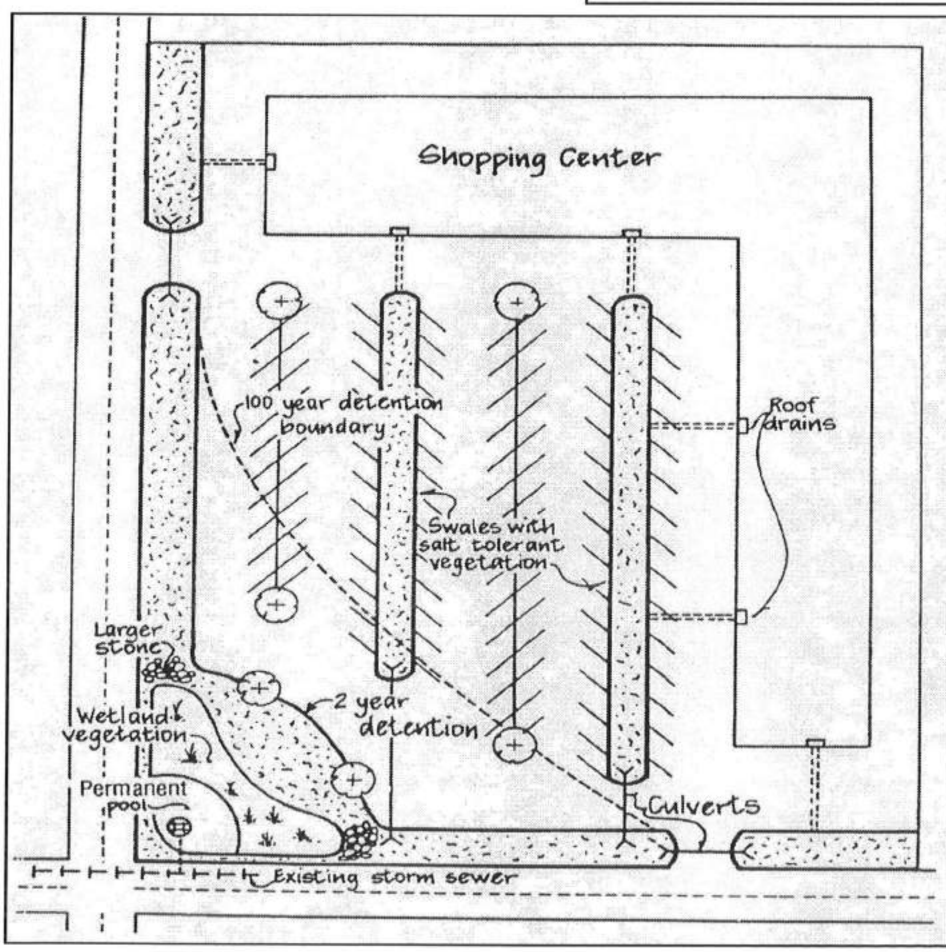


Figure 5.1.6-5 Example Treatment Train – Large Commercial Development
(Source: NIPC, 2000)

5.1.6.3 Calculation of Pollutant Removal for Structural Controls in Series

For two or more structural storm water controls used in combination, it is often important to have an estimate of the pollutant removal efficiency of the treatment train. Pollutant removal rates for structural controls in series are not additive. For pollutants in particulate form, the actual removal rate (expressed in terms of percentage of pollution removed) varies directly with the pollution concentration and sediment size distribution of runoff entering a facility.

For example, a storm water pond facility will have a much higher pollutant removal percentage for very turbid runoff than for clearer water. When two storm water ponds are placed in series, the second pond will treat an incoming particulate pollutant load very different from the first pond. The upstream pond captures the easily removed larger sediment sizes, passing on an outflow with a lower concentration of TSS but with a higher proportion of finer particle sizes. Hence, the removal capability of the second pond for TSS is considerably less than the first pond. Recent findings suggest that the second pond in series can provide as little as half the removal efficiency of the upstream pond.

To estimate the pollutant removal rate of structural controls in series, a method is used in which the removal efficiency of a downstream structural control is reduced to account for the pollutant removal of the upstream control(s). The following steps are used to determine the pollutant removal:

- For each drainage area, list the structural controls in order, upstream to downstream, along with their expected average pollutant removal rates from Table 5.1.2-1 for the pollutants of concern.
- For any structural control with a Primary TSS removal rate located downstream from another control that has an equivalent TSS removal rate, the designer should use 50% of the normal pollutant removal rate for the second control in series. For any structural control with a Primary TSS removal rate located downstream from a control that cannot achieve the Primary TSS reduction goal, the designer should use 75% of the normal pollutant removal rate for the second control in series.

  For example, if a structural control has a Primary TSS removal rate, then a 35% to 40% TSS removal rate would be assumed for this control if it were placed downstream from another equivalent control in the treatment train (0.5 x 70% to 80%). If it were placed downstream from a structural control that cannot achieve the Primary TSS reduction goal, a 52.5% to 60% TSS removal rate would be assumed (0.75 x 70% to 80%). Use this rule with caution depending on the actual pollutant of concern and make allowance for differences among structural control pollutant removal rates for different pollutants. Actual data from similar situations should be used to temper or override this rule of thumb where available.
- For cases where a structural control which cannot achieve a Primary TSS removal rate is sited upstream from a structural control which can achieve the 70% to 80% removal in the treatment train, the downstream structural control is given full credit for removal of pollutants.
- Apply the following equation for calculation of approximate total accumulated pollution removal for controls in series:

  Final Pollutant Removal = (Total load * Control1 removal rate) + (Remaining load * Control2 removal rate) + ... for other Controls in series.

Example

TSS is the pollutant of concern and a commercial device is inserted that has a 20% sediment removal rate. A storm water pond is designed at the site outlet. A second storm water pond is located downstream from the first one in series. What is the total TSS removal rate? The following information is given:

Control 1 (Commercial Device) = 20% TSS removal

Control 2 (Storm water Pond 1) = 80% TSS removal (use 1.0 x design removal rate)

Control 3 (Storm water Pond 2) = 40% TSS removal (use 0.5 x design removal rate)

Then applying the controls in order and working in terms of "units" of TSS starting at 100 units:

For Control 1:	100 units of TSS * 20% removal rate = 20 units removed
	100 units - 20 units removed = 80 units of TSS remaining
For Control 2:	80 units of TSS * 80% removal rate = 64 units removed
	80 units - 64 units removed = 16 units of TSS remaining
For Control 3:	16 units of TSS * 40% removal rate = 6 units removed
	16 units - 6 units removed = 10 units TSS remaining

For the treatment train in total = 100 units TSS – 10 units TSS remaining = **90% removal**

5.1.6.4 Routing with WQ_v Removed

When off-line structural controls such as bioretention areas, sand filters and infiltration trenches capture and remove the water quality volume (WQ_v), downstream structural controls do not have to account for this volume during design. That is, the WQ_v may be subtracted from the total volume that would otherwise need to be routed through the downstream structural controls.

From a calculation standpoint this would amount to removing the initial WQ_v from the beginning of the runoff hydrograph – thus creating a "notch" in the runoff hydrograph. Since most commercially available hydrologic modeling packages cannot handle this type of action, the following method to adjust "CN" values has been created to facilitate removal from the runoff hydrograph of approximately the WQ_v:

- Enter the horizontal axis on Figure 5.1.6-6 with the impervious percentage of the watershed and read upward to the predominant soil type (interpolation between curves is permitted)
- Read left to the factor
- Multiply the curve number for the sub-watershed that includes the water quality basin by this factor – this provides a smaller curve number

The difference in curve number will generate a runoff hydrograph that has a volume less than the original volume by an amount approximately equal to the WQ_v. This method should be used only for bioretention areas, filter facilities, and infiltration trenches where the drawdown time is ≥ 24 hours.

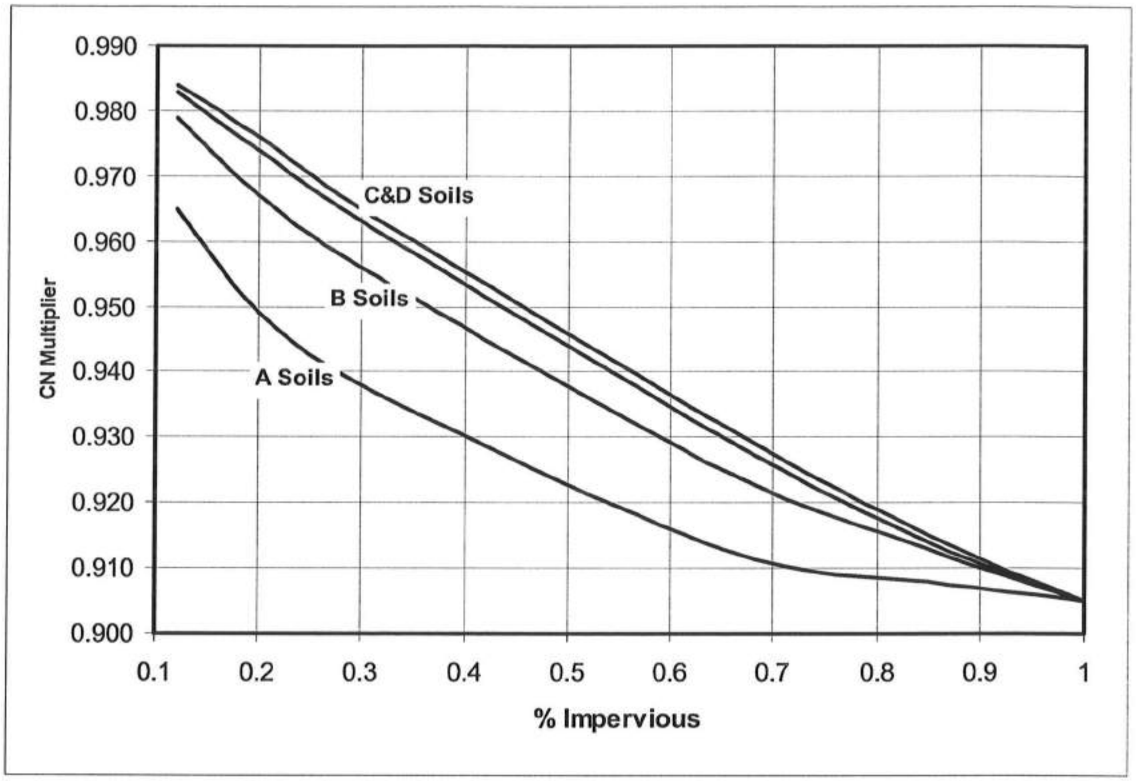


Figure 5.1.6-6 Curve Number Adjustment Factor

Example

A site design employs an infiltration trench for the WQ_v and has a curve number of 72, is B type soil, and has an impervious percentage of 60%, the factor from Figure 5.1.6-6 is 0.93. The curve number to be used in calculation of a runoff hydrograph for the quantity controls would be: (72*0.93) = 67.

Section 5.2
Storm Water Controls

5.2.1 Bioretention Areas

Structural Storm Water Control

Description: Shallow storm water basin or landscaped area that utilizes engineered soils and vegetation to capture and treat runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA:
- Maximum contributing drainage area of 5 acres (< 2 acres recommended)
- Often located in "landscaping islands"
- Treatment area consists of grass filter, sand bed, ponding area, organic/mulch layer, planting soil, and vegetation
- Typically requires 5 feet of head

ADVANTAGES / BENEFITS:
- Applicable to small drainage areas
- Good for highly impervious areas, flexible siting
- Good retrofit capability
- Relatively low maintenance requirements
- Can be planned as an aesthetic feature

DISADVANTAGES / LIMITATIONS:
- Requires extensive landscaping if in public area
- Not recommended for areas with steep slopes

MAINTENANCE REQUIREMENTS:
- Inspect and repair/replace treatment area components

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
60/50%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
M	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No Data	**Pathogens** - Coliform, Streptococci, E. Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
S	**Streambank Protection**
S	**On-Site Flood Control**
	Downstream Flood Control

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

S - in certain situations

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirement**
M	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max. (< 2 acres recommended)*

Soils: *Planting soils must meet specified criteria; No restrictions on surrounding soils*

Other Considerations:
- *Use of native plants is recommended*

L=Low M=Moderate H=High

5.2.1.1 General Description

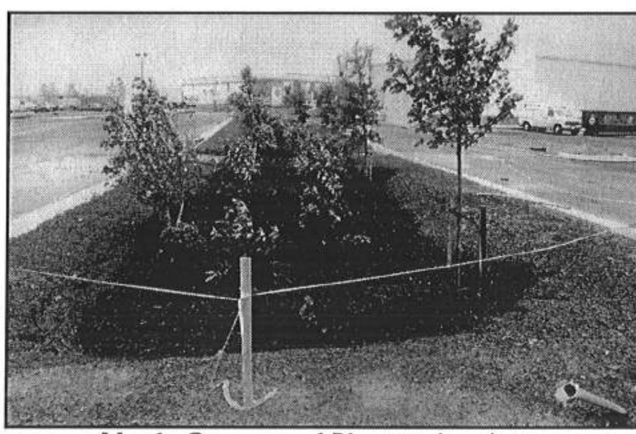
Bioretention areas (also referred to as *bioretention filters* or *rain gardens*) are structural storm water controls that capture and temporarily store the water quality protection volume (WQ_v) using soils and vegetation in shallow basins or landscaped areas to remove pollutants from storm water runoff.

Bioretention areas are engineered facilities in which runoff is conveyed as sheet flow to the "treatment area" which consists of a grass buffer strip, ponding area, organic or mulch layer, planting soil, and vegetation. An optional sand bed can also be included in the design to provide aeration and drainage of the planting soil. The filtered runoff is typically collected and returned to the conveyance system, though it can also infiltrate into the surrounding soil in areas with porous soils.

There are numerous design applications, both on- and off-line, for bioretention areas. These include use on single-family residential lots (*rain gardens*), as off-line facilities adjacent to parking lots, along highway and road drainage swales, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments. Figures 5.2.1-1 and 5.2.1-2 illustrate a number of examples of bioretention facilities in both photographs and drawings.

Single-Family Residential "Rain Garden"

Landscaped Island



Newly Constructed Bioretention Area

Newly Planted Bioretention Area After Storm

Figure 5.2.1-1 Bioretention Area Examples

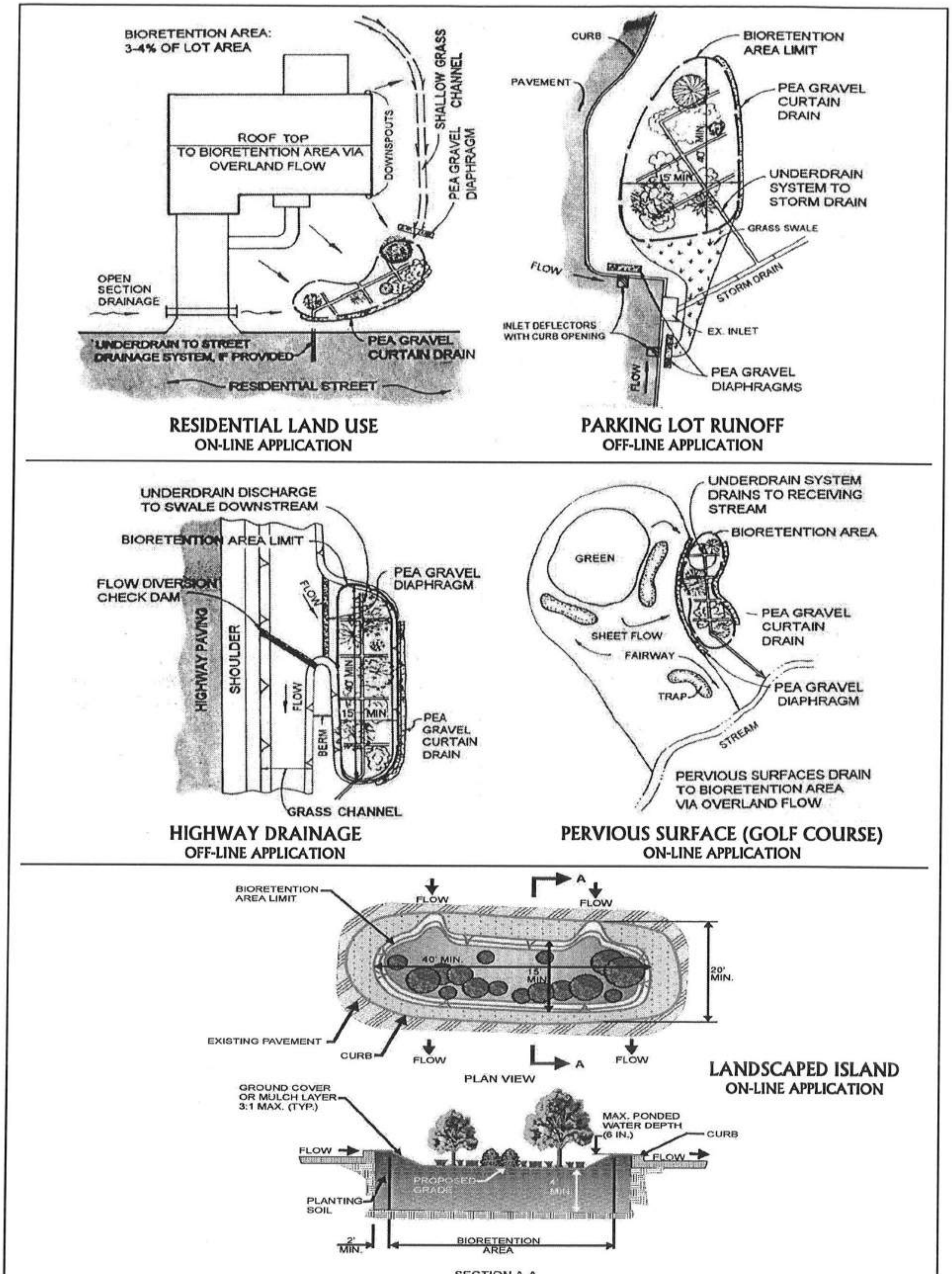


Figure 5.2.1-2 Bioretention Area Applications
(Source: Claytor and Schueler, 1996)

5.2.1.2 Storm Water Management Suitability

Bioretention areas are designed primarily for storm water quality, i.e. the removal of storm water pollutants. Bioretention can provide limited runoff quantity control, particularly for smaller storm events. These facilities may sometimes be used to partially or completely meet streambank protection requirements on smaller sites. However, bioretention areas will typically need to be used in conjunction with another structural control to provide streambank protection as well as flood control. It is important to ensure that a bioretention area safely bypasses higher flows.

Water Quality Protection

Bioretention is an excellent storm water treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention area is designed to perform a specific function (see Figure 5.2.1-3 on page 5.2-12). The *grass filter strip (or grass channel)* reduces incoming runoff velocity and filters particulates from the runoff. The *ponding area* provides for temporary storage of storm water runoff prior to its evaporation, infiltration, or uptake and provides additional settling capacity. The *organic or mulch layer* provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The *planting soil* in the bioretention facility acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants. Both *woody and herbaceous plants* in the ponding area provide vegetative uptake of runoff and pollutants and also serve to stabilize the surrounding soils. Finally, an optional *sand bed* provides for positive drainage and aerobic conditions in the planting soil and provides a final polishing treatment media.

Section 5.2.1.3 gives data on pollutant removal efficiencies that can be used for planning and design purposes.

Streambank Protection

For smaller sites, a bioretention area may be designed to capture the entire streambank protection volume SP_v in either an off- or on-line configuration. Given that a bioretention facility is typically designed to completely drain over 48 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites where only the WQ_v is diverted to the bioretention facility, another structural control must be used to provide SP_v extended detention.

Flood Control

Bioretention areas must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the ponding area, mulch layer, and vegetation.

Credit for the volume of runoff removed and treated in the bioretention area may be taken in flood control calculations (see Section 5.1).

5.2.1.3 Pollutant Removal Capabilities

Bioretention areas are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed bioretention areas can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 60%**

- **Total Nitrogen – 50%**
- **Fecal Coliform – insufficient data**
- **Heavy Metals – 80%**

For additional information and data on pollutant removal capabilities for bioretention areas, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Storm Water Best Management Practices (BMP) Database at www.bmpdatabase.org

5.2.1.4 Application and Site Feasibility Criteria

Bioretention areas are suitable for many types of development, from single-family residential to high-density commercial projects. Bioretention is also well suited for small lots, including those of one acre or less. Because of its ability to be incorporated in landscaped areas, the use of bioretention is extremely flexible. Bioretention areas are an ideal structural storm water control for use as roadway median strips and parking lot islands and are also good candidates for the treatment of runoff from pervious areas, such as a golf course. Bioretention can also be used to retrofit existing development with storm water quality treatment capacity.

The following criteria should be evaluated to ensure the suitability of a bioretention area for meeting storm water management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Storm Water Control – NO
- Hot Spot - YES

Physical Feasibility - Physical Constraints at Project Site

- Drainage Area – 5 acres maximum; 0.5 to 2 acres are preferred.
- Space Required – Approximately 5-7% of the tributary impervious area is normally required.
- Site Slope – No more than 6% slope
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 3-5 feet
- Minimum Depth to Water Table – A separation distance of 2 feet recommended between the bottom of the bioretention facility and the elevation of the seasonally high water table.
- Soils – No restrictions; engineered media required

Other Constraints / Considerations

- Aquifer Protection – Do not allow infiltration of filtered hotspot runoff into groundwater

5.2.1.5 Planning and Design Criteria

The following criteria are to be considered ***minimum*** *standards for the design of a bioretention facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

A. LOCATION AND SITING

- Bioretention areas should have a maximum contributing drainage area of 5 acres or less; 0.5 to 2 acres are preferred. Multiple bioretention areas can be used for larger areas.

- Bioretention areas can either be used to capture sheet flow from a drainage area or function as an off-line device. On-line designs should be limited to a maximum drainage area of 0.5 acres unless special precautions are taken to protect from erosion during high flows.
- When used in an off-line configuration, the water quality protection volume (WQ_v) is diverted to the bioretention area through the use of a flow splitter. Storm water flows greater than the WQ_v are diverted to other controls or downstream (see Section 5.1 for more discussion of off-line systems and design guidance for diversion structures and flow splitters).
- Bioretention systems are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.
- Bioretention area locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth.

B. GENERAL DESIGN

- A well-designed bioretention area consists of:
  1 **Grass filter strip (or grass channel) between the contributing drainage area and the ponding area, except where site conditions preclude its use,**
  2 **Ponding area containing vegetation with a planting soil bed,**
  3 **Organic/mulch layer,**
  4 **Pea gravel layer between the planting soil and the gravel underneath to provide filtering of the particles prior to entering gravel layer,**
  5 **Gravel and perforated pipe underdrain system to collect runoff that has filtered through the soil layers (bioretention areas can optionally be designed to infiltrate into the soil – see description of infiltration trenches for infiltration criteria).**
- A bioretention area design will also include some of the following:
  1 Optional **sand filter layer** to spread flow, filter runoff, and aid in aeration and drainage of the planting soil.
  2 **Stone diaphragm** at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter.
  3 **Inflow diversion** or an **overflow structure** consisting of one of five main methods:
    - Use a flow diversion structure
    - For curbed pavements use an inlet deflector (see Figure 5.2.1-6).
    - Use a slotted curb and design the parking lot grades to divert the WQ_v into the facility. Bypass additional runoff to a downstream catch basin inlet. Requires temporary ponding in the parking lot (see Figure 5.2.1-5).
    - Figure 5.2.1-2c illustrates the use of a short deflector weir (maximum height 6 inches) designed to divert the maximum water quality peak flow into the bioretention area.
    - An in-system overflow consisting of an overflow catch basin inlet and/or a pea gravel curtain drain overflow.

See Figure 5.2.1-3 for an overview of the various components of a bioretention area. Figure 5.2.1-4 provides a plan view and profile schematic of an on-line bioretention area. An example of an off-line facility is shown in Figure 5.2.1-5.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- Recommended minimum dimensions of a bioretention area are 10 feet wide by 40 feet long. All designs except small residential applications should maintain a length to width ratio of at least 2:1.
- The planting soil filter bed is sized using a Darcy's Law equation with a filter bed drain time of less than 48 hours (less than 6 hours residential neighborhoods and 24 hours non-residential preferred) and a coefficient of permeability (k) of greater than 0.5 ft/day.
- The maximum recommended ponding depth of the bioretention areas is 6 inches with a drain time normally of 3 to 4 hours in residential settings.
- The planting soil bed must be at least 2.5 feet in depth and up to 4 feet if large trees are to be planted. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 5 to 8%. The soil must have an infiltration rate of at least 0.5 inches per hour (1.0 in/hr preferred) and a pH between 5.5 and 6.5. In addition, the planting soil should have a 1.5 to 3% organic content and a maximum 500 ppm concentration of soluble salts.
- For on-line configurations, a grass filter strip with a pea gravel diaphragm is typically utilized (see Figure 5.2.1-3) as the pretreatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. Design guidance on filter strips for pretreatment can be found in subsection 5.2.12 (*Filter Strip)*.
- For off-line applications, a grass channel with a pea gravel diaphragm flow spreader is used for pretreatment. The length of the grass channel depends on the drainage area, land use, and channel slope. The minimum grassed channel length should be 20 feet. Design guidance on grass channels for pretreatment can be found in subsection 5.2.3 (*Grass Channel)*.
- The mulch layer should consist of 2 to 4 inches of commercially available fine shredded hardwood mulch or shredded hardwood chips.
- The sand bed (optional) should be 12 to 18 inches thick. Sand should be clean and have less than 15% silt or clay content.
- Pea gravel for the 4" to 9" thick layer above the gravel bedding (and diaphragm and curtain, where used), should be ASTM D 448 size No. 6 ($^1/_8$" to ¼").
- The underdrain collection system is equipped with a 6-inch perforated PVC pipe (AASHTO M 252) in an 8-inch gravel layer. The pipe should have 3/8-inch perforations, spaced at 6-inch centers, with a minimum of 4 holes per row. The pipe is spaced at a maximum of 10 feet on center and a minimum grade of 0.5% must be maintained.
- A narrow 24" wide permeable filter fabric is placed between the gravel layer and the pea gravel layer directly above the perforated pipes to limit piping of soil directly into the pipe. Filter fabric is also placed along the vertical or sloping outer walls of the bioretention system to limit vertical infiltration prior to filtration through the soil.

D. PRETREATMENT / INLETS

- Adequate pretreatment and inlet protection for bioretention systems is provided when all of the following are provided: (a) grass filter strip below a level spreader, or grass channel, (b) pea gravel diaphragm and (c) an organic or mulch layer.

E. OUTLET STRUCTURES

- Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary.

F. EMERGENCY SPILLWAY

- An overflow structure and nonerosive overflow channel must be provided to safely pass flows from the bioretention area that exceeds the storage capacity to a stabilized downstream area or watercourse. If the system is located off-line, the overflow should be set above the shallow ponding limit.
- The high flow overflow system <u>within</u> the structure consists of a yard drain catchbasin (Figure 5.2.1-3), though any number of conventional systems could be used. The throat of the catch basin inlet is normally placed 6 inches above the mulch layer. It should be designed as a domed grate or a covered weir structure to avoid clogging with floatation mulch and debris, and should be located at a distance from inlets to avoid short circuiting of flow. It may also be placed into the side slope of the structure maintaining a neat contoured appearance.

G. MAINTENANCE ACCESS

- Adequate access must be provided for all bioretention facilities for inspection, maintenance, and landscaping upkeep. Appropriate equipment and vehicles are essential.

H. SAFETY FEATURES

- Bioretention areas generally do not require any special safety features. Fencing of bioretention facilities is not generally desirable.

I. LANDSCAPING

- Landscaping is critical to the performance and function of bioretention areas.
- A dense and vigorous vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Side slopes should be sodded to limit erosion of fine particles onto the bioretention surface.
- The bioretention area should be vegetated to resemble a terrestrial forest ecosystem, with a mature tree canopy, subcanopy of understory trees, scrub layer, and herbaceous ground cover. Three species each of both trees and scrubs are recommended to be planted.
- The tree-to-shrub ratio should be 2:1 to 3:1. On average, the trees should be spaced 8 feet apart. Plants should be placed at regular intervals to replicate a natural forest. Woody vegetation should not be specified at inflow locations.
- After the trees and shrubs are established, the ground cover and mulch should be established.
- Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost aesthetics, maintenance, etc. Planting recommendations for bioretention facilities are as follows:
  - Native plant species should be specified over non-native species.
  - Vegetation should be selected based on a specified zone of hydric tolerance.
  - A selection of trees with an understory of shrubs and herbaceous materials should be provided.

Additional information and guidance on the appropriate woody and herbaceous species appropriate for bioretention in North Central Texas, and their planting and establishment, can be found in Appendix F, *Landscaping and Aesthetics Guidance*.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- <u>Low Relief</u> – Use of bioretention areas may be limited by low head
- <u>High Relief</u> – Ponding area surface must be relatively level

- Karst – Use poly-liner or impermeable membrane to seal bottom

Soils

- No restrictions

Special Downstream Watershed Considerations

- Aquifer Protection – No restrictions, if designed with no infiltration (i.e. outflow to groundwater)

5.2.1.6 Design Procedures

Step 1 Compute runoff control volumes from the *integrated* Design Approach

Calculate the Water Quality Protection Volume (WQ_v), Streambank Protection Volume (SP_v), and the 100-Year Flood Discharge (Q_f).

Details on the *integrated* Design Approach are found in Section 1.2.

Step 2 Determine if the development site and conditions are appropriate for the use of a bioretention area

Consider the Application and Site Feasibility Criteria in subsections 5.2.1.4 and 5.2.1.5-A (Location and Siting).

Step 3 Confirm local design criteria and applicability

Consider any special site-specific design conditions/criteria from subsection 5.2.1.5-J (Additional Site-Specific Design Criteria and Issues).

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 4 Compute WQ_v peak discharge (Q_{wq})

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures (see subsection 2.1.9).

(a) Using WQ_v (or total volume to be captured), compute CN

(b) Compute time of concentration using TR-55 method

(c) Determine appropriate unit peak discharge from time of concentration

(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

Step 5 Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the bioretention area.

Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 6 Determine size of bioretention ponding/filter area

The required planting soil filter bed area is computed using the following equation (based on Darcy's Law):

$$\mathbf{A_f = (WQ_v)\,(d_f)\,/\,[\,(k)\,(h_f + d_f)\,(t_f)]}$$

where:

A_f = surface area of ponding area (ft^2)

WQ_v = water quality protection volume (or total volume to be captured)

d_f = filter bed depth (2.5 feet minimum)

k = coefficient of permeability of filter media (ft/day) (use 0.5 ft/day for silt-loam)

h_f = average height of water above filter bed (ft) (typically 3 inches, which is half of the 6-inch ponding depth)

t_f = design filter bed drain time (days) (2.0 days or 48 hours is recommended maximum)

Step 7 Set design elevations and dimensions of facility

See subsection 5.2.1.5-C (Physical Specifications/Geometry).

Step 8 Design conveyances to facility (off-line systems)

See the example figures to determine the type of conveyances needed for the site.

Step 9 Design pretreatment

Pretreat with a grass filter strip (on-line configuration) or grass channel (off-line), and stone diaphragm.

Step 10 Size underdrain system

See subsection 5.2.1.5-C (Physical Specifications/Geometry)

Step 11 Design emergency overflow

An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Nonerosive velocities need to be ensured at the outlet point.

Step 12 Prepare Vegetation and Landscaping Plan

A landscaping plan for the bioretention area should be prepared to indicate how it will be established with vegetation.

See subsection 5.2.1.5-I (Landscaping) and Appendix F for more details.

See Appendix D-2 for a Bioretention Area Design Example

5.2.1.7 Inspection and Maintenance Requirements

Table 5.2.1-1 Typical Maintenance Activities for Bioretention Areas

Activity	Schedule
• Pruning and weeding to maintain appearance. • Mulch replacement when erosion is evident. • Remove trash and debris.	As needed
• Inspect inflow points for clogging (off-line systems). Remove any sediment. • Inspect filter strip/grass channel for erosion or gullying. Re-seed or sod as necessary. • Trees and shrubs should be inspected to evaluate their health and remove any dead or severely diseased vegetation.	Semi-annually
• The planting soils should be tested for pH to establish acidic levels. If the pH is below 5.2, limestone should be applied. If the pH is above 7.0 to 8.0, then iron sulfate plus sulfur can be added to reduce the pH.	Annually
• Replace mulch over the entire area. • Replace pea gravel diaphragm if warranted (or when the voids are obviously filled with sediment and water is no longer infiltrating).	2 to 3 years

(Source: EPA, 1999)

Additional Maintenance Considerations and Requirements

- The surface of the ponding area may become clogged with fine sediment over time. Core aeration or cultivating of unvegetated areas may be required to ensure adequate filtration.

> Regular inspection and maintenance is critical to the effective operation of bioretention facilities as designed. Maintenance responsibility for a bioretention area should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

5.2.1.8 Example Schematics

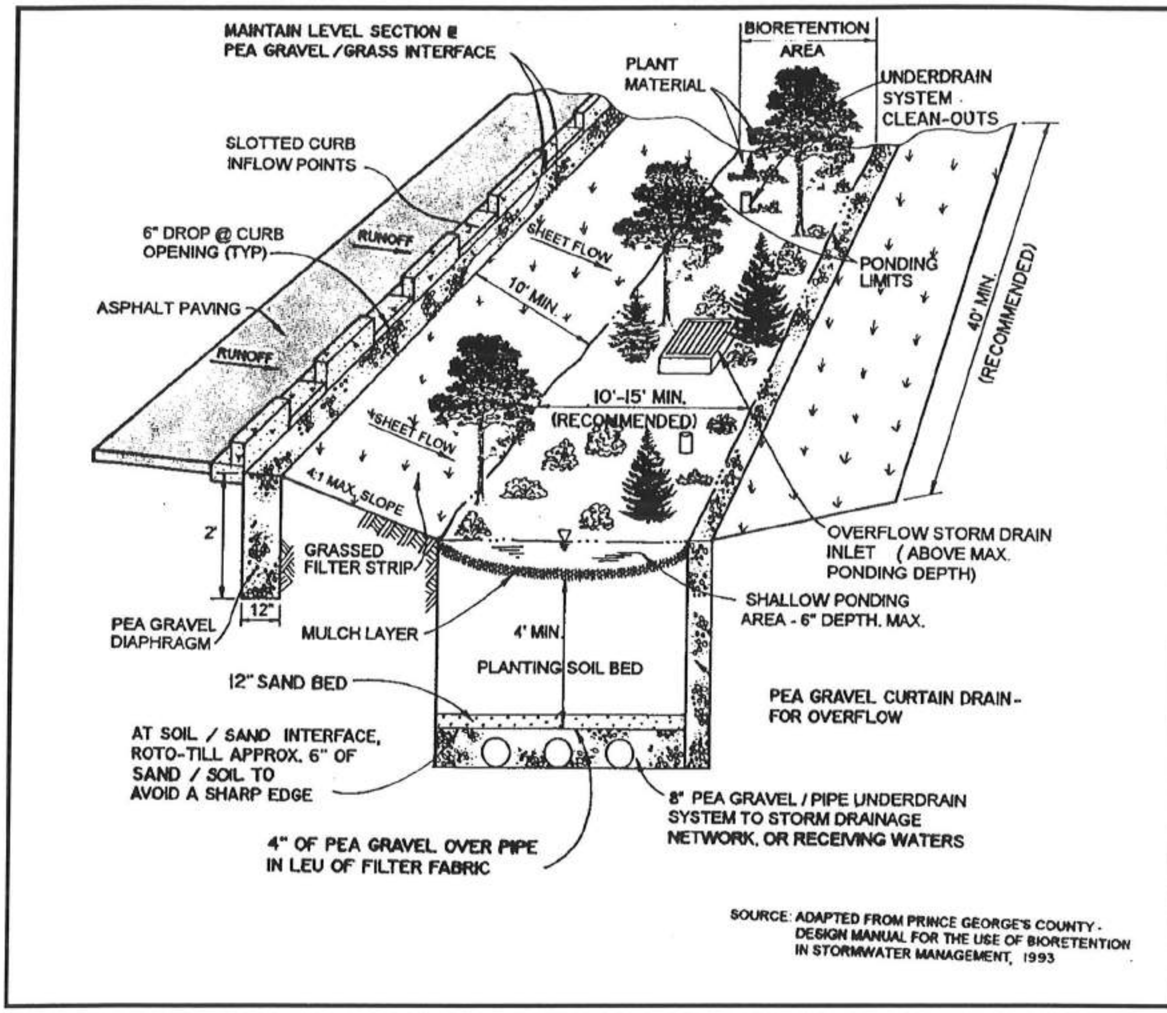


Figure 5.2.1-3 Schematic of a Typical Bioretention Area
(Source: Claytor and Schueler, 1996)

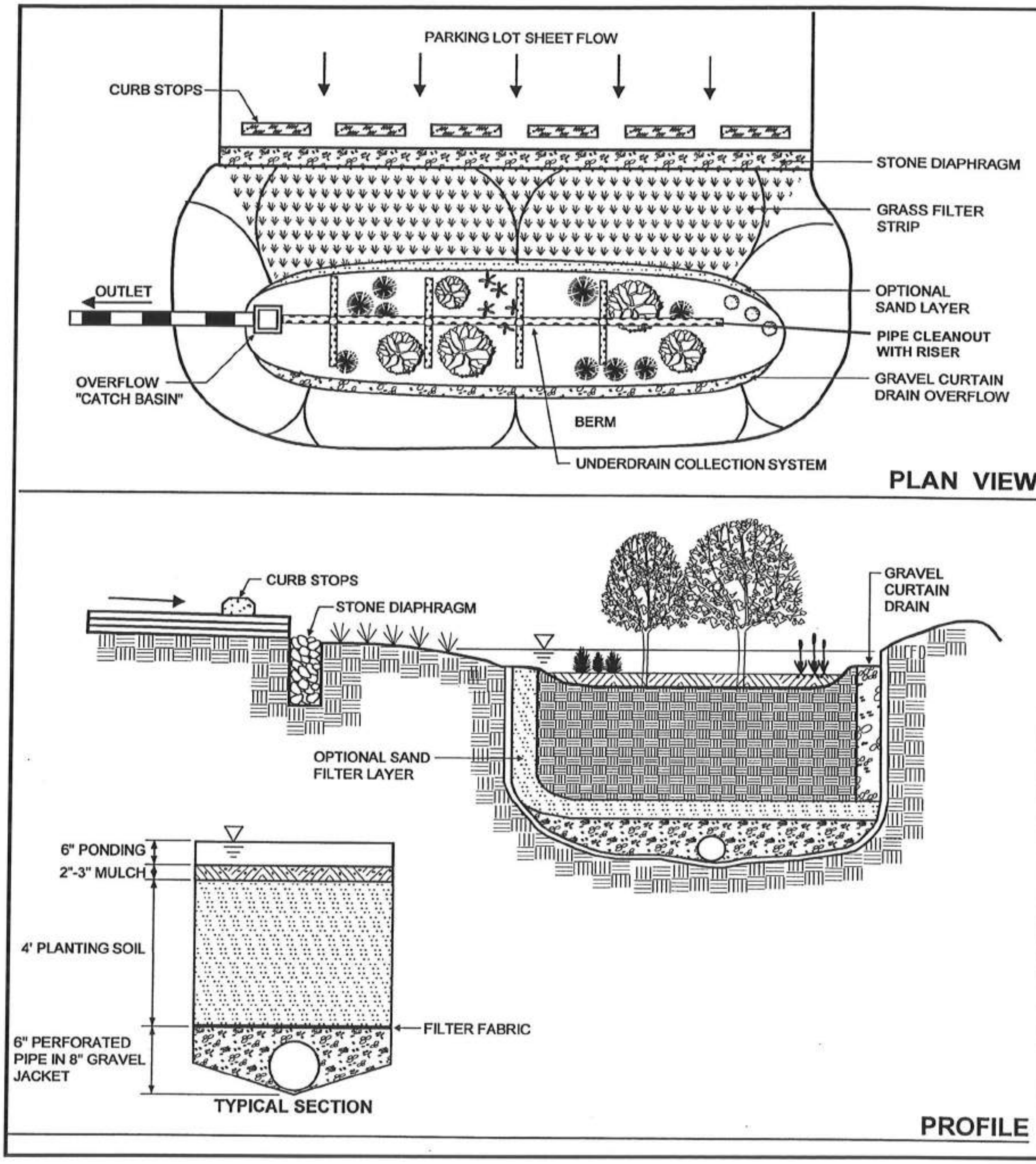


Figure 5.2.1-4 Schematic of a Typical On-Line Bioretention Area
(Source: Claytor and Schueler, 1996)

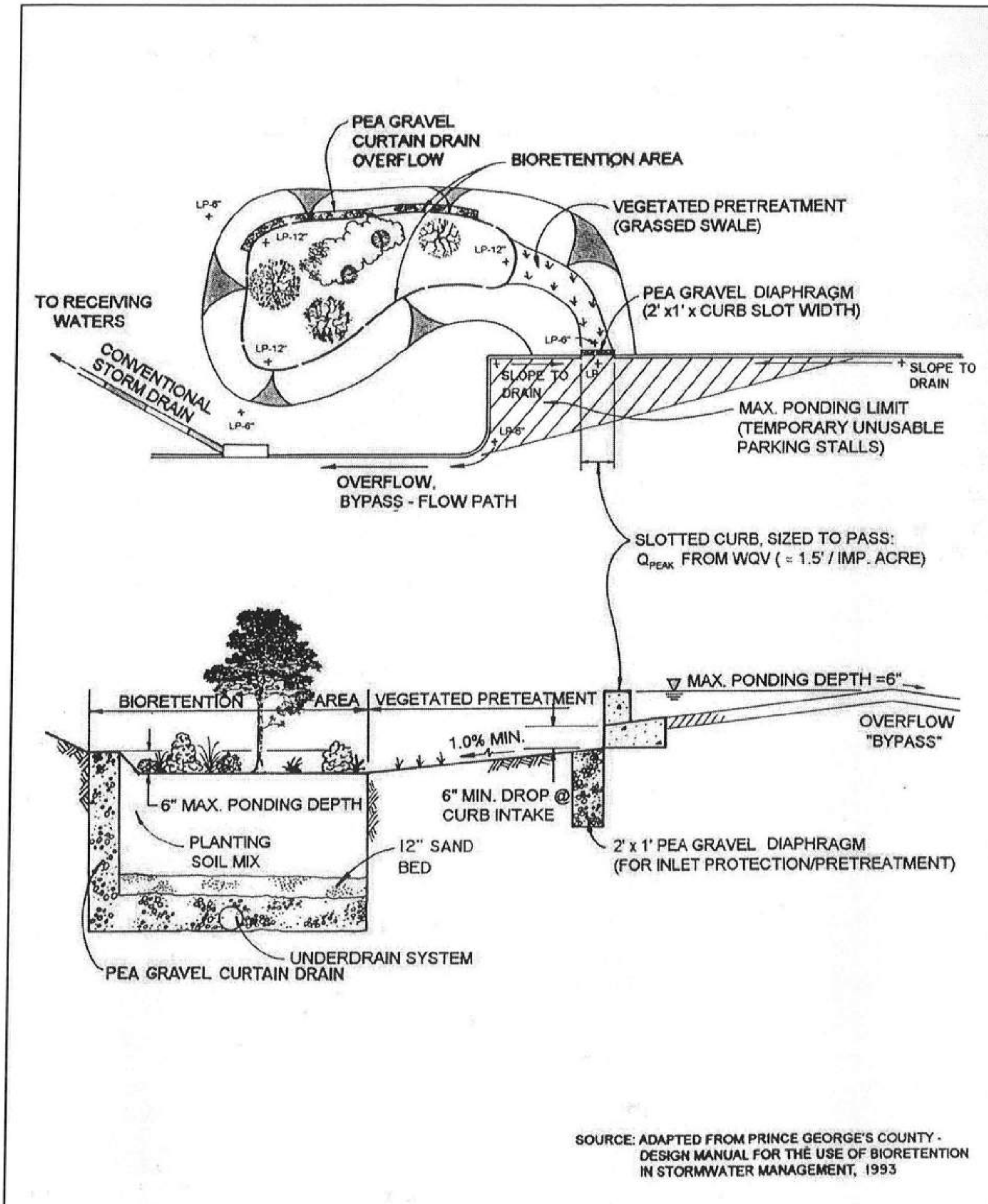


Figure 5.2.1-5 Schematic of a Typical Off-Line Bioretention Area
(Source: Claytor and Schueler, 1996)

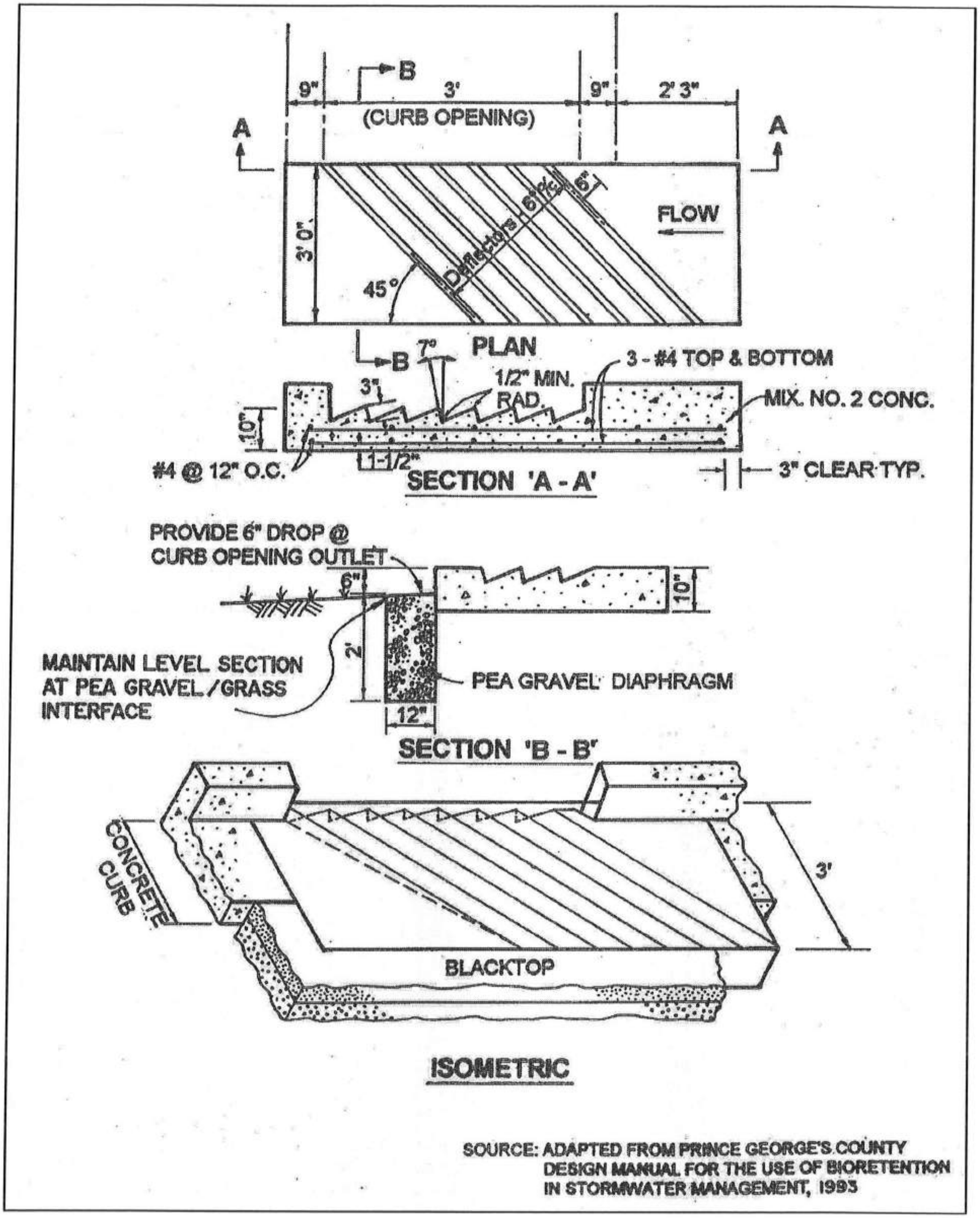


Figure 5.2.1-6 Schematic of a Typical Inlet Deflector
(Source: Claytor and Schueler, 1996)

Design Procedure Form: Bioretention Areas

PRELIMINARY HYDROLOGIC CALCULATIONS	
1a. Compute WQ_v volume requirements	
Compute Runoff Coefficient, R_v	R_v = ________
Compute WQ_v	WQ_v = ________ acre-ft
1b. Compute SP_v	SP_v = ________ acre-ft
Compute average release rate	release rate = ________ cfs
Compute (as necessary) Q_f	Q_f = ________ cfs
BIORETENTION AREA DESIGN	
2. Is the use of a bioretention area appropriate?	***See subsections 5.2.1.4 and 5.2.1.5 - A***
3. Confirm local design criteria and applicability	
4. Determine size of bioretention filter area	A_f = ________ ft^2
5. Set design elevations and dimensions	Length = ________ ft Width = ________ ft ________ elevation top of facility ________ other elev: ________ ________ other elev: ________ ________ other elev: ________
6. Conveyance to bioretention facilitiy	_____Online or _____ Offline?
7. Pretreatment	Type: ________________
8. Size underdrain area Based on guidance: Approx. 10% A_f	Length = ________ ft
9. Overdrain design	Type: ________________ Size: ________
10. Emergency storm weir design Overflow weir - Weir equation	Length = ________ ft
11. Choose plants for planting area	*Select native plants based on resistance to drought and inundation, cost, aesthetics, maintenance, etc.* ***See Appendix F***

Notes: ____

5.2.2 Enhanced Swales

General Application
Structural Storm Water Control

Description: Vegetated open channels that are explicitly designed and constructed to capture and treat storm water runoff within dry or wet cells formed by check dams or other means.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Longitudinal slopes must be less than 4%
- Bottom width of 2 to 8 feet
- Side slopes 2:1 or flatter; 4:1 recommended
- Convey the "Conveyance" storm event with minimum freeboard, as specified in Local Criteria

ADVANTAGES / BENEFITS:

- Combines storm water treatment with runoff conveyance system
- Less expensive than curb and gutter
- Reduces runoff velocity

DISADVANTAGES / LIMITATIONS:

- Higher maintenance than curb and gutter systems
- Cannot be used on steep slopes
- Possible resuspension of sediment
- Potential for odor / mosquitoes (wet swale)
- Concerns with aesthetics of 4"-6" high grass in residential areas

MAINTENANCE REQUIREMENTS:

- Maintain grass heights of approximately 4 to 6 inches (dry swale)
- Remove sediment from forebay and channel

POLLUTANT REMOVAL (DRY SWALE)

80%	**Total Suspended Solids**
25/40%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
40%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
S	**Streambank Protection**
S	**On-Site Flood Control**
S	**Downstream Flood Control**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirement**
M	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Permeable soil layer (dry swale)*
- *Wetland plants (wet swale)*

L=Low **M**=Moderate **H**=High

5.2.2.1 General Description

Enhanced swales (also referred to as *vegetated open channels* or *water quality swales*) are conveyance channels engineered to capture and treat the water quality volume (WQ_v) for a drainage area. They differ from a normal drainage channel or swale through the incorporation of specific features that enhance storm water pollutant removal effectiveness.

Enhanced swales are designed with limited longitudinal slopes to force the flow to be slow and shallow, thus allowing for particulates to settle and limiting the effects of erosion. Berms and/or check dams installed perpendicular to the flow path promote settling and infiltration.

There are two primary enhanced swale designs, the *dry swale* and the *wet swale* (or *wetland channel*). Below are descriptions of these two designs:

- **Dry Swale** – The dry swale is a vegetated conveyance channel designed to include a filter bed of prepared soil that overlays an underdrain system. Dry swales are sized to allow the entire WQ_v to be filtered or infiltrated through the bottom of the swale. Because they are dry most of the time, they are often the preferred option in residential settings.
- **Wet Swale (Wetland Channel)** – The wet swale is a vegetated channel designed to retain water or marshy conditions that support wetland vegetation. A high water table or poorly drained soils are necessary to retain water. The wet swale essentially acts as a linear shallow wetland treatment system, where the WQ_v is retained.

Enhanced Dry Swale

Enhanced Dry Swale

Figure 5.2.2-1 Enhanced Swale Examples

Dry and wet swales are not to be confused with a *filter strip* or *grass channel*, which are Limited Application structural controls and not considered acceptable for meeting the TSS removal performance goal by themselves. Ordinary *grass channels* are not engineered to provide the same treatment capability as a well-designed dry swale with filter media. *Filter strips* are designed to accommodate overland flow rather than channelized flow and can be used as storm water credits to help reduce the total water quality treatment volume for a site. Both of these practices may be used for pretreatment or included in a "treatment train" approach where redundant treatment is provided. Please see a further discussion of these limited application structural controls in subsections 5.2.12 and 5.2.3, respectively.

5.2.2.2 Storm Water Management Suitability

Enhanced swale systems are designed primarily for storm water quality and have only a limited ability to provide streambank protection or to convey higher flows to other controls.

Water Quality

Dry swale systems rely primarily on filtration through an engineered media to provide removal of storm water contaminants. Wet swales achieve pollutant removal both from sediment accumulation and biological removal.

Section 5.2.2.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Streambank Protection

Generally, only the WQ_v is treated by a dry or wet swale, and another structural control must be used to provide SP_v extended detention. However, for some smaller sites, a swale may be designed to capture and detain the full SP_v.

On-Site Flood Control

Enhanced swales must provide flow diversion and/or be designed to safely pass overbank flood flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow.

Downstream Flood Control

Enhanced swales must provide flow diversion and/or be designed to safely pass extreme storm flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow.

5.2.2.3 Pollutant Removal Capabilities

Both the dry and wet enhanced swale are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed swales can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – Dry Swale 50% / Wet Swale 25%**
- **Total Nitrogen – Dry Swale 50% / Wet Swale 40%**
- **Fecal Coliform – insufficient data**
- **Heavy Metals – Dry Swale 40% / Wet Swale 20%**

For additional information and data on pollutant removal capabilities for enhanced dry and wet swales, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org

5.2.2.4 Application and Feasibility Criteria

Enhanced swales can be used in a variety of development types; however, they are primarily applicable to residential and institutional areas of low to moderate density where the impervious cover in the contributing drainage area is relatively small and along roads and highways. Dry swales are mainly used in moderate to large lot residential developments, small impervious areas (parking lots and rooftops), and along rural highways. Wet swales tend to be used for highway runoff applications, small parking areas, and in commercial developments as part of a landscaped area.

Because of their relatively large land requirement, enhanced swales are generally not used in higher density areas. In addition, wet swales may not be desirable for some residential applications, due to the presence of standing and stagnant water, which may create nuisance odor or mosquito problems.

The topography and soils of a site will determine the applicability of the use of one of the two enhanced swale designs. Overall, the topography should allow for the design of a swale with sufficient slope and cross-sectional area to maintain nonerosive velocities. The following criteria should be evaluated to ensure the suitability of a storm water pond for meeting storm water management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – NO
- Regional Storm Water Control – NO

Physical Feasibility - Physical Constraints at Project Site

- Drainage Area – 5 acres maximum
- Space Required – Approximately 10 to 20% of the tributary impervious area
- Site Slope – Typically no more than 4% channel slope
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet for dry swale; 1 foot for wet swale
- Minimum Depth to Water Table – 2 feet required between the bottom of a dry swale and the elevation of the seasonally high water table if treating a hotspot or an aquifer recharge zone. Wet swale is below water table or placed in poorly drained soils
- Soils – Engineered media for dry swale

Other Constraints / Considerations

- Aquifer Protection – Infiltration should not be allowed for hotspots

5.2.2.5 Planning and Design Criteria

*The following criteria are to be considered **minimum** standards for the design of an enhanced swale system. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

A. LOCATION AND SITING

- A dry or wet swale should be sited such that the topography allows for the design of a channel with sufficiently mild slope (unless small drop structures are used) and cross-sectional area to maintain nonerosive velocities.
- Enhanced swale systems should have a contributing drainage area of 5 acres or less.

- Swale siting should also take into account the location and use of other site features, such as buffers and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape.
- A wet swale can be used where the water table is at or near the soil surface, or where there is a sufficient water balance in poorly drained soils to support a wetland plant community.

B. GENERAL DESIGN

- Both types of enhanced swales are designed to treat the WQ_v through a volume-based design, and to safely pass larger storm flows. Flow enters the channel through a pretreatment forebay. Runoff can also enter along the sides of the channel as sheet flow through the use of a pea gravel flow spreader trench along the top of the bank.

Dry Swale

- A dry swale system consists of an open conveyance channel with a filter bed of permeable soils that overlays an underdrain system. Flow passes into and is detained in the main portion of the channel where it is filtered through the soil bed. Runoff is collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. Figure 5.2.2-2 provides a plan view and cross-section schematic for the design of a dry swale system.

Wet Swale

- A wet swale or wetland channel consists of an open conveyance channel which has been excavated to the water table or to poorly drained soils. Check dams are used to create multiple wetland "cells," which act as miniature shallow marshes. Figure 5.2.2-3 provides a plan view and cross-section schematic for the design of a wet swale system.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- Channel slopes between 1% and 2% are recommended unless topography necessitates a steeper slope, in which case 6- to 12-inch drop structures can be placed to limit the energy slope to within the recommended 1 to 2% range. Energy dissipation will be required below the drops. Spacing between the drops should not be closer than 50 feet. Depth of the WQ_v at the downstream end should not exceed 18 inches.
- Dry and wet swales should have a bottom width of 2 to 8 feet to ensure adequate filtration. Wider channels can be designed, but should contain berms, walls, or a multi-level cross section to prevent channel braiding or uncontrolled sub-channel formation.
- Dry and wet swales are parabolic or trapezoidal in cross section and are typically designed with moderate side slopes no greater than 2:1 for ease of maintenance and side inflow by sheet flow (4:1 or flatter recommended).
- Dry and wet swales should maintain a maximum WQ_v ponding depth of 18 inches at the end point of the channel. A 12-inch average depth should be maintained.
- The peak velocity for the 3 storm events ("Streambank Protection", "Conveyance", and 100-year) must be nonerosive for the soil and vegetative cover provided.
- If the system is on-line, channels should be sized to convey runoff from a flood event safely with a minimum freeboard and without damage to adjacent property.

Dry Swale

- Dry swale channels are sized to store and infiltrate the entire water quality volume (WQ_v) with less than 18 inches of ponding and allow for full filtering through the permeable soil layer. The maximum ponding time is 48 hours, though a 24-hour ponding time is more desirable.
- The bed of the dry swale consists of a permeable soil layer of at least 30 inches in depth, above a 4-inch diameter perforated PVC pipe (AASHTO M 252) longitudinal underdrain in a 6-inch gravel layer.

The soil media should have an infiltration rate of at least 1 foot per day (1.5 feet per day maximum) and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil.

- The channel and underdrain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction and scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.

Wet Swale

- Wet swale channels are sized to retain the entire water quality volume (WQ_v) with less than 18 inches of ponding at the maximum depth point.
- Check dams can be used to achieve multiple wetland cells. V-notch weirs in the check dams can be utilized to direct low flow volumes.

D. PRETREATMENT / INLETS

- Inlets to enhanced swales must be provided with energy dissipaters such as riprap.
- Pretreatment of runoff in both a dry and wet swale system is typically provided by a sediment forebay located at the inlet. The pretreatment volume should be equal to 0.1 inches per impervious acre. This storage is usually obtained by providing check dams at pipe inlets and/or driveway crossings.
- Enhanced swale systems that receive direct concentrated runoff may have a 6-inch drop to a pea gravel diaphragm flow spreader at the upstream end of the control.
- A pea gravel diaphragm and gentle side slopes should be provided along the top of channels to provide pretreatment for lateral sheet flows.

E. OUTLET STRUCTURES

Dry Swale

- The underdrain system should discharge to the storm drainage infrastructure or a stable outfall.

Wet Swale

- Outlet protection must be used at any discharge point from a wet swale to prevent scour and downstream erosion.

F. EMERGENCY SPILLWAY

- Enhanced swales must be adequately designed to safely pass flows that exceed the design storm flows.

G. MAINTENANCE ACCESS

- Adequate access should be provided for all dry and wet swale systems for inspection and maintenance.

H. SAFETY FEATURES

- Ponding depths should be limited to a maximum of 18 inches.

I. LANDSCAPING

Landscape design should specify proper grass species and wetland plants based on specific site, soils, and hydric conditions present along the channel. Below is some specific guidance for dry and wet swales:

Dry Swale

- Information on appropriate turf grass species for North Central Texas can be found in Appendix F (*Landscaping and Aesthetics Guidance)*.

Wet Swale

- Emergent vegetation should be planted, or wetland soils may be spread on the swale bottom for seed stock.
- Information on establishing wetland vegetation and appropriate wetland species for North Central Texas can be found in Appendix F (*Landscaping and Aesthetics Guidance)*.
- Where wet swales do not intercept the groundwater table, a water balance calculation should be performed to ensure an adequate water budget to support the specified wetland species. See subsection 2.1.11 for guidance on water balance calculations.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- Low Relief – Reduced need for use of check dams
- High Relief – Often infeasible if slopes are greater than 4%
- Karst – No infiltration of hotspot runoff from dry swales; use impermeable liner

Soils

No additional criteria

Special Downstream Watershed Considerations

- Aquifer Protection – No infiltration of hotspot runoff from dry swales; use impermeable liner

5.2.2.6 Design Procedures

Step 1. Compute runoff control volumes from the *integrated* Design Approach

Calculate the Water Quality Volume (WQ_v), Streambank Protection Volume (SP_v), On-Site Flood Control Volume (V_s), and the Downstream Flood Control Volume (V_f).

Details on the *integrated* Design Approach are found in Section 1.2.

Step 2. Determine if the development site and conditions are appropriate for the use of an enhanced swale system (dry or wet swale).

Consider the Application and Site Feasibility Criteria in subsections 5.2.2.4 and 5.2.2.5-A (Location and Siting).

Step 3. Confirm local design criteria and applicability

Consider any special site-specific design conditions/criteria from subsection 5.2.2.5-J (Additional Site-Specific Design Criteria and Issues).

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 4. Determine pretreatment volume

The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage. The forebay storage volume counts toward the total WQ_v requirement, and should be subtracted from the WQ_v for subsequent calculations.

Step 5. Determine swale dimensions

Size bottom width, depth, length, and slope necessary to store WQ_v with less than 18 inches of ponding at the downstream end.

- Slope cannot exceed 4% (1 to 2% recommended)
- Bottom width should range from 2 to 8 feet
- Ensure that side slopes are no greater than 2:1 (4:1 recommended)

See subsection 5.2.2.5-C (Physical Specifications / Geometry) for more details

Step 6. Compute number of check dams (or similar structures) required to detain WQ_v

Step 7. Calculate draw-down time

Dry swale: Planting soil should pass a maximum rate of 1.5 feet in 24 hours and must completely filter WQ_v within 48 hours.

Wet swale: Must hold the WQ_v.

Step 8. Check low flow and design event velocity erosion potential and freeboard

Check for erosive velocities and modify design as appropriate. Provide 6 inches of freeboard.

Step 9. Design low flow orifice at downstream headwalls and checkdams

Design orifice to pass WQ_v in 6 hours. Use Orifice equation.

Step 10. Design inlets, sediment forebay(s), and underdrain system (dry swale)

See subsection 5.2.2.5-D through H for more details.

Step 11. Prepare Vegetation and Landscaping Plan

A landscaping plan for a dry or wet swale should be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation.

See subsection 5.2.2.5-I (Landscaping) and Appendix F for more details.

See Appendix D-5 for an Enhanced Swale Design Example

5.2.2.7 Inspection and Maintenance Requirements

Table 5.2.2-1 Typical Maintenance Activities for Enhanced Swales
(Source: WMI, 1997; Pitt, 1997)

Activity	Schedule
• For dry swales, mow grass to maintain a height of 4 to 6 inches. Remove grass clippings.	As needed (frequent/seasonally)
• Inspect grass along side slopes for erosion and formation of rills or gullies and correct. • Remove trash and debris accumulated in the inflow forebay. • Inspect and correct erosion problems in the sand/soil bed of dry swales. • Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established. • Replant wetland species (for wet swale) if not sufficiently established. • Inspect pea gravel diaphragm for clogging and correct the problem.	Annually (Semi-annually the first year)
• Roto-till or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours. • Remove sediment build-up within the bottom of the swale once it has accumulated to 25% of the original design volume.	As needed

Regular inspection and maintenance is critical to the effective operation of an enhanced swale system as designed. Maintenance responsibility for a dry or wet swale should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

5.2.2.8 Example Schematics

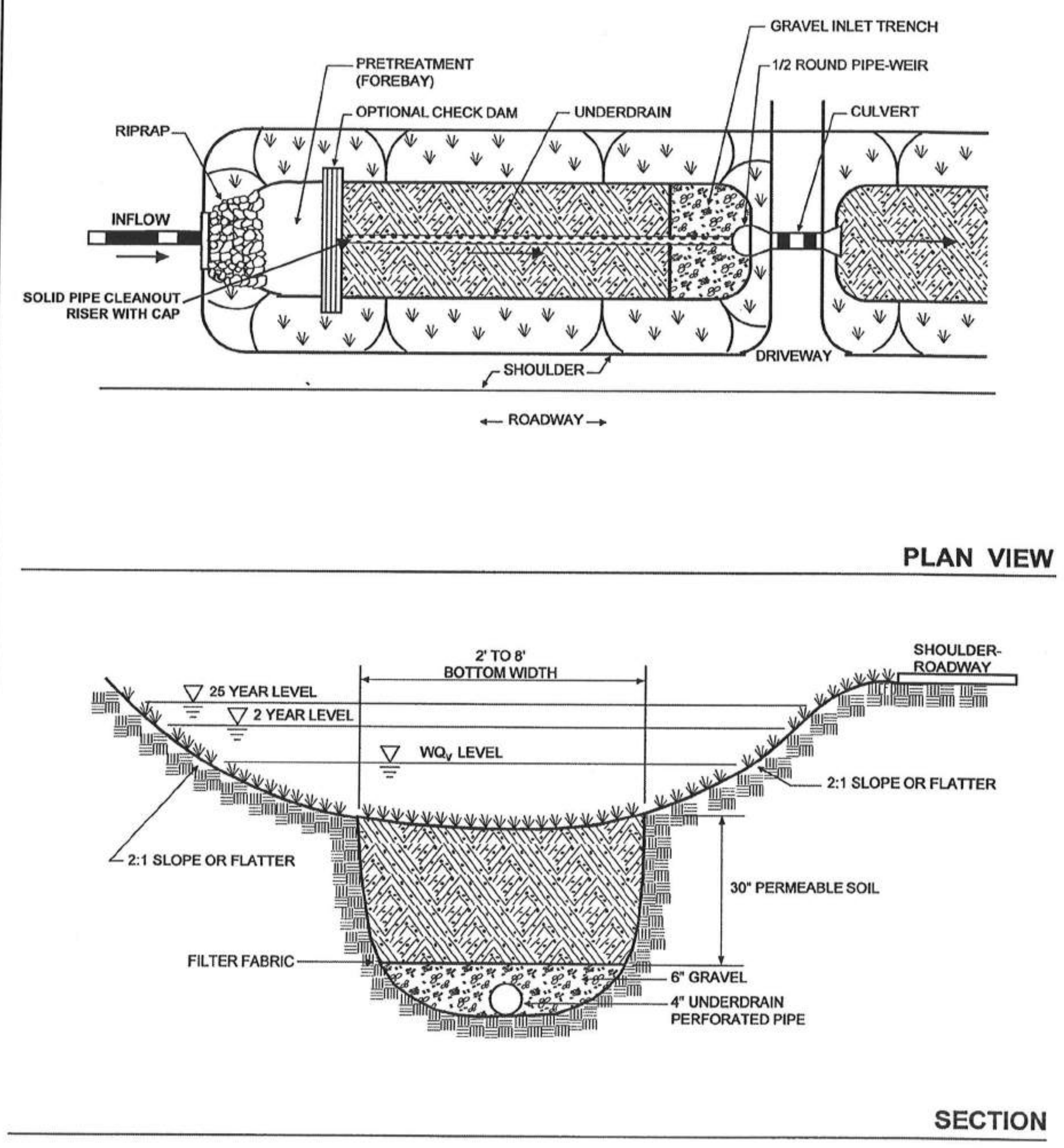


Figure 5.2.2-2 Schematic of Dry Swale
(Source: Center for Watershed Protection)

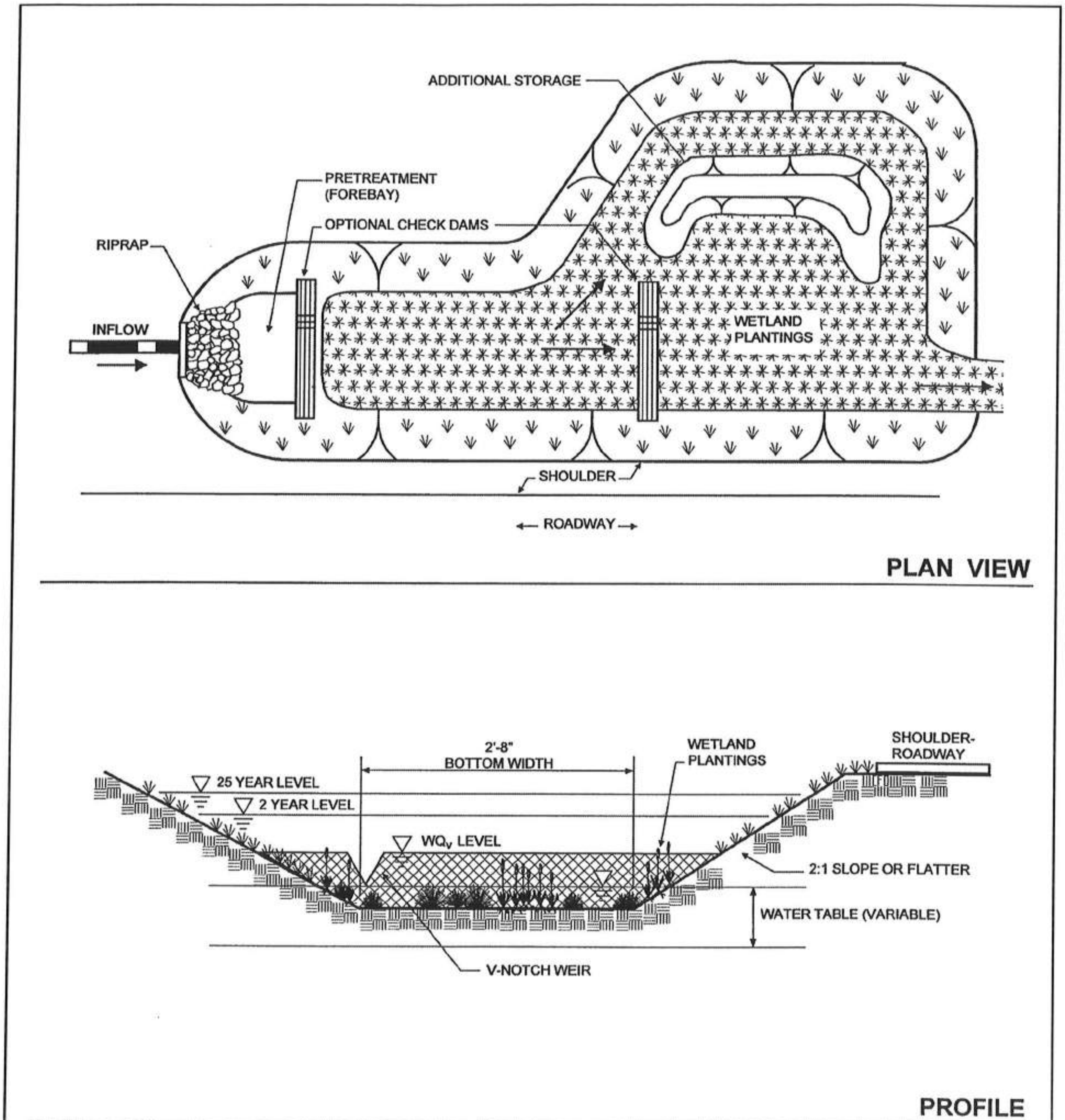


Figure 5.2.2-3 Schematic of Wet Swale
(Source: Center for Watershed Protection)

5.2.2.9 Design Forms

Design Procedure Form: Enhanced Swales

PRELIMINARY HYDROLOGIC CALCULATIONS	
1a. Compute WQ_v volume requirements	
Compute Runoff Coefficient, R_v	R_v = ______
Compute WQ_v	WQ_v = ______ acre-ft
1b. Compute SP_v	SP_v = ______ acre-ft
Compute average release rate	release rate = ______ cfs
Compute Q_p (100-year detention volume required)	Q_p = ______ acre-ft
Compute (as necessary) Q_f	Q_f = ______ cfs
ENHANCED SWALE DESIGN	
2. Is the use of an enhanced swale appropriate?	***See subsections 5.2.2.4 and 5.2.2.5 - A***
3. Confirm local design criteria and applicability.	***See subsection 5.2.2.5 - J***
4. Pretreatment Volume Vol_{pre} = I (0.1")(1'/12")	Vol_{pre} = ______ acre-ft
5. Determine swale dimensions Assume trapezoidal channel with max depth of 18 inches	Length = ______ ft Width = ______ ft Side Slopes = ______ Area = ______ ft^2
6. Compute number of check dams (or similar structures) required to detain WQ_v	Slope = ______ ft/ft Depth = ______ ft Distance = ______ ft Number = ______ each
7. Calculate draw-down time Require k = 1.5 ft per day for dry swales	t = ______ hr
8. Check low flow and design storm velocity erosion potential and freeboard	V_{min} = ______ fps
Requires separate computer analysis for velocity	
Overflow wier (use weir equation) Use weir equation for slot length ($Q = CLH^{3/2}$)	Weir Length = ______ ft
9. Design low flow orifice at headwall Area of orifice from orifice equation $Q = CA(2gh)^{0.5}$	Area = ______ ft^2 diam = ______ inch
10. Design inlets, sediment forebays, outlet structures, maintenance access, and safety features.	***See subsection 5.2.2.5 - D through H***
11. Attach landscaping plan (including wetland vegetation)	***See Appendix F***

Notes: ______________________________

5.2.3 Grass Channel

Structural Storm Water Control

Description: Vegetated open channels designed to filter storm water runoff and meet velocity targets for the water quality design storm and the "Streambank Protection" storm event.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Should not be used on slopes greater than 4%; slopes between 1% and 2% recommended
- Ineffective unless carefully designed to achieve low flow rates in the channel (<1.0 ft/s)

ADVANTAGES / BENEFITS:

- Can be used as part of the runoff conveyance system to provide pretreatment
- Grass channels can act to partially infiltrate runoff from small storm events if underlying soils are pervious
- Less expensive to construct than curb and gutter systems

DISADVANTAGES / LIMITATIONS:

- May require more maintenance than curb and gutter system
- Cannot alone achieve the 80% TSS removal target
- Potential for bottom erosion and re-suspension
- Standing water may not be acceptable in some areas

POLLUTANT REMOVAL

50%	**Total Suspended Solids**
25/20%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
30%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
S	**Streambank Protection**
P	**On-Site Flood Control**
S	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirement**
L	**Capital Cost**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Curb and gutter replacement*

L=Low **M**=Moderate **H**=High

5.2.3.1 General Description

Grass channels, also termed "biofilters," are typically designed to provide nominal treatment of runoff as well as meet runoff velocity targets for the water quality design storm. Grass channels are well suited to a number of applications and land uses, including treating runoff from roads and highways and pervious surfaces.

Grass channels differ from the enhanced dry swale design in that they do not have an engineered filter media to enhance pollutant removal capabilities and, therefore, have a lower pollutant removal rate than for a dry or wet (enhanced) swale. Grass channels can partially infiltrate runoff from small storm events in areas with pervious soils. When properly incorporated into an overall site design, grass channels can reduce impervious cover, accent the natural landscape, and provide aesthetic benefits.

When designing a grass channel, the two primary considerations are channel capacity and minimization of erosion. Runoff velocity should not exceed 1.0 foot per second during the peak discharge associated with the water quality design rainfall event, water depth should generally be less than 4 inches (height of the grass), and the total length of a grass channel should provide at least 5 minutes of residence time. To enhance water quality treatment, grass channels must have broader bottoms, lower slopes, and denser vegetation than most drainage channels. Additional treatment can be provided by placing check-dams across the channel below pipe inflows, and at various other points along the channel.

5.2.3.2 Pollutant Removal Capabilities

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- **Total Suspended Solids – 50%**
- **Total Phosphorus – 25%**
- **Total Nitrogen – 20%**
- **Fecal Coliform – insufficient data**
- **Heavy Metals – 30%**

Fecal coliform removal is uncertain. In fact, grass channels are often a source of fecal coliforms from local residents walking their dogs.

5.2.3.3 Design Criteria and Specifications

- Grass channels should generally be used to treat small drainage areas of less than 5 acres. If the practices are used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.
- Grass channels should be designed on relatively flat slopes of less than 4%; channel slopes between 1% and 2% are recommended.
- Grass channels can be used on most soils with some restrictions on the most impermeable soils. Grass channels should not be used on soils with infiltration rates less than 0.27 inches per hour if infiltration of small runoff flows is intended.
- A grass channel should accommodate the peak flow for the water quality design storm Q_{wq} (see Section 2.1.10).
- Grass channels should have a trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter).
- The bottom of the channel should be between 2 and 6 feet wide. The minimum width ensures an adequate filtering surface for water quality treatment, and the maximum width prevents braiding, which is the formation of small channels within the swale bottom. The bottom width is a dependent

variable in the calculation of velocity based on Manning's equation. If a larger channel is needed, the use of a compound cross section is recommended.

- Runoff velocities must be nonerosive. The full-channel design velocity will typically govern.
- A 5-minute residence time is recommended for the water quality peak flow. Residence time may be increased by reducing the slope of the channel, increasing the wetted perimeter, or planting a denser grass (raising the Manning's n).
- The depth from the bottom of the channel to the groundwater should be at least 2 feet to prevent a moist swale bottom, or contamination of the groundwater.
- Incorporation of check dams within the channel will maximize retention time.
- Designers should choose a grass that can withstand relatively high velocity flows at the entrances for both wet and dry periods. See Appendix F for a list of appropriate grasses for use in North Central Texas.

See Section 4.4 (*Open Channel Design*) for more information and specifications on the design of grass channels.

Grass Channels for Pretreatment

A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a grass channel as a pretreatment measure. The length of the grass channel depends on the drainage area, land use, and channel slope. Table 5.2.3-1 provides sizing guidance for grass channels for a 1-acre drainage area. The minimum grassed channel length should be 20 feet.

Table 5.2.3-1 Bioretention Grass Channel Sizing Guidance

Parameter	<= 33% Impervious		Between 34% and 66% Impervious		>= 67% Impervious	
Slope (max = 4%)	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%
Grass channel minimum length* (feet) *assumes 2-foot wide bottom width	25	40	30	45	35	50

(Source: Claytor and Schueler, 1996)

5.2.3.4 Inspection and Maintenance Requirements

Table 5.2.3-2 Typical Maintenance Activities for Grass Channels

Activity	Schedule
• Mow grass to maintain a height of 3 to 4 inches.	As needed (frequently/seasonally)
• Remove sediment build-up within the bottom of the grass channel once it has accumulated to 25% of the original design volume.	As needed (Infrequently)
• Inspect grass along side slopes for erosion and formation of rills or gullies and correct. • Remove trash and debris accumulated in the channel. • Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established.	Annually (Semi-annually the first year)

(Source: Adapted from CWP, 1996)

5.2.3.5 Example Schematics

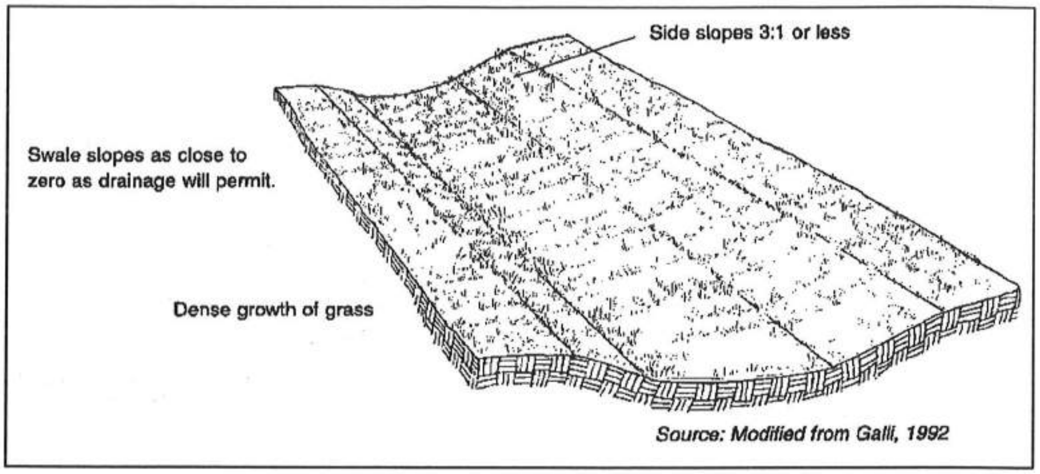


Figure 5.2.3-1 Typical Grass Channel

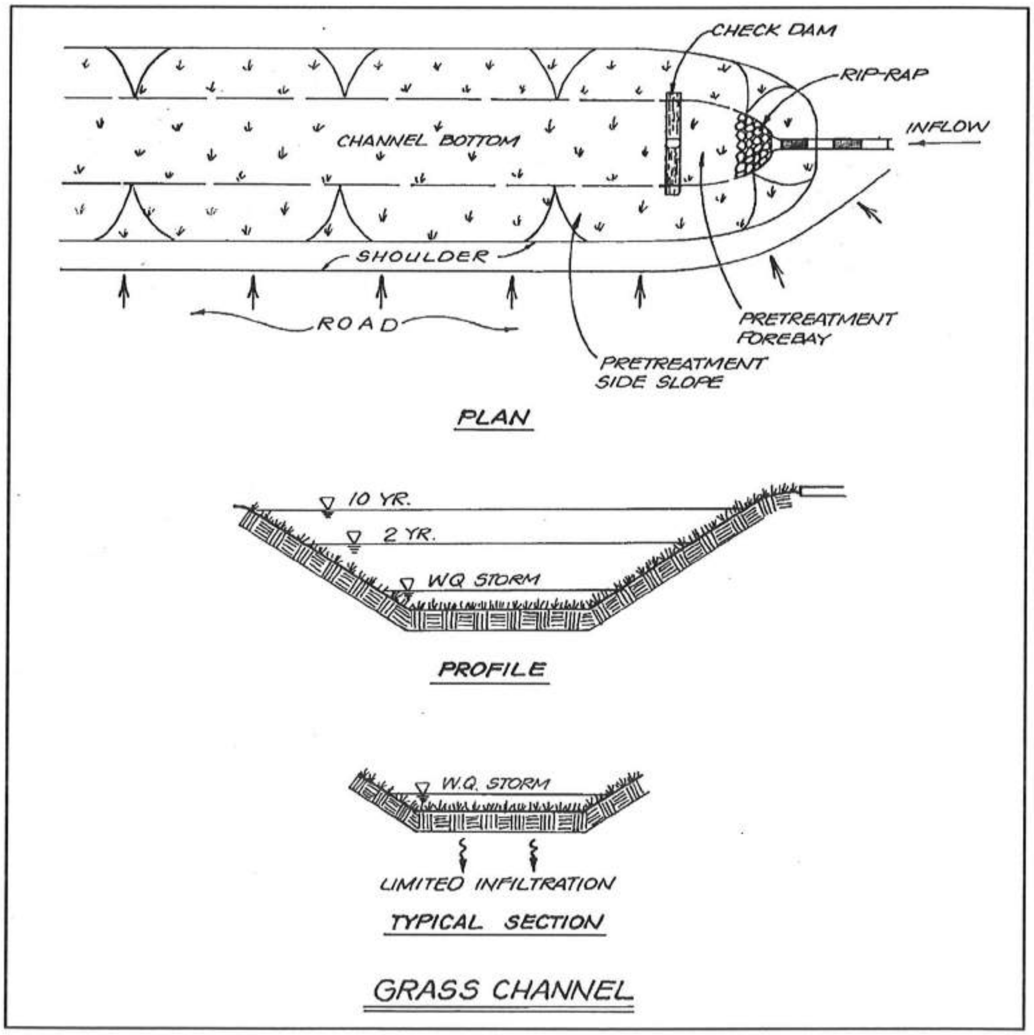


Figure 5.2.3-2 Schematic of Grass Channel

5.2.3.6 Design Example

Basic Data

Small commercial lot 300 feet deep x 145 feet wide

- Drainage area (A) = 1.0 acres
- Impervious percentage (I) = 70%

Water Quality Peak Flow

See subsection 1.4.2.1 for details

Compute the Water Quality Protection Volume in inches:

$WQ_v = 1.5\ (0.05 + 0.009 * 70) = 1.02$ inches

Compute modified CN for 1.5-inch rainfall (P=1.5):

$$\begin{aligned} CN &= 1000/[10+5P+10Q-10(Q^2+1.25*Q*P)^{1/2}] \\ &= 1000/[10+5*1.5+10*0.82-10(0.82^2+1.25*0.82*1.5)^{1/2}] \\ &= 92.4 \quad \text{(Use CN = 92)} \end{aligned}$$

For CN = 92 and an estimated time of concentration (T_c) of 8 minutes (0.13 hours), compute the Q_{wq} for a 1.5-inch storm.

From Table 2.1.5-3, $I_a = 0.174$, therefore $I_a/P = 0.174/1.5 = 0.116$.

From Figure 2.1.5-6 for a Type II storm (using the limiting values) $q_u = 950$ csm/in, and therefore:

Q_{wq} = (950 csm/in) (1.0ac/640ac/mi^2) (1.02") = 1.51 cfs

Utilize Q_{wq} to Size the Channel

The maximum flow depth for water quality treatment should be approximately the same height of the grass. A maximum flow depth of 4 inches is allowed for water quality design. A maximum flow velocity of 1.0 foot per second for water quality treatment is required. For Manning's n use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass. Site slope is 2%.

Input variables:

n = 0.15
S = 0.02 ft/ft
D = 4/12 = 0.33 ft

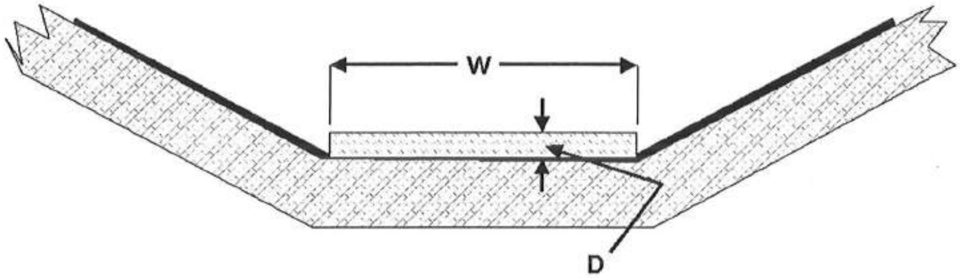
Then:

$Q_{wq} = Q = VA = 1.49/n\ D^{2/3}\ S^{1/2}\ DW$

where:

Q = peak flow (cfs)
V = velocity (ft/sec)
A = flow area (ft^2) = WD
W = channel bottom width (ft)
D = flow depth (ft)
S = slope (ft/ft)

(Note: D approximates hydraulic radius for shallow flows)



Then for a known n, Q, D and S minimum width can be calculated.

$(nQ)/(1.49\ D^{5/3}\ S^{1/2}) = W = (0.15*1.51)/(1.49*0.33^{5/3}*0.02^{1/2}) = 6.84$ feet minimum

$V = Q/(WD) = 1.51/(6.84 * 4/12) = 0.66$ fps (okay)

(Note: WD approximates flow area for shallow flows.)

Minimum length for 5-minute residence time, L = V * (5*60) = 198 feet

Depending on the site geometry, the width or slope or density of grass (Manning's n value) might be adjusted to slow the velocity and shorten the channel in the next design iteration. For example, using a 10-foot bottom width* of flow and a Manning's n of 0.20, solve for new depth and length.

$Q = VA = 1.49/n\ D^{5/3}\ S^{1/2}\ W$

$D = [(Q * n)/(1.49 * S^{1/2} * W)]^{3/5}$

$= [(1.51 * 0.20)/(1.49 * 0.02^{1/2} * 10.0)]^{3/5} = 0.31$ ft = 4" (okay)

$V = Q/WD = 1.51/(10.0 * 0.31) = 0.49$ feet per second

$L = V * 5 * 60 = 146$ feet

** In this case a dividing berm should be used to control potential braiding.*

Refer to Section 4.4 (*Open Channel Design*) to complete the grass channel design for a specified design storm event.

5.2.4 Open Conveyance Channel

Storm Water Control

Description: An open channel is a conduit in which water flows with a free surface. Open channels include conveyance channels or drainage ditches; grass channels; and enhanced swales. An open conveyance channel is designed for conveyance purposes only.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- A maximum of 2:1 should be used for channel side slopes. Roadside ditches should have maximum side slope of 3:1.
- Slope stability should be confirmed with a geotechnical study or investigation
- Channel banks should be stabilized at site

ADVANTAGES / BENEFITS:

- Can be aesthetically pleasing
- Vegetated channels provide natural habitats
- Once established, little maintenance is required

DISADVANTAGES / LIMITATIONS:

- Velocity will limit the type of channel lining, for example, vegetated channels require slower velocities and lower longitudinal slopes

STORM WATER MANAGEMENT SUITABILITY

	Water Quality Protection
	Streambank Protection
P	**On-Site Flood Control**
S	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirement**
L	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

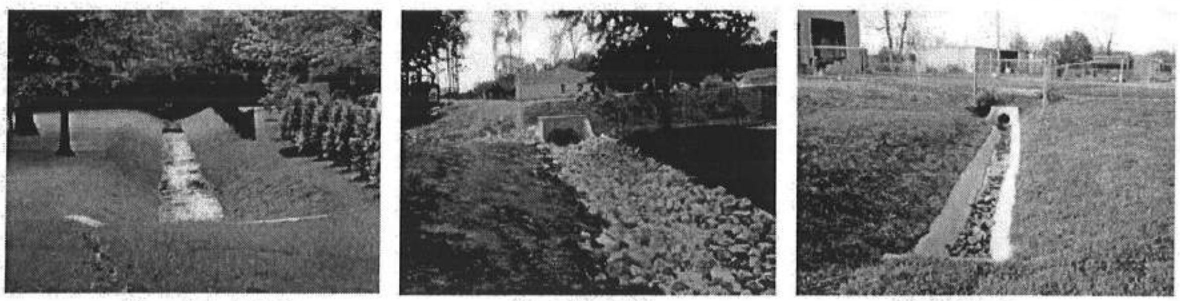
L=Low **M**=Moderate **H**=High

5.2.4.1 General Description

An open channel is a conduit in which water flows with a free surface. Open channel systems and their design are an integral part of storm water drainage design, particularly for development sites utilizing better sited design practices and open channel structural controls. The broad category of open channels includes conveyance channels or drainage ditches, grass channels, and dry and wet enhanced swales. Grass channels and enhanced swales are designed to provide water quality benefits and are further described in detail in Sections 5.2.3 and 5.2.2, respectively.

Channel Classifications

Open channels may be classified into three main categories according to the type of channel linings: vegetated, flexible, and rigid. Vegetated linings include grass with mulch, sod and lapped sod, and wetland channels. Flexible linings include stone riprap and some forms of flexible man-made linings or gabions. Rigid linings are generally concrete or rigid block.



Vegetated Lining Flexible Lining Rigid Lining

Figure 5.2.4-1 Open Channel Examples

5.2.4.2 Pollutant Removal Capabilities

Open conveyance channels or drainage ditches are designed for conveyance purposes only. For open channels with pollutant capabilities, refer to Sections 5.2.3 and 5.2.2, Grass Channels and Enhanced Swales, respectively.

5.2.4.3 Design Criteria and Specifications

Detailed design criteria and specifications, as prepared by the Federal Highway Administration, are presented in Section 4.4, Open Channel Design. Uniform flow, critical flow, and design details for the three main categories of channel classification (vegetative, riprap, and rigid lining) are also included in the noted Section.

In general, the following criteria should be followed for open channel design:

- Channels with bottom widths greater than 10 feet shall be designed with a minimum bottom cross slope of 12 to 1, or with compound cross sections.
- Channel side slopes shall be stable throughout the entire length and side slope shall depend on the channel material. A maximum of 2:1 should be used for channel side slopes, unless otherwise justified by calculations. Roadside ditches should have a maximum side slope of 3:1. All side slopes should be verified with a geotechnical evaluation to ensure slope stability.
- Trapezoidal or parabolic cross sections are preferred over triangular shapes.
- If relocation of a stream channel is unavoidable, the cross-sectional shape, meander, pattern, roughness, sediment transport, and slope should conform to the existing conditions insofar as practicable. Some means of energy dissipation may be necessary when existing conditions cannot be duplicated.

- Streambank stabilization should be provided, when appropriate, as a result of any stream disturbance such as encroachment and should include both upstream and downstream banks as well as the local site.
- Open channel drainage systems are sized to adequately convey the "Conveyance" design storm, and are normally checked with the 100-year storm event.

5.2.4.4 Inspection and Maintenance Requirements

Open channels should be inspected after large storm events for debris causing blockages or re-routing. Channels with vegetated linings should be inspected and maintained periodically to insure vegetation is still in place and prevent growth of taller or woody vegetation. Flexible linings, such as rock riprap, have self-healing qualities that reduce maintenance. However, they should be inspected and maintained periodically to prevent growth of trees, grass, and weeds. Concrete channels should be checked periodically for scour at the channel lining transitions and channel headcutting.

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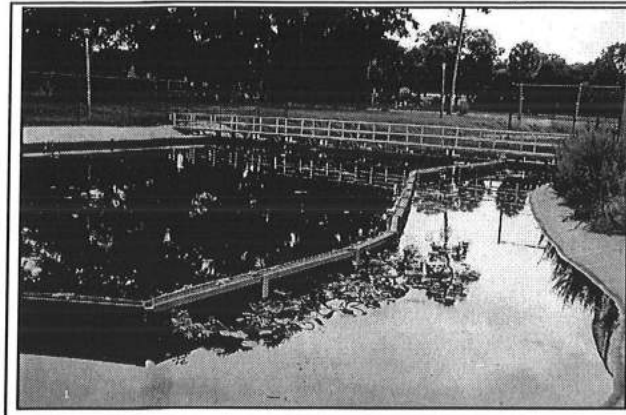
5.2.5 Alum Treatment System

Structural Storm Water Control



Description: Chemical treatment of storm water runoff entering a wet pond by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events.

KEY CONSIDERATIONS

ADVANTAGES / BENEFITS:

- Requires no additional land purchase
- Reduces concentrations of total phosphorus, total aluminum and heavy metals
- Dependent on pH level ranging from 6.0 to 7.5 during treatment process

DISADVANTAGES / LIMITATIONS:

- Intended for areas requiring regional storm water treatment from a piped storm water drainage system
- High maintenance requirements
- Alum application will lower pH of receiving waters
- High capital and operations and maintenance costs

POLLUTANT REMOVAL

90%	**Total Suspended Solids**
80/60%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
75%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
90%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *25 acres min.*

Soils: *No restrictions*

Other Considerations:

- *Regional Treatment*

L=Low **M**=Moderate **H**=High

5.2.5.1 General Description

The process of alum (aluminum sulfate) treatment provides treatment of storm water runoff from a piped storm water drainage system entering a wet pond by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events. When added to runoff, liquid alum forms nontoxic precipitates of aluminum hydroxide [$Al(OH)_3$] and aluminum phosphate [$AlPO_4$]. However, Alum will lower the pH of receiving waters and must be closely monitored to avoid adverse impacts on aquatic life.

The alum precipitate or "floc" formed during coagulation of storm water combines with phosphorus, suspended solids, and heavy metals and removes them from the water column. The floc can be allowed to settle in receiving water or collected in small settling basins. Once settled, the floc is stable in sediments and will not re-dissolve due to changes in redox potential or pH under conditions normally found in surface water bodies. Laboratory or field testing may be necessary to verify feasibility and to establish design, maintenance, and operational parameters, such as the optimum coagulant dose required to achieve the desired water quality goals, chemical pumping rates and pump sizes.

Construction costs for existing alum storm water treatment facilities in Florida have ranged from $135,000 to $400,000. The capital construction costs of alum storm water treatment systems is independent of watershed size and depends primarily on the number of outfall locations treated.

Estimated annual operations and maintenance (O&M) costs for chemicals and routine inspections range from approximately $6,500 to $25,000 per year. O&M costs include chemical, power, manpower for routine inspections, equipment renewal, and replacement costs.

Ferric chloride has also been used for flow-proportional injection for removing phosphorus and other pollutants. Although ferric chloride is less toxic to aquatic life than alum, it has a number of significant disadvantages. Ferric chloride dosage rates are dependent on the pollutant concentrations in the storm water runoff, unlike alum. Ferric chloride does not form a floc that settles out suspended pollutants. And, once settled, ferric chloride may be released from sediments under anoxic conditions.

5.2.5.2 Pollutant Removal Capabilities

Alum treatment has consistently achieved a 85 to 95% reduction in total phosphorus, 90 to 95% reduction in orthophosphorus, 60 to 70% reduction in total nitrogen, 50 to 90% reduction in heavy metals, 95 to 99% reduction in turbidity and TSS, 60% reduction in BOD, and >99% reduction in fecal coliform bacteria compared with raw storm water characteristics.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- **Total Suspended Solids – 90%**
- **Total Phosphorus – 80%**
- **Total Nitrogen – 60%**
- **Fecal Coliform – 90%**
- **Heavy Metals – 75%**

5.2.5.3 Design Criteria and Specifications

Alum treatment systems are fairly complex, and design details are beyond the scope of this Manual. However, further information can be obtained from the Internet and by contacting local municipalities and engineers who have designed and implemented successful systems. The following are general guidelines for alum treatment systems:

- Injection points should be 100 feet upstream of discharge points.

- Alum concentration is typically 10 μg/l.
- Alum treatment systems may need to control pH.
- For new pond design, the required size is approximately 1% of the drainage basin size, as opposed to 10 to 15% of the drainage basin area for a standard detention pond.
- No additional volume is required when discharging to existing lakes.

5.2.5.4 Inspection and Maintenance Requirements

Table 5.2.5-1 Typical Maintenance Activities for Alum Treatment

Activity	Schedule
• Perform routine inspection. • Monitor water quality and pH of receiving water.	Monthly
• Perform maintenance of pump equipment, chemical supplies, and delivery system.	As Needed

(Source: Harper, Herr, and Livingston)

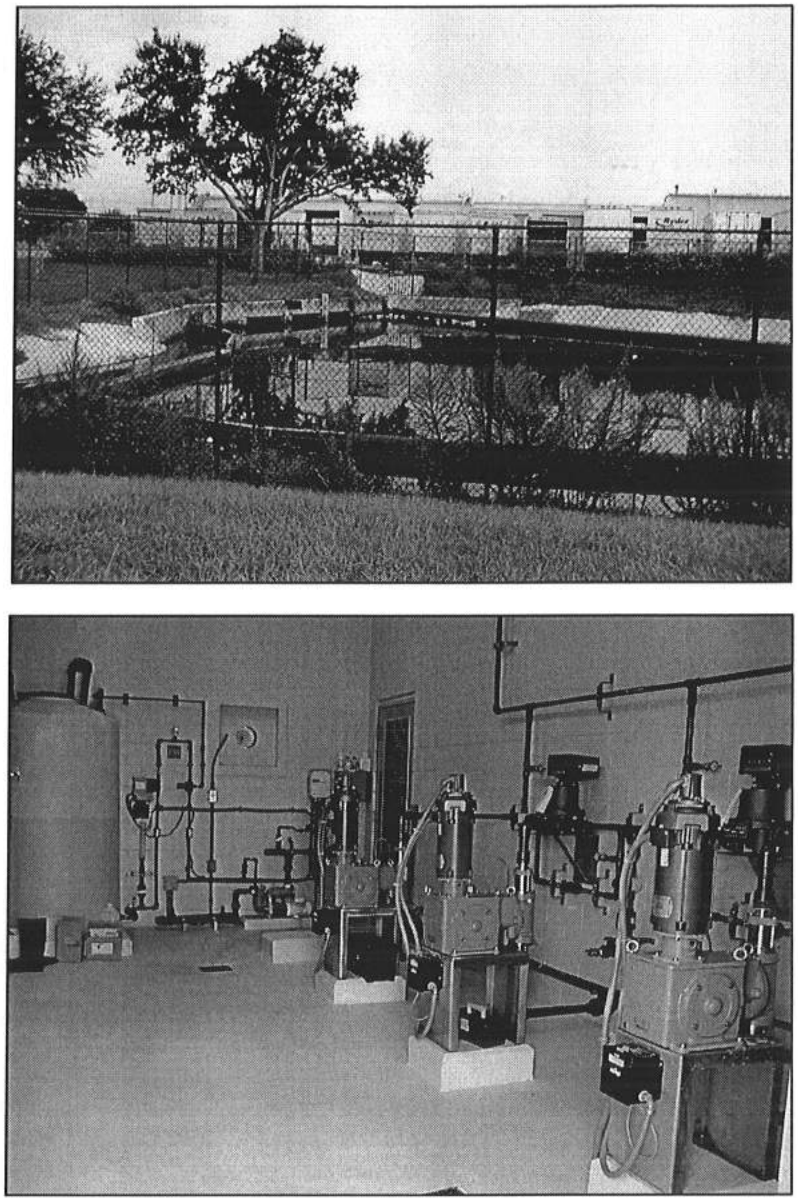
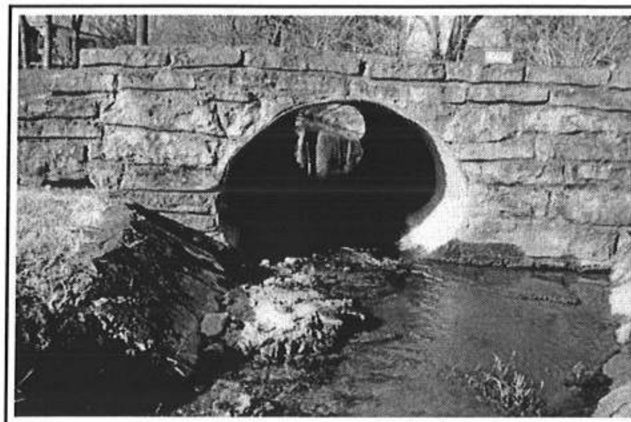


Figure 5.2.5-1. Alum Treatment System and Injection Equipment

5.2.6 Culvert

Storm Water Control



Description: A short, closed (covered) conduit that conveys storm water runoff under an embankment, usually a roadway.

KEY CONSIDERATIONS

DESIGN CRITERIA:
- Designed for conveyance purposes, not pollutant removal capability
- Normally designed for the "Conveyance" storm event

VELOCITY:
- Maximum velocity of 15 fps for corrugated metal pipe
- Minimum velocity of 2.5 fps, for the "Streambank Protection" storm event

SLOPE:
- Maximum slope of 14% for corrugated metal pipe
- Maximum slope of 10% for concrete pipe
- Maximum drop in a drainage structure is 10 feet.

OTHER:
- Skew not to exceed 45 degrees
- Minimum diameter of 18 inches

MAINTENANCE REQUIREMENTS:
- Reinforced concrete pipe for use (1) under roadway, (2) when pipe slopes are less than 1%, or (3) for all flowing streams.
- RCP and fully coated corrugated metal pipe
- High-density polyethylene (HDPE) may be used as specified in municipal regulations

STORM WATER MANAGEMENT SUITABILITY

☐	**Water Quality Protection**
☐	**Streambank Protection**
P	**On-Site Flood Control**
P	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
L	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

5.2.6.1 General Description

A culvert is a short, closed (covered) conduit that conveys storm water runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and/or roadway, and protect traffic and adjacent property owners from flood hazards to the extent practicable.

5.2.6.2 Pollutant Removal Capabilities

Culverts are designed for storm water conveyance purposes and do not provide pollutant removal capabilities.

5.2.6.3 Design Criteria and Specifications

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The following design criteria should be considered for all culvert designs as applicable:

- Frequency Flood;
- Velocity Limitations;
- Buoyancy Protection;
- Length and Slope;
- Debris Control;
- Headwater Limitations;
- Tailwater Considerations;
- Storage;
- Inlets;
- Inlets with Headwalls;
- Wingwalls and Aprons;
- Improved Inlets;
- Material Selection;
- Culvert Skews;
- Culvert Sizes;
- Weep Holes;
- Outlet Protection;
- Erosion and Sediment Control; and
- Environmental Considerations.

There are two types of flow conditions for culverts (see Figure 5.2.6-1) that are based upon the location of the control section and the critical flow depth:

- Inlet Control – Inlet control occurs when the culvert barrel is capable of conveying more flow than the inlet will accept. This typically happens when a culvert is operating on a steep slope. The control section of a culvert is located just inside the entrance. Critical depth occurs at or near this location, and the flow regime immediately downstream is supercritical.

- Outlet Control – Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions.

Proper culvert design and analysis requires checking for both inlet and outlet control to determine which will govern particular culvert designs.

There are three procedures for designing culverts: manual use of inlet and outlet control equations, nomographs, and the use of computer programs such as HY8. It is recommended that the HY8 computer model or equivalent be used for culvert design. The computer software package HYDRAIN, which includes HY8, uses the theoretical basis from the nomographs to size culverts. In addition, this software can evaluate improved inlets, route hydrographs, consider road overtopping, and evaluate outlet streambed scour. By using water surface profiles, this procedure is more accurate in predicting backwater effects and outlet scour.

Examples of small culverts are shown in Figure 5.2.6-2. See Section 4.2 for detailed culvert design procedures and instruction.

5.2.6.4 Inspection and Maintenance Requirements

Culverts located at the end of urban drainage channels are often clogged by refuse dumped into the channel or by trash washed off the city streets. Under such conditions, a debris rack can usually be installed at a low cost to prevent clogging. In designing debris control structures it is recommended that the Federal Highway Administration, Hydraulic Engineering Circular No. 9 entitled *Debris Control Structures* be consulted. This Circular discusses the variety of methods for controlling debris by: (a) intercepting the debris at or above the inlet; (b) deflecting the debris for detention near the inlet; or (c) passing the debris through the structure.

Additionally, to ensure self-cleaning during partial depth flow, a minimum velocity of 2.5 feet per second, for the 2-year flow, when the culvert is flowing partially full is required.

5.2.6.5 Example Schematic

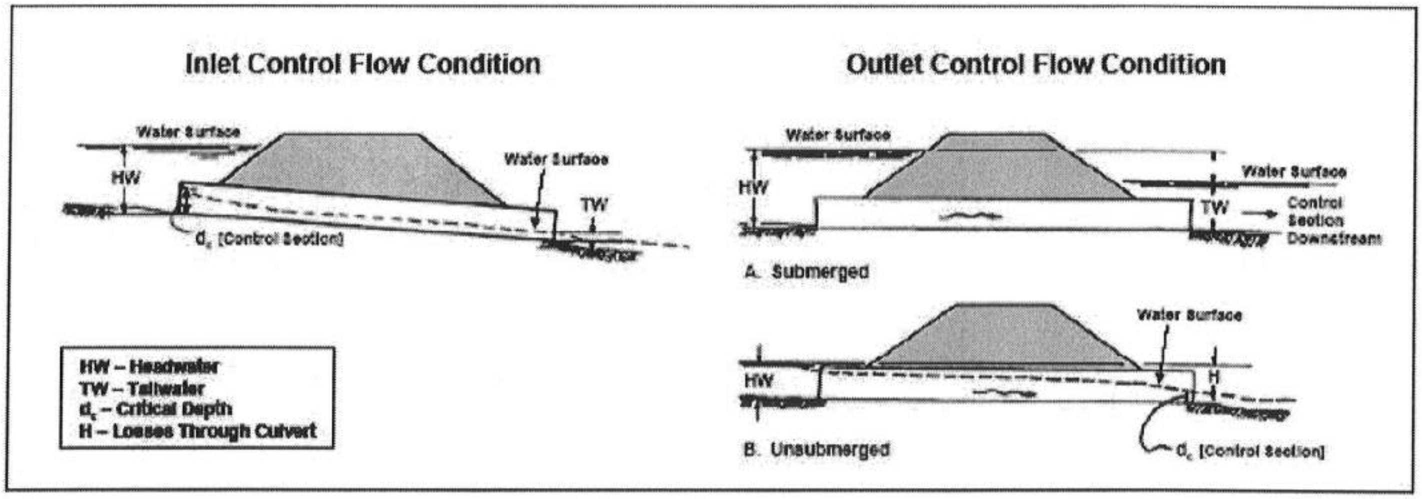


Figure 5.2.6-1 Culvert Flow Conditions

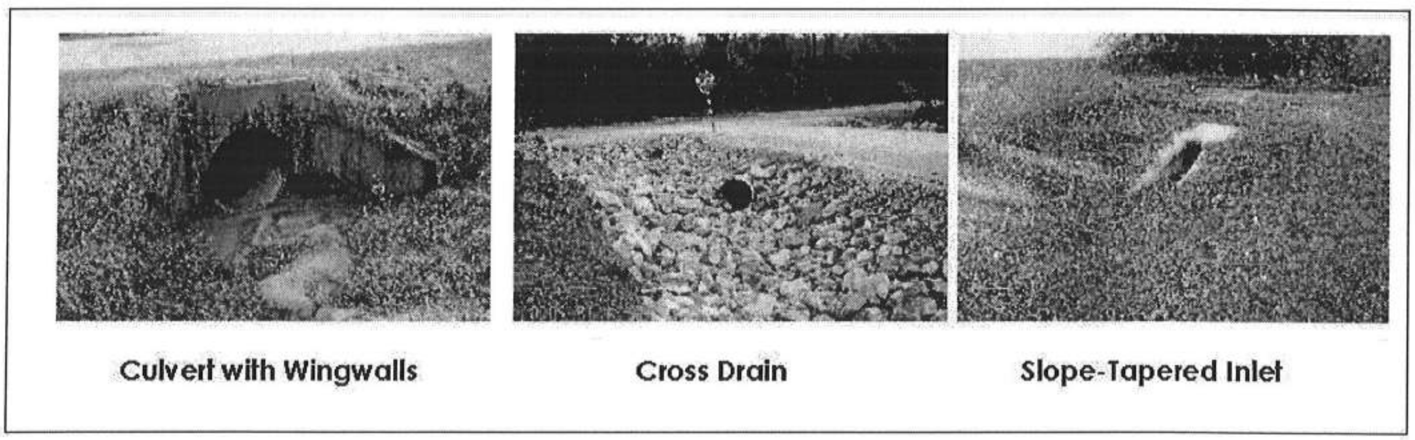


Figure 5.2.6-2 Culvert Examples

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5.2.7 Inlets

Storm Water Controls

Description: Drainage structure used to collect surface water through grate or curb openings and convey it to pipe systems or direct outlet to culverts.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Designed for conveyance purposes, not pollutant removal capability
- Interception capacity depends on depth of water next to curb.

ADVANTAGES / BENEFITS:

- Aesthetically pleasing, less obvious than most storm water structures.

DISADVANTAGES / LIMITATIONS:

- Efficiency is typically reduced in order to meet safety standards.

MAINTENANCE REQUIREMENTS:

- Must be inspected and cleaned regularly due to trash and debris build-up.

STORM WATER MANAGEMENT SUITABILITY

	Water Quality Protection
	Streambank Protection
P	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	Land Requirement
L	Capital Cost
L	Maintenance Burden

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *No restrictions*

Other Considerations:

- *Overflow parking, driveways and related issues*

L=Low **M**=Moderate **H**=High

5.2.7.1 General Description

Inlets are drainage structures used to collect surface water through grate or curb openings and convey it to pipe systems or direct outlet to culverts. Inlets are typically located in close proximity to impervious areas such as streets and parking lots. Inlets can also be located at a low point in a channel or area that concentrates overland flow (ponding areas).

5.2.7.2 Pollutant Removal Capabilities

Although inlets prevent large debris from passing to the storm sewer system, they are designed for storm water conveyance purposes and do not provide pollutant removal capabilities.

5.2.7.3 Design Criteria and Specifications

Inlets used for drainage of surfaces can be divided into three major classes:

- Grate Inlets – These inlets include grate inlets, consisting of an opening in the gutter covered by one or more grates, and slotted inlets, consisting of a pipe cut along the longitudinal axis with a grate or spacer bars to form slot openings.
- Curb-Opening Inlets – These inlets are vertical openings in the curb covered by a top slab.
- Combination Inlets – These inlets usually consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located in part upstream of the grate.

Inlets may be classified as on a *continuous grade* or in a *sump*. The term "continuous grade" refers to an inlet located on the street with a continuous slope past the inlet with water entering from one direction. The "sump" condition exists when the inlet is located at a low point and water enters from both directions. There are specific design criteria for the following types of inlets:

- Grate Inlets on Grade
- Grate Inlets in Sag
- Curb Inlets on Grade
- Curb Inlets in Sump
- Combination Inlets on Grade
- Combination Inlets in Sump

Where significant ponding can occur, in locations such as underpasses and in sag vertical curves in depressed sections, it is good engineering practice to place flanking inlets on each side of the inlet at the low point in the sag. The flanking inlets should be placed so that they will limit spread on low gradient approaches to the level point and act in relief of the inlet at the low point if it should become clogged or if the design spread is exceeded.

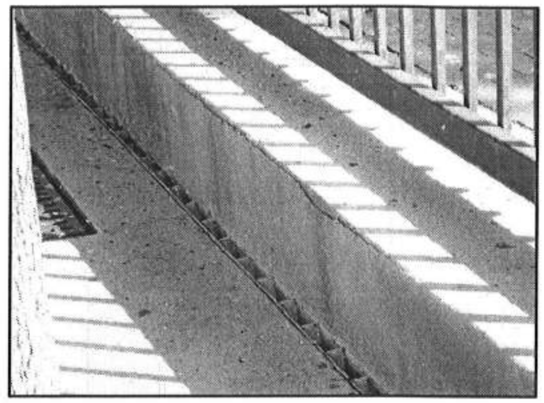
When designing an inlet, the grate length, bar configuration, and gutter velocity must be taken into account. Inlet location should not compromise safety or aesthetics. It should not allow for standing water in areas of vehicular or pedestrian traffic, and should take advantage of natural depression storage where possible. Grate inlets subject to traffic should be bicycle safe (horizontal and vertical cross-bars) and provide adequate load-bearing capabilities.

See Section 4.2 for detailed inlet design procedures and instruction.

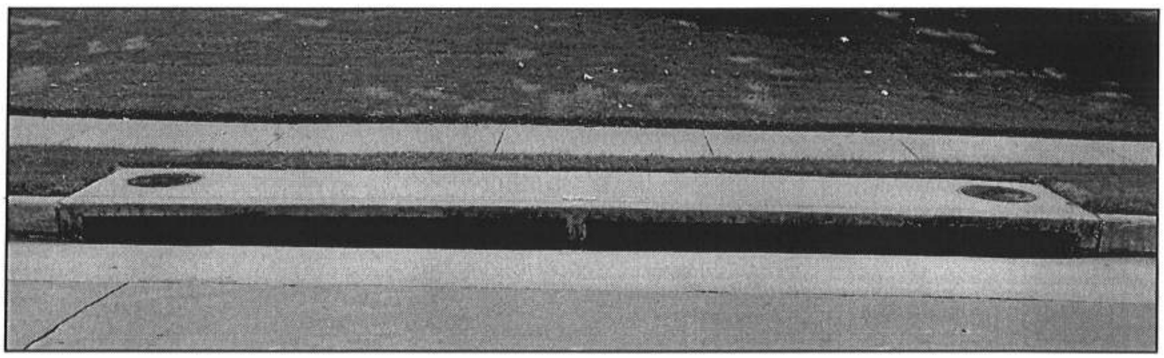
5.2.7.4 Inspection and Maintenance Requirements

Inlets are often blocked by trash washed off the city streets and parking lots. Regular inspection and removal of this debris will result in cleaner, more efficient storm water conveyance systems. The public might also misunderstand inlets as places to dispose of household wastes. To prevent this and to promote water quality education, some cities and non-profit organizations have begun "stamping" inlets or attaching decals with "No Dumping" instructions.

Grate Inlet in Parking Lot

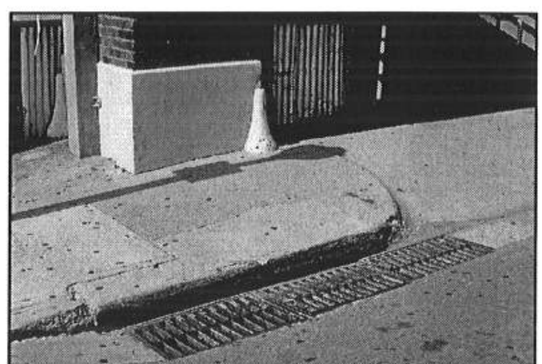


Slotted Inlet



Curb Inlet

Stamp on Inlet



Combination Inlet

Figure 5.2.7-1 Example Inlets

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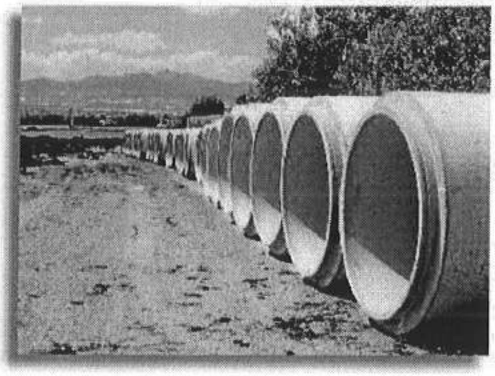
5.2.8 Pipe Systems

Storm Water Control



Description: Pipe conveyances used for transporting runoff from roadway and other inlets to outfalls at structural storm water controls and receiving waters.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Designed for conveyance purposes, not pollutant removal capability
- All systems should be designed with velocities greater than 2.5 fps with a minimum slope of 0.5%
- Size system under the assumption of full flow, but not pressure flow
- Hydraulic gradient should not produce velocity in excess of 15 fps
- Manning's Equation recommended for capacity computations

STORM WATER MANAGEMENT SUITABILITY

	Water Quality Protection
P	**Streambank Protection**
P	**On-Site Flood Control**
P	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
L	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *No restrictions*

L=Low M=Moderate H=High

5.2.8.1 General Description

Storm drain pipe systems, also known as *storm sewers*, are pipe conveyances used in the minor storm water drainage system for transporting runoff from roadway and other inlets to outfalls at structural storm water controls and receiving waters. Pipe drain systems are suitable mainly for medium to high-density residential and commercial/industrial development where the use of natural drainageways and/or vegetated open channels is not feasible.

5.2.8.2 Pollutant Removal Capabilities

The storm water pipe system is designed for conveyance purposes and does not provide pollutant removal capabilities.

5.2.8.3 Design Criteria and Specifications

The design of storm drain systems generally follows these steps:

Step 1 Determine inlet location and spacing.

Step 2 Prepare a tentative plan layout of the storm sewer drainage system including:

a. Location of storm drains
b. Direction of flow
c. Location of manholes
d. Location of existing facilities such as water, gas, or underground cables

Step 3 Determine drainage areas and compute runoff using the Rational Method

Step 4 After the tentative locations of inlets, drain pipes, and outfalls (including tailwaters) have been determined and the inlets sized, compute the rate of discharge to be carried by each storm drain pipe and determine the size and gradient of pipe required to care for this discharge. This is done by proceeding in steps from upstream of a line to downstream to the point at which the line connects with other lines or the outfall, whichever is applicable. The discharge for a run is calculated, the pipe serving that discharge is sized, and the process is repeated for the next run downstream. The storm drain system design computation form (Figure 3.2-12) can be used to summarize hydrologic, hydraulic, and design computations.

Step 5 Examine assumptions to determine if any adjustments are needed to the final design.

It should be recognized that the rate of discharge to be carried by any particular section of storm drain pipe is not necessarily the sum of the inlet design discharge rates of all inlets above that section of pipe, but as a general rule is somewhat less than this total. It is useful to understand that the time of concentration is most influential and as the time of concentration grows larger, the proper rainfall intensity to be used in the design grows smaller.

See Section 3.2.8 for detailed pipe system design procedures and instruction.

5.2.8.4 Inspection and Maintenance Requirements

Maintaining storm water conveyance structures on a regular basis will prevent clogging of the downstream conveyance system and ensure the system functions properly hydraulically to avoid flooding.

Storm Drain Conveyance System

- Locate reaches of storm drain with deposit problems and develop a flushing schedule that keeps the pipe clear of excessive buildup.
- Collect flushed effluent and pump to the sanitary sewer for treatment after sediment removal, if necessary.

Illicit Connections and Discharges

- During routine maintenance of conveyance system and drainage structures field staff should look for evidence of illegal discharges or illicit connections:
  - Is there evidence of spills such as paints, discoloring, etc.

- Are there any odors associated with the drainage system
- Record locations of apparent illegal discharges/illicit connections
- Track flows back to potential dischargers and conduct aboveground inspections. This can be done through visual inspection of up gradient manholes or alternate techniques including zinc chloride smoke testing, fluorometric dye testing, physical inspection testing, or television camera inspection.
- Once the origin of flow is established, require illicit discharger to eliminate the discharge.

- Stencil storm drains, where applicable, to prevent illegal disposal of pollutants. Storm drain inlets should have messages such as "Dump No Waste Drains to Stream" stenciled next to them to warn against uninformed or intentional dumping of pollutants into the storm drainage system.

Illegal Dumping

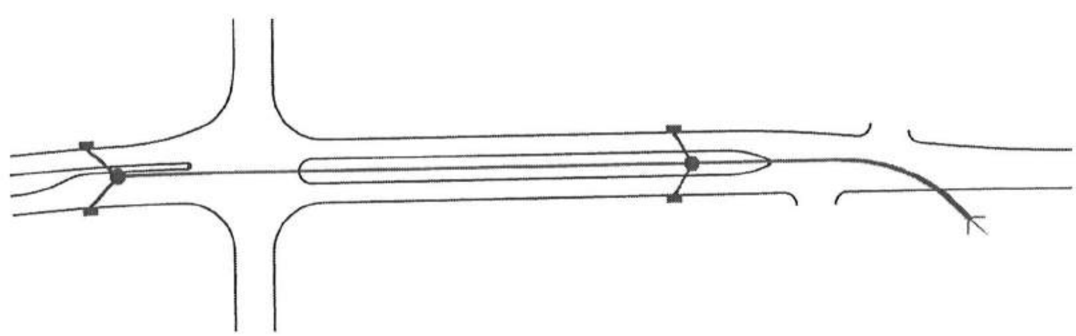
- Regularly inspect and clean up hot spots and other storm drainage areas where illegal dumping and disposal occurs.
- Establish a system for tracking incidents. The system should be designed to identify the following:
    - Illegal dumping hot spots
    - Types and quantities (in some cases) of wastes
    - Patterns in time of occurrence (time of day/night, month, or year)
    - Mode of dumping (abandoned containers, "midnight dumping" from moving vehicles, direct dumping of materials, accidents/spills)
    - Responsible parties
- Post "No Dumping" signs in problem areas with a phone number for reporting dumping and disposal. Signs should also indicate fines and penalties for illegal dumping.

Storm drain flushing is most effective in small diameter pipes (36-inch diameter pipe or less, depending on water supply and sediment collection capacity). Other considerations associated with storm drain flushing may include the availability of a water source, finding a downstream area to collect sediments, liquid/sediment disposal, and disposal of flushed effluent to sanitary sewer may be prohibited in some areas.

Maintenance

- Identifying illicit discharges requires teams of at least two people (volunteers can be used), plus administrative personnel, depending on the complexity of the storm sewer system.
- Arrangements must be made for proper disposal of collected wastes.
- Requires technical staff to detect and investigate illegal dumping violations, and to coordinate public education.

5.2.8.5 Example Schematic



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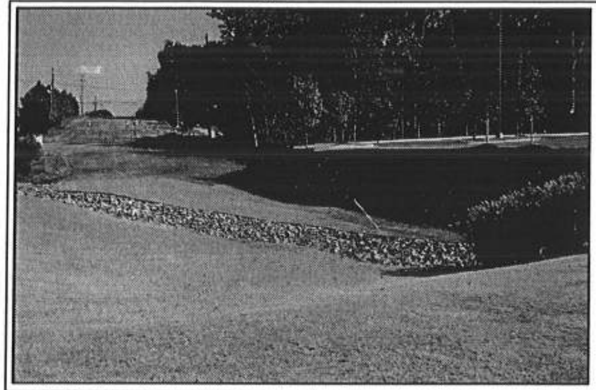
5.2.9 Dry Detention / Extended Detention Dry Basins

Detention
Structural Storm Water Control



Description: A surface storage basin or facility designed to provide water quantity control through detention and/or extended detention of storm water runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Designed for the reduction of maximum runoff values associated with development to their pre-development levels.

ADVANTAGES / BENEFITS:

- Typically less costly than storm water (wet) ponds for equivalent flood storage, as less excavation is required
- Used in conjunction with water quality structural control
- Recreational and other open space opportunities between storm runoff events

DISADVANTAGES / LIMITATIONS:

- Controls for storm water quantity primarily –extended detention may provide limited water quality treatment and streambank protection

POLLUTANT REMOVAL

65%	**Total Suspended Solids**
50/30%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
No data	**Metals** - Cadmium, Copper, Lead, and Zinc removal
70%	**Pathogens** Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
P	**Streambank Protection**
P	**On-Site Flood Control**
P	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirement**
L	**Capital Cost**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *No restrictions.*

Soils: *Hydrologic group 'A' and 'B' soils may require pond liner*

Other Considerations:

- *Recreational and open space uses for dry detention*

L=Low **M**=Moderate **H**=High

5.2.9.1 General Description

Dry detention and dry extended detention (ED) basins are surface facilities intended to provide for the temporary storage of storm water runoff to reduce downstream water quantity impacts. These facilities temporarily detain storm water runoff, releasing the flow over a period of time. They are designed to completely drain following a storm event and are normally dry between rain events.

Dry detention basins are intended to provide on-site flood control (peak flow reduction) and can be designed to control the extreme flood (100-year) storm event. Extended detention dry basins provide downstream streambank protection through extended detention of the streambank protection volume (SP_v), flood control.

Both dry detention and extended detention dry basins provide limited pollutant removal benefits and are not intended for water quality treatment. Detention-only facilities must be used in a treatment train approach with other structural controls that provide full treatment of the WQ_v (see Section 5.1).

Compatible multi-objective use of dry detention facilities in strongly encouraged.

5.2.9.2 Design Criteria and Specifications

Location

- Dry detention and extended detention dry basins are to be located downstream of other structural storm water controls providing treatment of the water quality volume (WQ_v). Extended detention dry basins may be part of a treatment train which treats the WQ_v. See Section 5.1 for more information on the use of multiple structural controls in a treatment train.

General Design

- Dry detention basins are sized to temporarily store the volume of runoff required to provide flood protection above the Q_f storm event up to the 100-year storm, if required.

  Extended detention dry basins are sized to provide extended detention of the streambank protection volume over 24 hours and can also provide additional storage volume for normal detention (peak flow reduction) of the 100-year storm event.

  Routing calculations must be used to demonstrate that the storage volume and outlet structure configuration are adequate. See Section 4.5 (*Storage Design*) for procedures on the design of detention storage.
- Storage may be subject to the requirements of the Texas Dam Safety Program (see Appendix H) based on the volume, dam height, and level of hazard.
- Earthen embankments less than 6 feet in height that are exposed to flood waters shall have side slopes no greater than the natural angle of repose of the fill material as determined by a geotechnical study. In lieu of a geotechnical study side slopes shall be 4:1 (horizontal to vertical) maximum.
- Earthen embankments 6 feet in height or greater shall be designed per Texas Commission on Environmental Quality guidelines for dam safety (see Appendix H).
- Vegetated slopes shall be less than 20 feet in height and shall have side slopes no steeper than 2:1 (horizontal to vertical) although 3:1 is preferred. Riprap-protected slopes shall be no steeper than 2:1. Geotechnical slope stability analysis is recommended for slopes greater than 10 feet in height.
- Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage and to prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions. A low flow or pilot channel

across the facility bottom from the inlet to the outlet (often constructed with riprap) is recommended to convey low flows and prevent standing water conditions.

- Adequate maintenance access must be provided for all dry detention and extended detention dry basins.

Inlet and Outlet Structures

- Inflow channels are to be stabilized with flared riprap aprons, or the equivalent. A sediment forebay sized to 0.1 inches per impervious acre of contributing drainage should be provided for dry detention and extended detention dry basins that are in a treatment train with off-line water quality treatment structural controls.
- For a dry detention basin, the outlet structure is sized to its SP_v and Q_f functions (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.

  For an extended detention dry basin, a low flow orifice capable of releasing WQ_v and SP_v over 24 hours must be provided. The streambank protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (e.g., an overperforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.

  See Section 4.6 (*Outlet Structures*) for more information on the design of outlet works.
- Seepage control or anti-seep collars should be provided for all outlet pipes.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. See Section 4.7, *Energy Dissipation Design*, for more guidance.
- An emergency spillway is to be included in the storm water pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be designed to State of Texas guidelines for dam safety (see Appendix H) and must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood, to the lowest point of the dam embankment not counting the emergency spillway.

5.2.9.3 Inspection and Maintenance Requirements

Table 5.2.9-1 Typical Maintenance Activities for Dry Detention / Extended Detention Dry Basins
(Source: Denver Urban Storm Drainage Manual, 1999)

Activity	Schedule
• Remove debris from basin surface to minimize outlet clogging and improve aesthetics.	Annually and following significant storm events
• Remove sediment buildup. • Repair and revegetate eroded areas. • Perform structural repairs to inlet and outlets.	As needed based on inspection
• Mow to limit unwanted vegetation.	Routine

5.2.9.4 Example Schematics

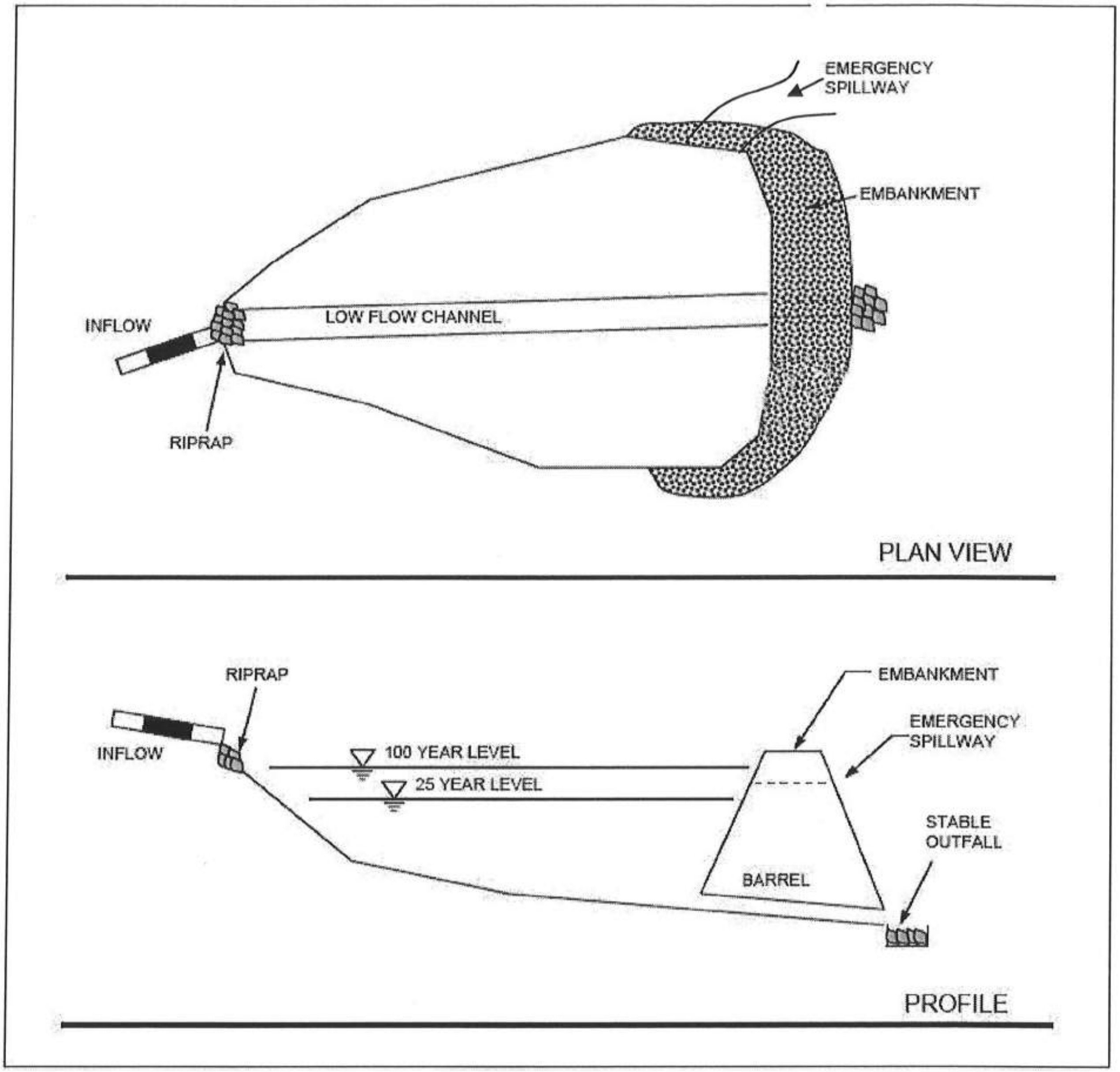


Figure 5.2.9-1 Schematic of Dry Detention Basin

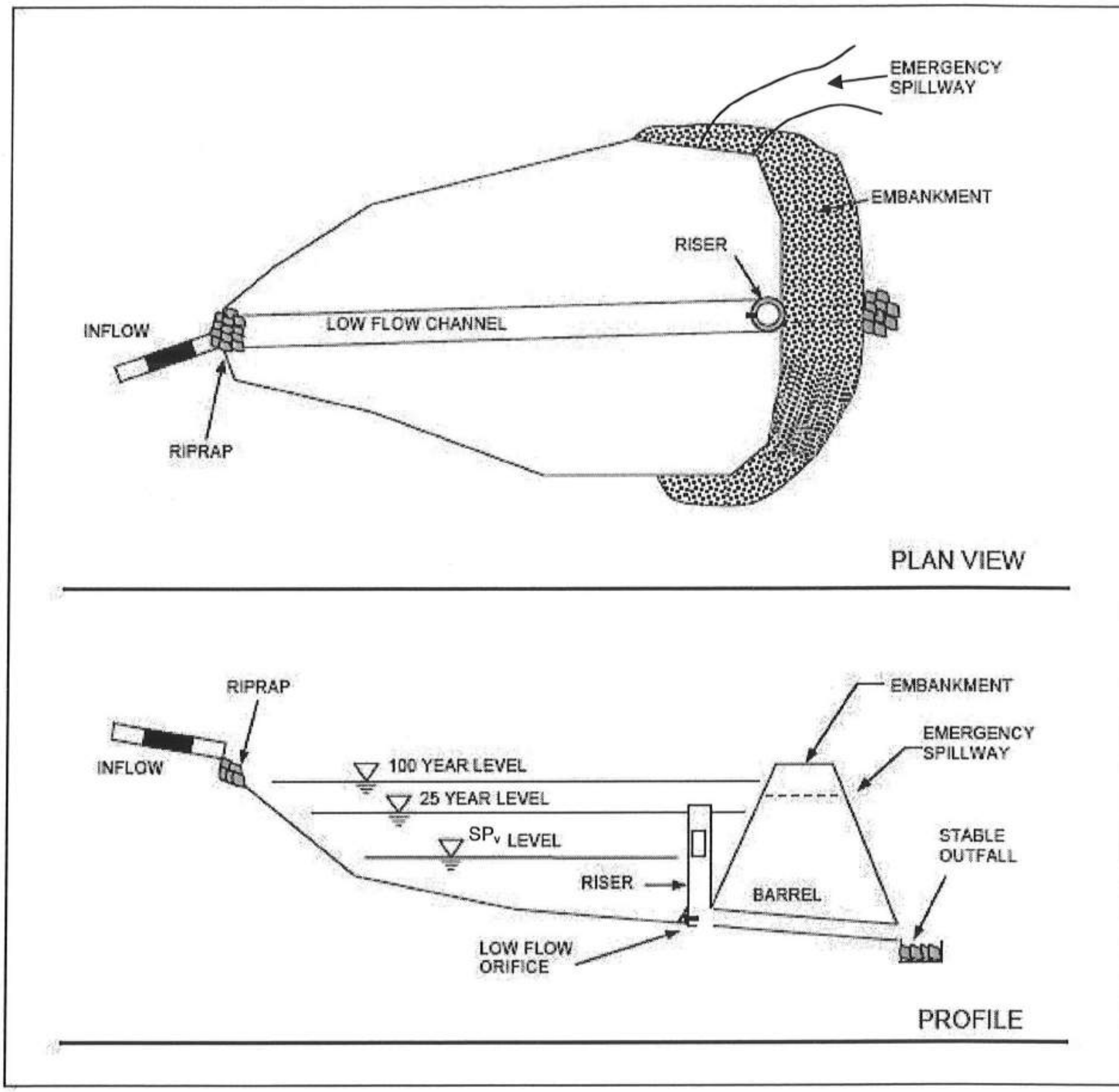


Figure 5.2.9-2 Schematic of Dry Extended Detention Basin

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5.2.10 Multi-Purpose Detention Areas

Structural Storm Water Control

Description: A facility designed primarily for another purpose, such as parking lots and rooftops that can provide water quantity control through detention of storm water runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Adequate grading and drainage must be provided to allow full use of facility's primary purposes following a storm event

ADVANTAGES / BENEFITS:

- Allows for multiple uses of site areas and reduces the need for downstream detention facilities
- Can be used in conjunction with water quality structural control

DISADVANTAGES / LIMITATIONS:

- Controls for storm water quantity only – not intended to provide water quality protection
- Localized flooding of area as intended may lead to property damage and additional liability

STORM WATER MANAGEMENT SUITABILITY

	Water Quality Protection
P	**Streambank Protection**
P	**On-Site Flood Control**
P	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
L	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

5.2.10.1 General Description

Multi-purpose detention areas are site areas primarily used for one or more specific activities that are also designed to provide for the temporary storage of storm water runoff to reduce downstream water quantity impacts. Example of multi-purpose detention areas include:

- Parking Lots

- Rooftops
- Sports Fields
- Recessed Plazas

Multi-purpose detention areas are normally dry between rain events, and by their very nature must be useable for their primary function the majority of the time. As such, multi-purpose detention areas should not be used for extended detention (SP_v control).

Multi-purpose detention areas are not intended for water quality protection and must be used in a treatment train approach with other structural controls that provide treatment of the WQ_v (see Section 5.1).

5.2.10.2 Design Criteria and Specifications

Location

- Multi-purpose detention areas can be located upstream or downstream of other structural storm water controls providing treatment of the water quality protection volume (WQ_v). See Section 5.1 for more information on the use of multiple structural controls in a treatment train.

General Design

- Multi-purpose detention areas are sized to temporarily store a portion or all of the volume of runoff required to control the 100-year storm, if required.

  Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 4.5 (*Storage Design*) for procedures on the design of detention storage.
- All multi-purpose detention facilities must be designed to minimize potential safety risks, potential property damage, and inconvenience to the facility's primary purposes. Emergency overflows are to be provided for storm events larger than the design storm. The overflow must not create a significant adverse impact to downstream properties or the conveyance system.

Parking Lot Storage

- Parking lot detention can be implemented in areas where portions of large, paved lots can be temporarily used for runoff storage without significantly interfering with normal vehicle and pedestrian traffic. Parking lot detention can be created in two ways: by using ponding areas along sections of raised curbing, or through depressed areas of pavement at drop inlet locations.
- The maximum depth of detention ponding in a parking lot, except at a flow control structure, should be 6 inches for a 10-year storm, and 9 inches for a 100-year storm. The maximum depth of ponding at a flow control structure is 12 inches for a 100-year storm.
- The storage area (portion of the parking lot subject to ponding) must have a minimum slope of 0.5% towards the outlet to ensure complete drainage following a storm. A slope of 1% or greater is recommended.
- Fire lanes used for emergency equipment must be free of ponding water for runoff events up to the extreme storm (100-year) event.
- Flows are typically backed up in the parking lot using a wye inlet.

Rooftop Storage

- Rooftops can be used for detention storage as long as the roof support structure is designed to address the weight of ponded water and is sufficiently waterproofed to achieve a minimum service life of 30 years. All rooftop detention designs must meet Texas State Building Code and local building code requirements.

- The minimum pitch of the roof area subject to ponding is 0.25 inches per foot.
- The rooftop storage system must include another mechanism for draining the ponding area in the event that the primary outlet is clogged.

Sports Fields

- Athletic facilities such as football and soccer fields and tracks can be used to provide storm water detention. This is accomplished by constructing berms around the facilities, which in essence creates very large detention basins. Outflow can be controlled through the use of an overflow weir or other appropriate control structure. Proper grading must be performed to ensure complete drainage of the facility.

Public Plazas

- In high-density areas, recessed public common areas such as plazas and pavilions can be utilized for storm water detention. These areas can be designed to flood no more than once or twice annually, and provide important open recreation space during the rest of the year.

5.2.10.3 Inspection and Maintenance Requirements

Table 5.2.10-1. Typical Maintenance Activities for Multi-Purpose Detention Areas

Activity	Schedule
• Remove debris from ponding area to minimize outlet clogging and improve aesthetics.	Annually and following significant storm events
• Remove sediment buildup. • Repair and revegetate eroded areas. • Perform structural repairs to inlet and outlets.	As needed based on inspection
• Perform additional maintenance activities specific to the type of facility.	As required

(Based on: Denver Urban Storm Drainage Manual, 1999)

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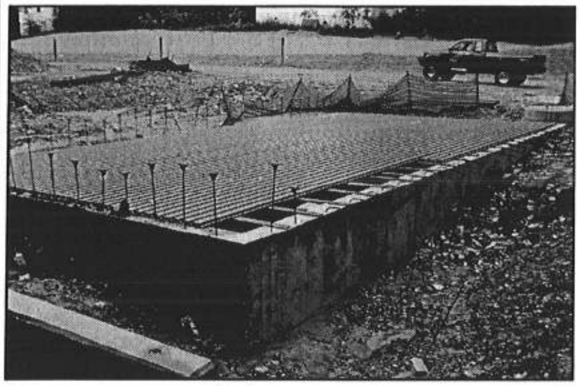
5.2.11 Underground Detention

Detention
Structural Storm Water Control



Description: Detention storage located in underground pipe/tank systems or vaults designed to provide water quantity control through detention and/or extended detention of storm water runoff.

KEY CONSIDERATIONS

ADVANTAGES / BENEFITS:

- Does not take up surface space
- Used in conjunction with water quality structural control
- Concrete vaults or pipe/tank systems can be used

DISADVANTAGES / LIMITATIONS:

- Controls for storm water quantity only – not intended to provide water quality treatment
- Intended for space-limited applications
- High initial construction cost as well as replacement cost at the end of its economic life

STORM WATER MANAGEMENT SUITABILITY

☐	Water Quality Protection
P	Streambank Protection
P	On-Site Flood Control
P	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	Land Requirement
H	Capital Cost
M	Maintenance Burden

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *160 acres max.*

Soils: *No restrictions*

L=Low M=Moderate H=High

5.2.11.1 General Description

Detention vaults are box-shaped underground storm water storage facilities typically constructed with reinforced concrete. Detention pipe/tank systems are underground storage facilities typically constructed with large diameter metal or plastic pipe. Both serve as an alternative to surface dry detention for storm water quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area.

Both underground vaults and pipe/tank systems can provide streambank protection through extended detention of the streambank protection volume (SP_v), and flood (in some cases extreme flood Q_f) control through normal detention. Basic storage design and routing methods are the same as for detention basins except that the bypass for high flows is typically included.

Underground detention vaults and pipe/tank systems are not intended for water quality treatment and must be used in a treatment train approach with other structural controls that provide treatment of the WQ_v (see Section 5.1). This will prevent the underground vault or tank from becoming clogged with trash or sediment and significantly reduces the maintenance requirements for an underground detention system.

Prefabricated concrete vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems.

5.2.11.2 Design Criteria and Specifications

Location

- Underground detention systems are to be located downstream of other structural storm water controls providing treatment of the water quality volume (WQ_v). See Section 5.1 for more information on the use of multiple structural controls in a treatment train.
- The maximum contributing drainage area to be served by a single underground detention vault or tank is 200 acres.

General Design

- Underground detention systems are sized to provide extended detention of the streambank protection volume over 24 hours and temporarily store the volume of runoff required to provide the desired flood protection.
- Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 4.5 (*Storage Design*) for procedures on the design of detention storage.
- Detention Vaults: Minimum 3,000 psi structural reinforced concrete may be used for underground detention vaults. All construction joints must be provided with water stops. Cast-in-place wall sections must be designed as retaining walls. The maximum depth from finished grade to the vault invert should be 20 feet.
- Detention Pipe/Tank Systems: The minimum pipe diameter for underground detention tanks is 36 inches.
- Underground detention vaults and pipe/tank systems must meet structural requirements for overburden support and traffic loading if appropriate.
- Adequate maintenance access must be provided for all underground detention systems. Access must be provided over the inlet pipe and outflow structure. Access openings can consist of a standard frame, grate and solid cover, or a removable panel. Vaults with widths of 10 feet or less should have removable lids.

Inlet and Outlet Structures

- A separate sediment sump or vault chamber sized to 0.1 inches per impervious acre of contributing drainage should be provided at the inlet for underground detention systems that are in a treatment train with off-line water quality treatment structural controls.
- For SP_v control, a low flow orifice capable of releasing the streambank protection volume over 24 hours must be provided. The streambank protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an overperforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.

  For on-site flood control, an additional outlet is sized for control of the chosen return period (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure.

  See Section 4.6 (*Outlet Structures*) for more information on the design of outlet works.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion. See Section 4.7, *Energy Dissipation Design*, for more guidance.
- A high flow bypass is to be included in the underground detention system design to safely pass the extreme flood flow.

5.2.11.3 Inspection and Maintenance Requirements

Table 5.2.11-1 Typical Maintenance Activities for Underground Detention Systems

Activity	Schedule
• Remove any trash/debris and sediment buildup in the underground vaults or pipe/tank systems.	Annually
• Perform structural repairs to inlet and outlets.	As needed, based on inspection

5.2.11.4 Example Schematics

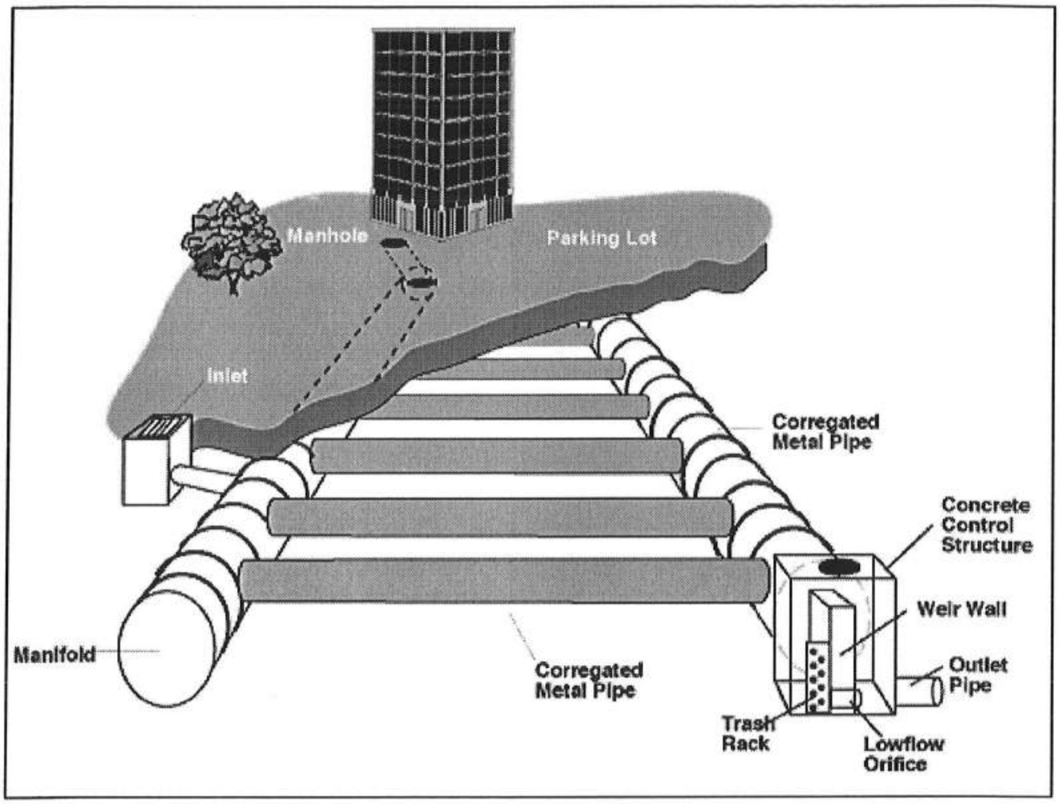


Figure 5.2.11-1 Example Underground Detention Tank System

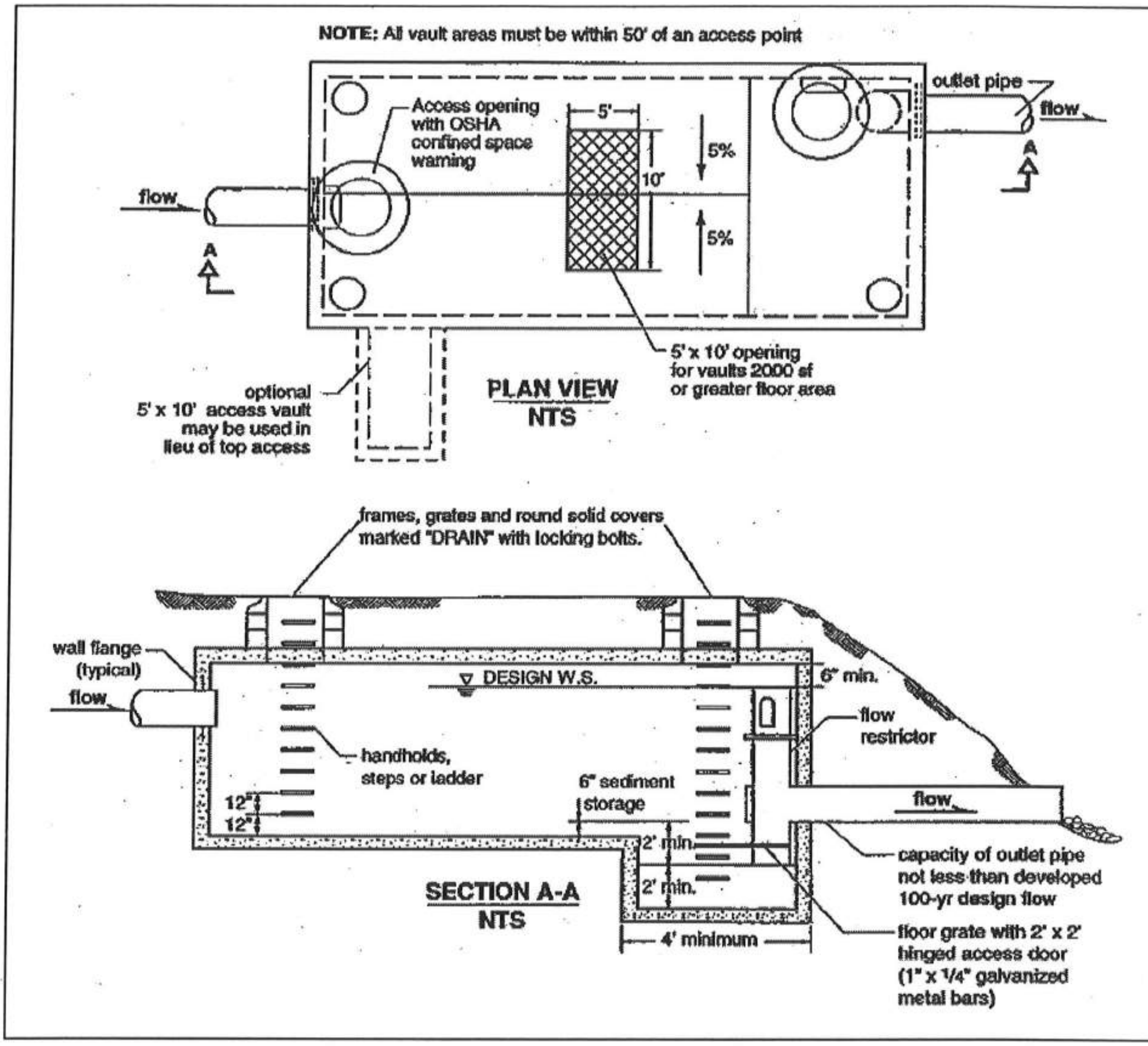


Figure 5.2.11-2 Schematic of Typical Underground Detention Vault
(Source: WDE, 2000)

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5.2.12 Filter Strip

Structural Storm Water Control

Description: Filter strips are uniformly graded and densely vegetated sections of land engineered and designed to treat runoff from and remove pollutants through vegetative filtering and infiltration.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Runoff from an adjacent impervious area must be evenly distributed across the filter strip as sheet flow

ADVANTAGES / BENEFITS:

- Can be used as part of the runoff conveyance system to provide pretreatment
- Can provide groundwater recharge
- Reasonably low construction cost

DISADVANTAGES / LIMITATIONS:

- Cannot alone achieve the 80% TSS removal target
- Large land requirement

MAINTENANCE REQUIREMENTS:

- Requires periodic repair, regrading, and sediment removal to prevent channelization

POLLUTANT REMOVAL

50%	**Total Suspended Solids**
20/20%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
40%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirement**
L	**Capital Cost**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *2 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Use in buffer system*
- *Treating runoff from pervious areas*

L=Low **M**=Moderate **H**=High

5.2.12.1 General Description

Filter strips are uniformly graded and densely vegetated sections of land engineered and designed to treat runoff and remove pollutants through vegetative filtering and infiltration. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer, or as pretreatment for another structural storm water control. Filter strips can serve as a buffer between incompatible land uses, be landscaped to be aesthetically pleasing, and provide groundwater recharge in areas with pervious soils. Filter strips are often used as an *integrated* site design reduction credit (see Section 1.4 for more information).

Filter strips rely on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from urban storm water. There can also be a significant reduction in runoff volume for smaller flows that infiltrate pervious soils while contained within the filter strip. To be effective, however, sheet flow must be maintained across the entire filter strip. Once runoff flow concentrates, it effectively short-circuits the filter strip and reduces any water quality benefits. Therefore, a flow spreader must normally be included in the filter strip design.

There are two different filter strip designs: a simple filter strip and a design that includes a permeable berm at the bottom. The presence of the berm increases the contact time with the runoff, thus reducing the overall width of the filter strip required to treat storm water runoff. Filter strips are typically an on-line practice, so they must be designed to withstand the full range of storm events without eroding.

5.2.12.2 Pollutant Removal Capabilities

Pollutant removal from filter strips is highly variable and depends primarily on density of vegetation and contact time for filtration and infiltration. These, in turn, depend on soil and vegetation type, slope, and presence of sheet flow.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- **Total Suspended Solids – 50%**
- **Total Phosphorus – 20%**
- **Total Nitrogen – 20%**
- **Fecal Coliform – insufficient data**
- **Heavy Metals – 40%**

5.2.12.3 Design Criteria and Specifications

General Criteria

- Filter strips should be used to treat small drainage areas. Flow must enter the filter strip as sheet flow spread out over the width (long dimension normal to flow) of the strip, generally no deeper than 1 to 2 inches. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (CWP, 1996). For longer flow paths, special provision must be made to ensure design flows spread evenly across the filter strip, instead of becoming concentrated.
- Filter strips should be integrated within site designs.
- Filter strips should be constructed outside the natural stream buffer area whenever possible to maintain a more natural buffer along the streambank.
- Filter strips should be designed for slopes between 2% and 6%. Greater slopes than this would encourage the formation of concentrated flow. Flatter slopes would encourage standing water.

- Filter strips should not be used on soils that cannot sustain a dense grass cover with high retardance. Designers should choose a grass that can withstand relatively high velocity flows at the entrances, and both wet and dry periods. See Appendix F for a list of appropriate grasses for use in North Central Texas.
- The flow path should be at least 15 feet across the strip to provide filtration and contact time for water quality treatment. Twenty-five (25) feet is preferred (where available), though the length of the flow path will normally be dictated by design method.
- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.
- An effective flow spreader is a pea gravel diaphragm at the top of the slope (ASTM D 448 size no. 6, 1/8" to 3/8"). The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip. Other types of flow spreaders include a concrete sill, curb stops, or curb and gutter with "sawteeth" cut into it.
- Ensure that flows in excess of design flow move across or around the strip without damaging it. Often a bypass channel or overflow spillway with protected channel section is designed to handle higher flows.
- Pedestrian traffic across the filter strip should be limited through channeling onto sidewalks.
- Maximum discharge loading per foot of filter strip width (perpendicular to flow path) is found using the Manning's equation:

$$q = \frac{0.0237}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}} \qquad \textbf{(5.2.12.1)}$$

where:

q = discharge per foot of width of filter strip (cfs/ft)
Y = allowable depth of flow (inches)
S = slope of filter strip (percent)
N = Manning's "n" roughness coefficient

(use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

- The minimum width of a filter strip is:

$$W_{fMIN} = \frac{Q}{q} \qquad \textbf{(5.2.12.2)}$$

where:

W_{fMIN} = minimum filter strip width perpendicular to flow (feet)

Filter without Berm

- Size filter strip (parallel to flow path) for a contact time of 5 minutes minimum
- Equation for filter length is based on the SCS TR55 travel time equation (SCS, 1986):

$$L_f = \frac{(T_t)^{1.25} (P_{2\text{-}24})^{0.625} (S)^{1/2}}{3.34n} \qquad \textbf{(5.2.12.3)}$$

where:

L_f = length of filter strip parallel to flow path (ft)

T_t = travel time through filter strip (minutes)

P_{2-24} = 2-year, 24-hour rainfall depth (inches)

S = slope of filter strip (percent)

n = Manning's "n" roughness coefficient

(use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

Filter Strips with Berm

- Size outlet pipes to ensure that the bermed area drains within 24 hours.
- Specify grasses resistant to frequent inundation within the shallow ponding limit.
- Berm material should be of sand, gravel and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02"-0.04", Gravel: AASHTO M-43 ½" to 1").
- Size filter strip to contain the WQ_v within the wedge of water backed up behind the berm.
- Maximum berm height is 12 inches.

Filter Strips for Pretreatment

- A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a filter strip as a pretreatment measure. The required length of the filter strip flow path depends on the drainage area, imperviousness, and the filter strip slope. Table 5.2.12-1 provides sizing guidance for bioretention filter strips for pretreatment.

Table 5.2.12-1 Bioretention Filter Strip Sizing Guidance

Parameter	Impervious Areas				Pervious Areas (Lawns, etc)			
Maximum inflow approach length (feet)	35		75		75		100	
Filter strip slope (max = 6%)	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%
Filter strip minimum length (feet)	10	15	20	25	10	12	15	18

(Source: Claytor and Schueler, 1996)

5.2.12.4 Inspection and Maintenance Requirements

Table 5.2.12-2. Typical Maintenance Activities for Filter Strips

Activity	Schedule
• Mow grass to maintain a 2 to 4 inch height.	Regularly (frequently)
• Inspect pea gravel diaphragm for clogging and remove built-up sediment. • Inspect vegetation for rills and gullies and correct. Seed or sod bare areas. • Inspect to ensure that grass has established. If not, replace with an alternative species.	Annual Inspection (Semi-annual first year)

(Source: CWP, 1996)
If berm is used per example, inspect outlet pipes for clogging

Additional Maintenance Considerations and Requirements

- Filter strips require similar maintenance to other vegetative practices. Maintenance is very important for filter strips, particularly in terms of ensuring that flow does not short circuit the practice.

5.2.12.5 Example Schematic

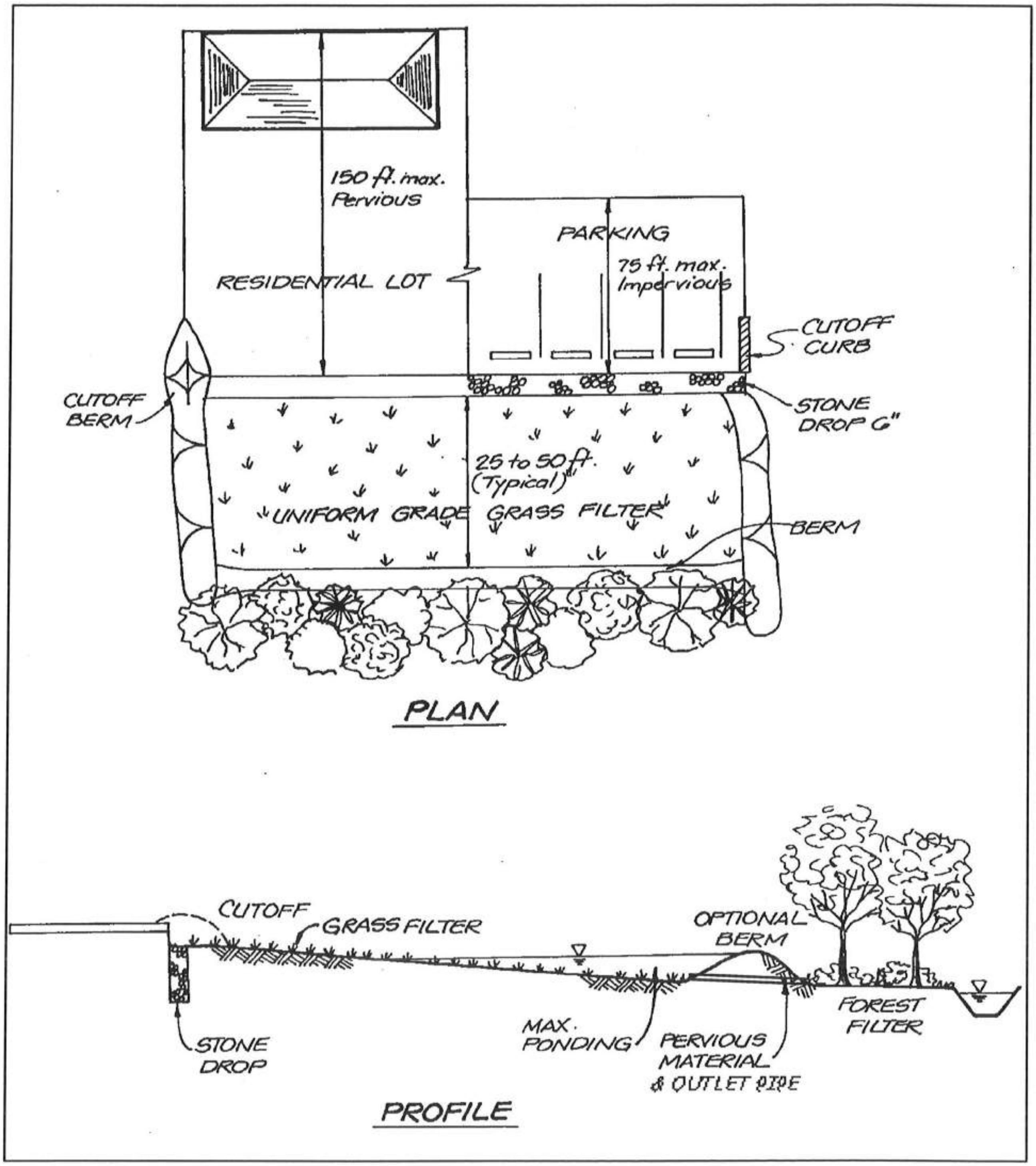

Figure 5.2.12-1 Schematic of Filter Strip (with Berm)

5.2.12.6 Design Example

Basic Data

Small commercial lot 150 feet deep x 100 feet wide located in Denison

- Drainage area (A) = 0.34 acres
- Impervious percentage (I) = 70%
- Slope equals 4%, Manning's n = 0.25

Calculate Maximum Discharge Loading Per Foot of Filter Strip Width

Using equation 5.2.12.1:

$$q = 0.0237/0.25 * (1.0)^{5/3} * (4)^{1/2} = 0.19 \text{ cfs/ft}$$

Water Quality Peak Flow

See subsections 1.2.3 and 2.1.10.2 for details

Compute the Water Quality Volume in inches:

$$WQ_v = 1.5\ (0.05 + 0.009 * 70) = 1.02 \text{ inches}$$

Compute modified CN for 1.5-inch rainfall (P=1.5):

$$\begin{aligned} CN &= 1000/[10+5P+10Q-10(Q^2+1.25*Q*P)^{½}] \\ &= 1000/[10+5*1.5+10*0.82-10(0.82^2+1.25*0.82*1.5)^{½}] \\ &= 92.4 \quad \text{(Use CN = 92)} \end{aligned}$$

For CN = 92 and an estimated time of concentration (T_c) of 8 minutes (0.13 hours), compute the Q_{wq} for a 1.5-inch storm.

From Table 2.1.5-3, I_a = 0.174, therefore I_a/P = 0.174/1.5 = 0.116.

From Figure 2.1.5-6 for a Type II storm (using the limiting values) q_u = 950 csm/in, and therefore:

$$Q_{wq} = (950 \text{ csm/in})\ (0.34\text{ac}/640\text{ac/mi}^2)\ (1.02") = 0.51 \text{ cfs}$$

Minimum Filter Width

Using equation 5.3.2:

$$W_{fMIN} = Q/q = 0.51/0.19 = 2.7 \text{ feet}$$

Since the width of the lot is 100 feet, the actual width of the filter strip will depend on site grading and the ability to deliver the drainage to the filter strip in sheet flow through a pea gravel filled trench.

Filter without Berm

- 2-year, 24-hour storm (see Appendix A) = 0.17 in/hr or 0.17*24= 4.08 inches
- Use 5 minute travel (contact) time

Using equation 5.2.12.3:

$$L_f = (5)^{1.25} * (4.08)^{0.625} * (4)^{0.5} / (3.34 * 0.25) = 43 \text{ feet}$$

Note: Reducing the filter strip slope to 2% and planting a denser grass (raising the Manning n to 0.35) would reduce the filter strip length to 22 feet. Sensitivity to slope and Manning's n changes are illustrated for this example in Figure 5.2.12-2.

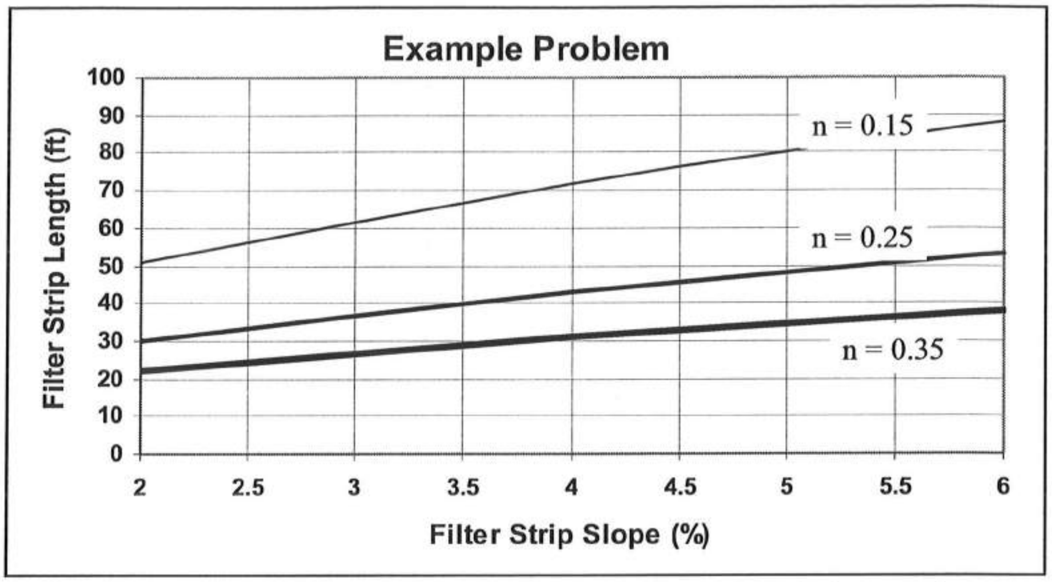

Figure 5.2.12-2 Example Problem Sensitivity of Filter Strip Length to Slope and Manning's n Values

Filter With Berm

- Pervious berm height is 6 inches

Compute the Water Quality Volume in cubic feet:

WQ_v = Rv * 1.5/12 * A = (0.05 + 0.009 * 70) * 1.5/12 * 0.34 = 0.029 Ac-ft or 1,259 ft^3

For a berm height of 6 inches the "wedge" of volume captured by the filter strip is:

Volume = W_f * 0.5 * L_f * 0.5 = $0.25W_fL_f$ = 1,259 ft^3

For a maximum width of the filter of 100 feet, the length of the filter would then be 50 feet.

For a 1-foot berm height, the length of the filter would be 25 feet.

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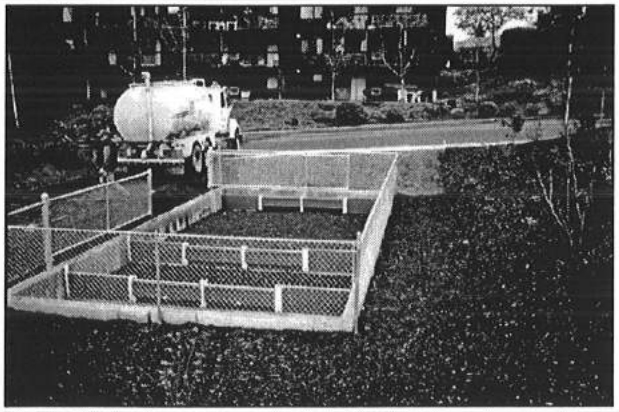
5.2.13 Organic Filter

Structural Storm Water Control



Description: Design variant of the surface sand filter using organic materials in the filter media.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Minimum head requirement of 5 to 8 feet

ADVANTAGES / BENEFITS:

- High pollutant removal capability
- Removal of dissolved pollutants is greater than sand filters due to cation exchange capacity

DISADVANTAGES / LIMITATIONS:

- Severe clogging potential if exposed soil surfaces exist upstream
- Intended for hotspot or space-limited applications, or for areas requiring enhanced pollutant removal capability
- High maintenance requirements
- Filter may require more frequent maintenance than most of the other storm water controls

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
60/40%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
75%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
50%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *10 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Hotspot areas*

L=Low **M**=Moderate **H**=High

5.2.13.1 General Description

The organic filter is a design variant of the surface sand filter, which uses organic materials such as leaf compost or a peat/sand mixture as the filter media. The organic material enhances pollutant removal by providing adsorption of contaminants such as soluble metals, hydrocarbons, and other organic chemicals.

As with the surface sand filter, an organic filter consists of a pretreatment chamber, and one or more filter cells. Each filter bed contains a layer of leaf compost or the peat/sand mixture, followed by filter fabric and a gravel/perforated pipe underdrain system. The filter bed and subsoils can be separated by an impermeable polyliner or concrete structure to prevent movement into groundwater.

Organic filters are typically used in high-density applications, or for areas requiring enhanced pollutant removal ability. Maintenance is typically higher than the surface sand filter facility due to the potential for clogging. In addition, organic filter systems have a higher head requirement than sand filters.

5.2.13.2 Pollutant Removal Capabilities

Peat/sand filter systems provide good removal of bacteria and organic waste metals. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. (Note: In some cases, organic materials may be a source of soluble phosphorus and nitrates.)

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 60%**
- **Total Nitrogen – 40%**
- **Fecal Coliform – 50%**
- **Heavy Metals – 75%**

5.2.13.3 Design Criteria and Specifications

- Organic filters are typically used on relatively small sites (up to 10 acres), to minimize potential clogging.
- The minimum head requirement (elevation difference needed at a site from the inflow to the outflow) for an organic filter is 5 to 8 feet.
- Organic filters can utilize a variety of organic materials as the filtering media. Two typical media bed configurations are the peat/sand filter and compost filter (see Figure 5.2.13-1). The peat filter includes an 18-inch 50/50 peat/sand mix over a 6-inch sand layer and can be optionally covered by 3 inches of topsoil and vegetation. The compost filter has an 18-inch compost layer. Both variants utilize a gravel underdrain system.
- The type of peat used in a peat/sand filter is critically important. Fibric peat in which undecomposed fibrous organic material is readily identifiable is the preferred type. Hemic peat containing more decomposed material may also be used. Sapric peat made up of largely decomposed matter should *not* be used in an organic filter.
- Typically, organic filters are designed as "off-line" systems, meaning that the water volume (WQ_v) is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Storm water flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
- Consult the design criteria for the surface sand filter (see subsection 5.2.15, *Sand Filters*) for the organic filter sizing and design steps.

5.2.13.4 Inspection and Maintenance Requirements

The inspection and maintenance requirements for organic filters are similar to those for surface sand filter facilities (see subsection 5.2.15)

5.2.13.5 Example Schematic

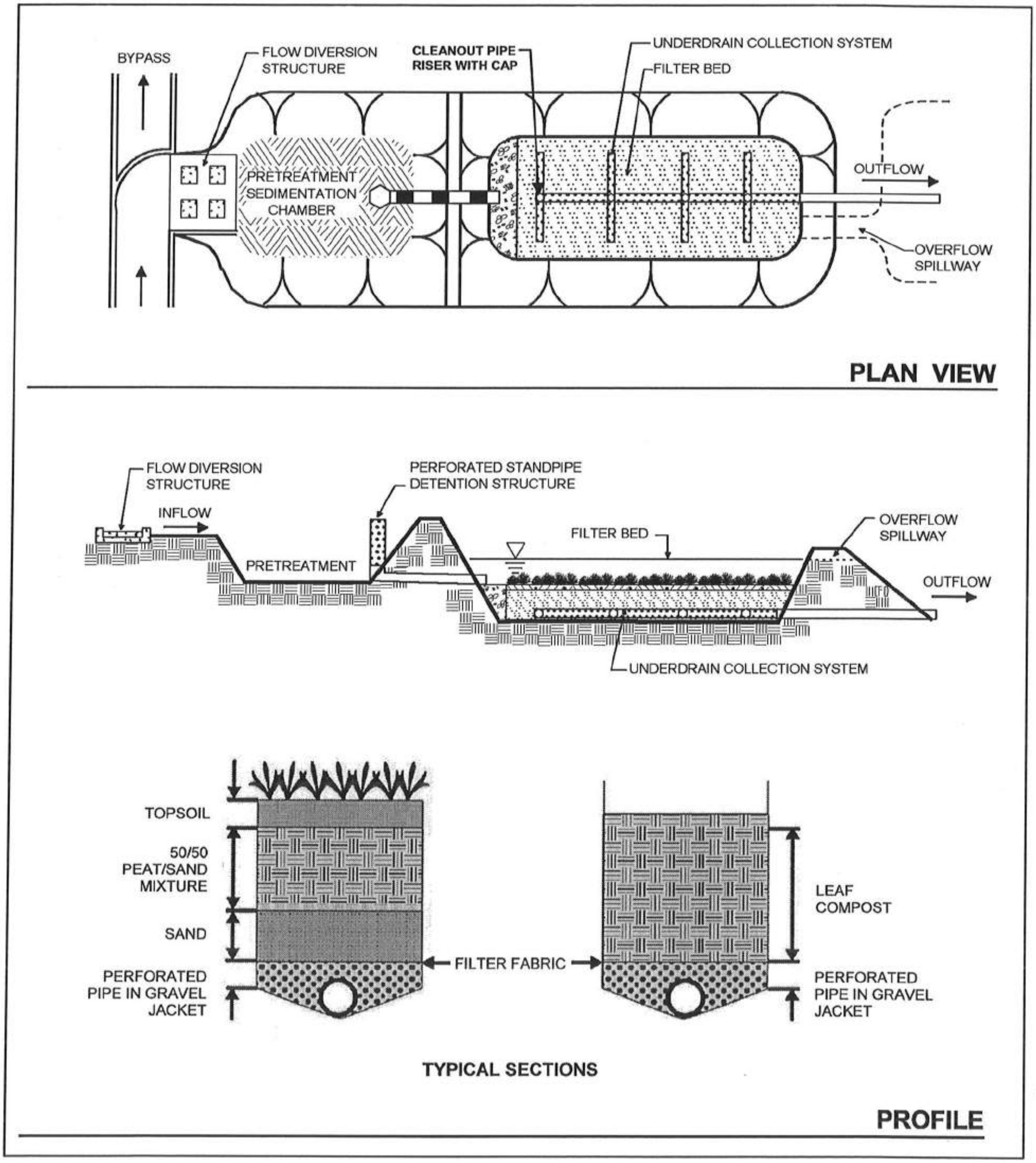


Figure 5.2.13-1 Schematic of Organic Filter
(Source: Center for Watershed Protection)

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5.2.14 Planter Boxes

Structural Storm Water Control

Description: Planter boxes are used on impervious surfaces in highly urbanized areas to collect and detain / infiltrate rainfall and runoff. The boxes may be prefabricated or constructed in place and contain growing medium, plants, and a reservoir.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Planter boxes should not be used for storm water containing high sediment loads to minimize clogging potential

ADVANTAGES / BENEFITS:

- Filtration provides pollutant removal capability
- Reservoir decreases peak flow rates

DISADVANTAGES / LIMITATIONS:

- Intended for space-limited applications, or for areas requiring additional pollutant removal capability
- Limited data on pollutant removal effectiveness

MAINTENANCE REQUIREMENTS:

- Vegetation will require frequent maintenance
- Filter may require more frequent maintenance than most of the other storm water controls

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
60/40%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
No data	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirement**
L	**Capital Cost**
M	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

5.2.14.1 General Description

Planter boxes are essentially large pots filled with soil or other growing media. There are several variations of this basic design. The contained planter box receives only rainfall, which filters through the soil and is then either taken up by its vegetation or allowed to seep out the bottom of the planter to the pavement or sidewalk. The infiltration planter box can receive both rainfall and runoff, which eventually filters through the bottomless planter and enters the underlying soil. The flow-through planter box collects flow in a perforated pipe along the bottom of the box and discharges out the side of the planter or into a storm sewer.

Each of the three planter box types has certain advantages and drawbacks:

- The contained planter is not tied into underlying soil or pipes and can therefore be placed almost anywhere and moved when needed. However, it does not have a reservoir to provide additional storage for flow control. Care should also be used in placing it next to building foundations and heavy pedestrian traffic areas.
- The infiltration planter should not be used next to foundations and underlying soils must drain rapidly enough to avoid ponding.
- The flow-through planter can be used next to building foundations since it directs flow off to the side and away from the building. It must be located next to a suitable discharge point into the storm water conveyance system.

5.2.14.2 Pollutant Removal Capabilities

Field tests of planters are lacking, however, tests of a bioretention cell by the EPA showed results that were generally similar to those of the Organic Filter, with somewhat less metals removal (43-78%).

5.2.14.3 Design Criteria and Specifications

- The infiltration and flow-through planter boxes can capture runoff from surrounding areas and provide limited storage in reservoirs. The ratio of planter area to impervious area should be 7%, assuming a storm volume of 1.5 inches and a reservoir depth in the planter of 12 inches.
- The planter should be constructed of stone, concrete, or brick. Pressure-treated wood may be used if it does not leach out toxic chemicals that might contaminate storm water.
- Filter media should consist of sand, gravel and topsoil as shown in the figures below. As an alternative, compost/mulch can be used in place of the sand, gravel, and topsoil, but will have different infiltration characteristics. Compost with organics will aid in pollutant removal through absorption, but it will remove nitrogen from the plant material as it breaks down/decomposes. A nitrogen fertilizer may need to be added should this occur.
- Planter vegetation should be relatively self-sustaining, with minimal fertilizer or pesticide requirements. Grasses, herbs, succulents, shrubs, and trees may be used in planter boxes. Examples include rushes, reeds, sedges, iris, dogwood, currants, and other approved species. Trees are encouraged as their foliage traps additional precipitation.
- All of the planters require 18 inches of growing media. The contained planter does not require a minimum width. A minimum width of 30 inches is recommended for the infiltration planter. The flow-through planter should be at least 18 inches wide. The minimum widths help reduce water wicking down the insides of the planter wall.
- Water should drain through a planter within 3-4 hours after the storm event.
- Soils underneath an infiltration planter should be SCS Hydrologic Type A or B.

5.2.14.4 Inspection and Maintenance Requirements

The inspection and maintenance requirements for planter boxes focus on maintaining an adequate drainage rate through the planting media and attractive and healthy vegetation.

Table 5.2.14-1 Typical Maintenance Activities for Planter Boxes

Activity	Schedule
• Ensure that downspout or sheet flow from paving is unimpeded. • Ensure planter reservoir drains within 3-4 hours. • Replace or amend topsoil if drainage unsatisfactory.	Quarterly and within 48 hours of major storms
• Ensure that contributing area and planter boxes are clear of debris. • Remove accumulated sediment if greater than 4 inches in depth. • Ensure that planter vegetation is healthy and planter is weeded and shrubs and trees pruned. • Planter vegetation may require watering during long dry spells.	As needed, based on inspection
• Fallen leaves and debris from deciduous plants should be removed.	Three to four times a year
• Replenish mulch. • Training/written materials provided to property owners and tenants.	Annually
• Replace planter if cracked or rotted.	Upon failure

5.2.14.5 Example Schematics

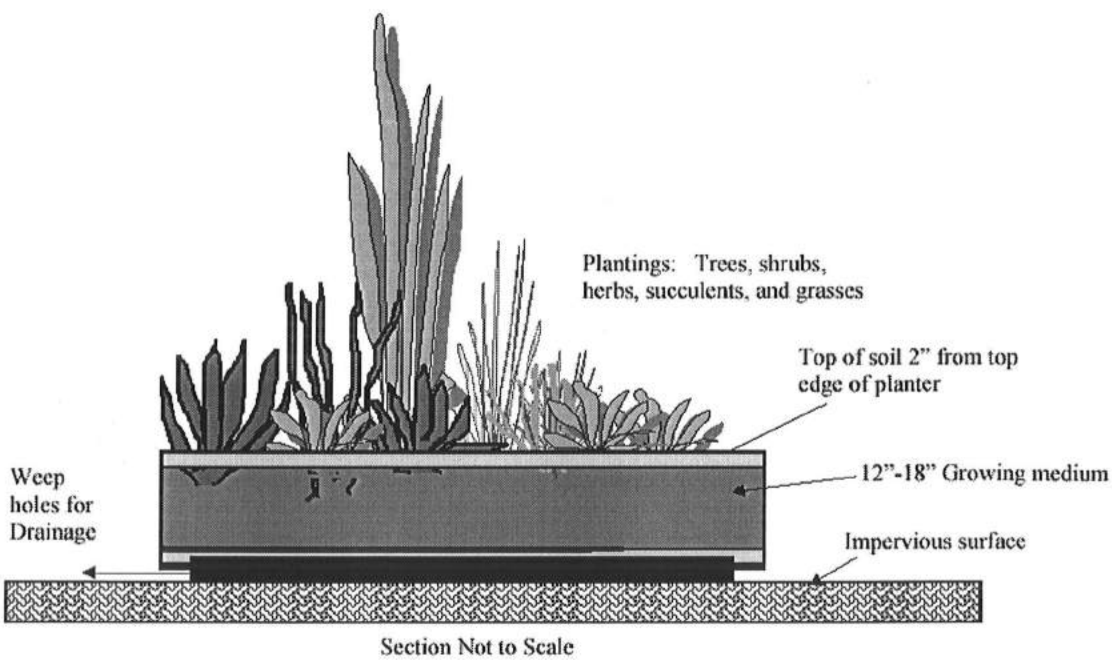


Figure 5.2.14-1 Schematic of Contained Planter Box
(Source: City of Portland, Oregon)

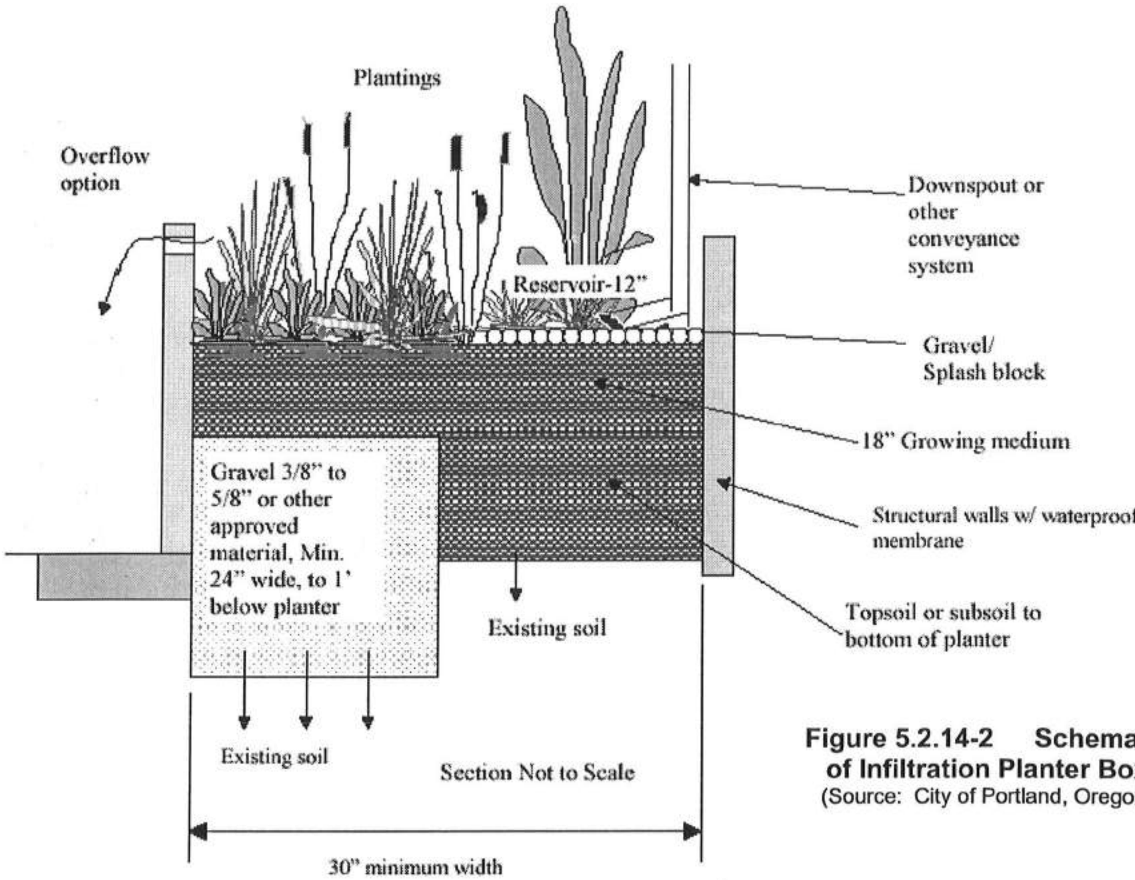


Figure 5.2.14-2 Schematic of Infiltration Planter Box
(Source: City of Portland, Oregon)

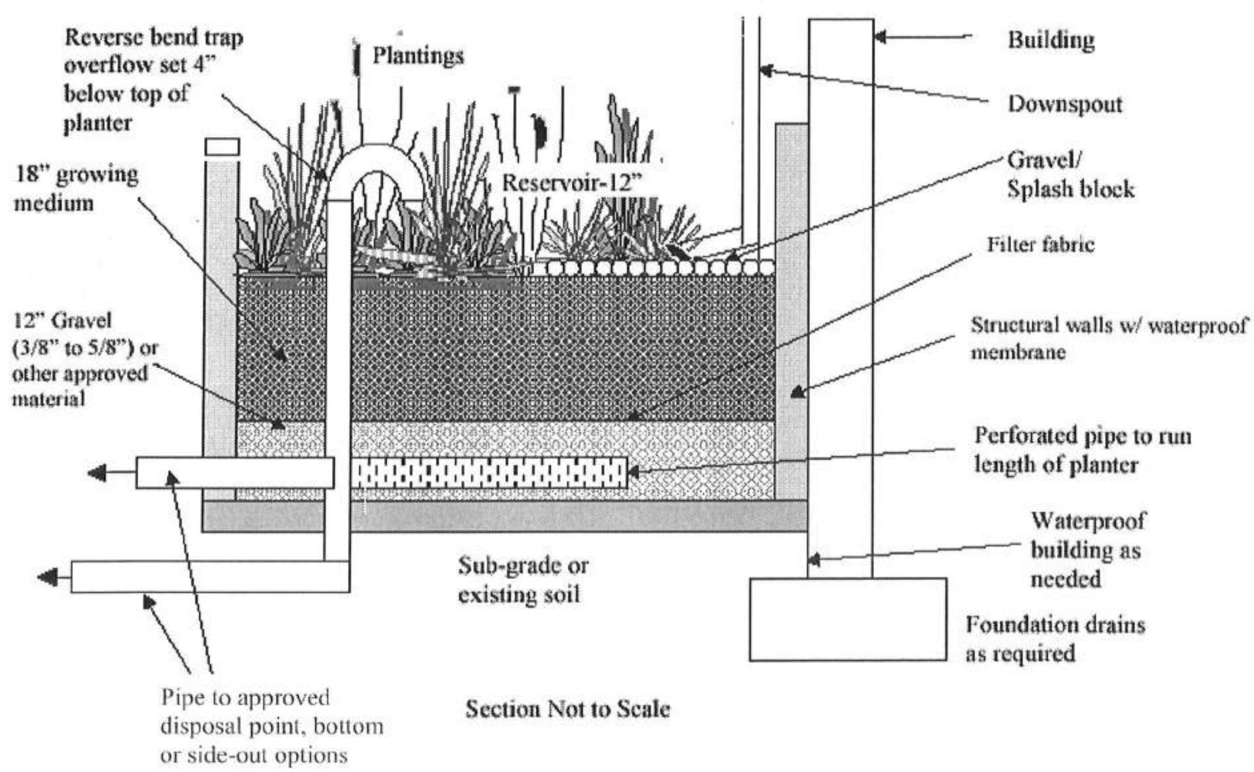
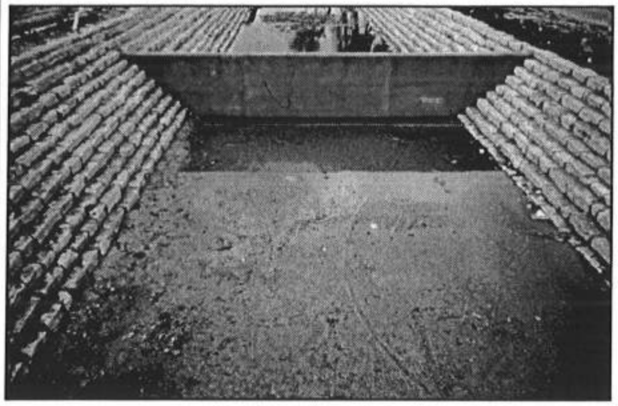


Figure 5.2.14-3 Schematic of Flow-Through Planter Box
(Source: City of Portland, Oregon)

5.2.15 Sand Filters

General Application
Structural Storm Water Control



Description: Multi-chamber structure designed to treat storm water runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and, typically, an underdrain collection system.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Typically requires 2 to 6 feet of head
- Maximum contributing drainage area of 10 acres for surface sand filter; 2 acres for perimeter sand filter
- Sand filter media with underdrain system

ADVANTAGES / BENEFITS:

- Applicable to small drainage areas
- Good for highly impervious areas
- Good retrofit capability

DISADVANTAGES / LIMITATIONS:

- High maintenance burden
- Not recommended for areas with high sediment content in storm water or clay/silt runoff areas
- Relatively costly
- Possible odor problems

MAINTENANCE REQUIREMENTS:

- Inspect for clogging – rake first inch of sand
- Remove sediment from forebay/chamber
- Replace sand filter media as needed

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
50/25%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
50%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
40%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
S	**Streambank Protection**
	On-Site Flood Control
	Downstream Flood Control

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *2-10 acres max.*

Soils: *Clay or silty soils may require pretreatment*

Other Considerations:

- Typically needs to be combined with other controls to provide water quantity control

L=Low **M**=Moderate **H**=High

5.2.15.1 General Description

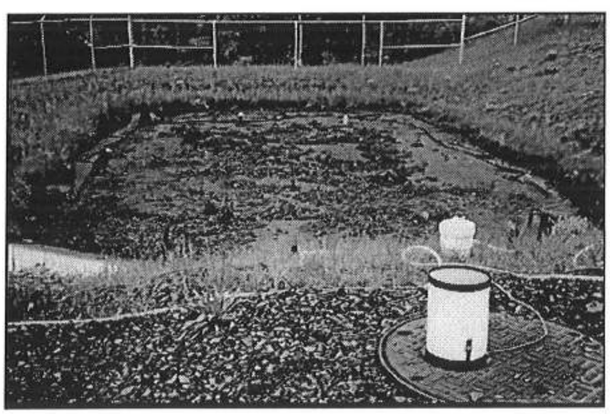
Sand filters (also referred to as *filtration basins*) are structural storm water controls that capture and temporarily store storm water runoff and pass it through a filter bed of sand. Most sand filter systems consist of two-chamber structures. The first chamber is a sediment forebay or sedimentation chamber, which removes floatables and heavy sediments. The second is the filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. The filtered runoff is typically collected and returned to the conveyance system, though it can also be partially or fully infiltrated into the surrounding soil in areas with porous soils.

Because they have few site constraints beside head requirements, sand filters can be used on development sites where the use of other structural controls may be precluded. However, sand filter systems can be relatively expensive to construct, install, and maintain.

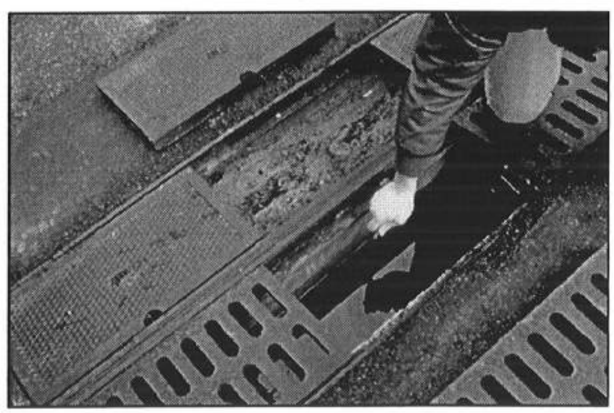
There are two primary sand filter system designs, the *surface sand filter* and the *perimeter sand filter*. Below are descriptions of these filter systems:

- **Surface Sand Filter** – The surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a filter bed chamber. This system can treat drainage areas up to 10 acres in size and is typically located off-line. Surface sand filters can be designed as an excavation with earthen embankments or as a concrete or block structure.
- **Perimeter Sand Filter** – The perimeter sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. The system consists of a sedimentation chamber and a sand bed filter. Runoff flows into the structure through a series of inlet grates located along the top of the control.

A third design variant, the *underground sand filter*, is intended primarily for extremely space limited and high density areas and is thus considered a limited application structural control. See subsection 5.2.16 for more details.



Surface Sand Filter



Perimeter Sand Filter

Figure 5.2.15-1 Sand Filter Examples

5.2.15.2 Storm Water Management Suitability

Sand filter systems are designed primarily as off-line systems for storm water quality (i.e., the removal of storm water pollutants) and will typically need to be used in conjunction with another structural control to provide downstream streambank protection, on-site flood control, and downstream flood control, if required. However, under certain circumstances, filters can provide limited runoff quantity control, particularly for smaller storm events.

Water Quality

In sand filter systems, storm water pollutants are removed through a combination of gravitational settling, filtration, and adsorption. The filtration process effectively removes suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants. Surface sand filters with a grass cover have additional opportunities for bacterial decomposition as well as vegetation uptake of pollutants, particularly nutrients. Section 5.2.15.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Streambank Protection

For smaller sites, a sand filter may be designed to capture the entire streambank protection volume SP_v in either an off- or on-line configuration. Given that a sand filter system is typically designed to completely drain over 40 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites or where only the WQ_v is diverted to the sand filter facility, another structural control must be used to provide SP_v extended detention.

On-Site Flood Control

Another structural control must be used in conjunction with a sand filter system to reduce the post-development peak flow to pre-development levels (detention) if needed.

Downstream Flood Control

Sand filter facilities must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the filter bed and facility.

The volume of runoff removed and treated by the sand filter may be taken in the on-site flood control and downstream flood control calculations (see Section 5.1).

5.2.15.3 Pollutant Removal Capabilities

Both the surface and perimeter sand filters are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed sand filters can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 50%**
- **Total Nitrogen – 25%**
- **Fecal Coliform – 40%**
- **Heavy Metals – 50%**

For additional information and data on pollutant removal capabilities for sand filters, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Storm Water Best Management Practices (BMP) Database at www.bmpdatabase.org

5.2.15.4 Application and Site Feasibility Criteria

Sand filter systems are well suited for highly impervious areas where land available for structural controls is limited. Sand filters should primarily be considered for new construction or retrofit opportunities for commercial, industrial, and institutional areas where the sediment load is relatively low, such as: parking lots, driveways, loading docks, gas stations, garages, airport runways/taxiways, and storage yards. Sand filters may also be feasible and appropriate in some multi-family or higher density residential developments.

To avoid rapid clogging and failure of the filter media, the use of sand filters should be avoided in areas with less than 50% impervious cover, or high sediment yield sites with clay/silt soils.

The following basic criteria should be evaluated to ensure the suitability of a sand filter facility for meeting storm water management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – NO
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Storm Water Control – NO

Physical Feasibility - Physical Constraints at Project Site

- Drainage Area – 10 acres maximum for surface sand filter; 2 acres maximum for perimeter sand filter
- Space Required – Function of available head at site
- Site Slope – No more than 6% slope across filter location
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 5 feet for surface sand filters; 2 to 3 feet for perimeter sand filters
- Minimum Depth to Water Table – For a surface sand filter with infiltration (earthen structure), 2 feet are required between the bottom of the sand filter and the elevation of the seasonally high water table
- Soils – No restrictions; Group "A" soils generally required to allow infiltration (for surface sand filter earthen structure)
- Downstream Water Surface - Downstream flood conditions need to be verified to avoid surcharging and back washing of the filter material.

Other Constraints / Considerations

- Aquifer Protection – Do not allow infiltration of filtered hotspot runoff into groundwater

5.2.15.5 Planning and Design Criteria

*The following criteria are to be considered **minimum** standards for the design of a sand filter facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

A. LOCATION AND SITING

- Surface sand filters should have a contributing drainage area of 10 acres or less. The maximum drainage area for a perimeter sand filter is 2 acres.

Sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or high clay/silt sediment loads must not use a sand filter without adequate pretreatment due to potential clogging and failure of the filter bed. Any disturbed areas within the sand filter facility drainage area should be identified and stabilized. Filtration controls should only be constructed after the construction site is stabilized.

- Surface sand filters are generally used in an off-line configuration where the water quality volume (WQ_v) is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Storm water flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
- Perimeter sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.
- Sand filter systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

B. GENERAL DESIGN

Surface Sand Filter

- A surface sand filter facility consists of a two-chamber open-air structure, which is located at ground-level. The first chamber is the sediment forebay (a.k.a sedimentation chamber) while the second chamber houses the sand filter bed. Flow enters the sedimentation chamber where settling of larger sediment particles occurs. Runoff is then discharged from the sedimentation chamber through a perforated standpipe into the filtration chamber. After passing though the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. Figure 5.2.15-6 provides plan view and profile schematics of a surface sand filter.

Perimeter Sand Filter

- A perimeter sand filter facility is a vault structure located just below grade level. Runoff enters the device through inlet grates along the top of the structure into the sedimentation chamber. Runoff is discharged from the sedimentation chamber through a weir into the filtration chamber. After passing through the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. Figure 5.2.15-7 provides plan view and profile schematics of a perimeter sand filter.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

Surface Sand Filter

- The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQ_v prior to filtration. Figure 5.2.15-2 illustrates the distribution of the treatment volume ($0.75\ WQ_v$) among the various components of the surface sand filter, including:
  - V_s – volume within the sedimentation basin
  - V_f – volume within the voids in the filter bed
  - $V_{f\text{-}temp}$ – temporary volume stored above the filter bed
  - A_s – the surface area of the sedimentation basin
  - A_f – surface area of the filter media
  - h_s – height of water in the sedimentation basin
  - h_{temp} - depth of temporary volume
  - h_f – average height of water above the filter media ($1/2\ h_{temp}$)
  - d_f – depth of filter media
- The sedimentation chamber must be sized to at least 25% of the computed WQ_v and have a length-to-width ratio of at least 2:1. Inlet and outlet structures should be located at opposite ends of the chamber.

The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.

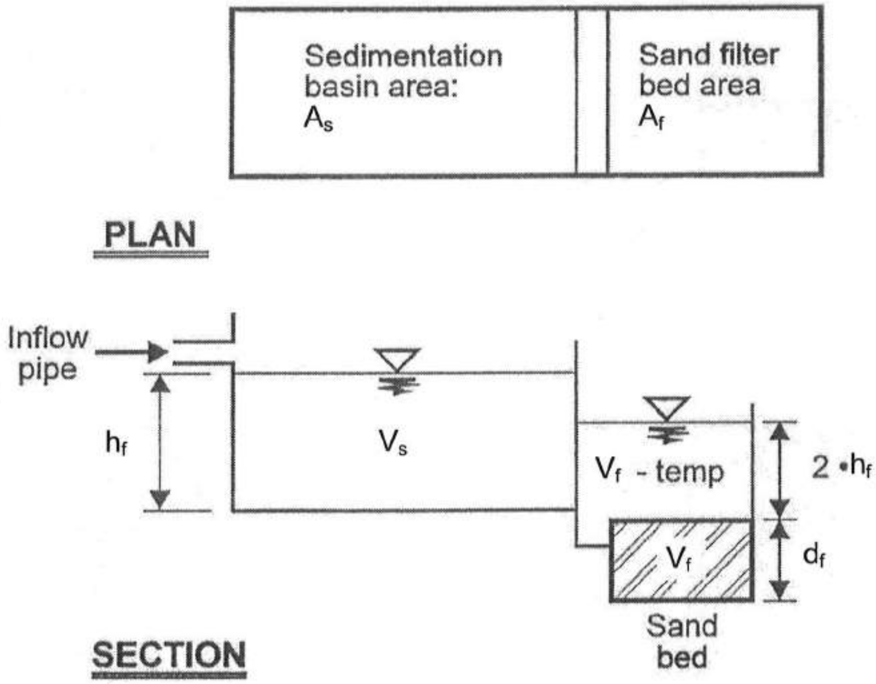


Figure 5.2.15-2 Surface Sand Filter Volumes
Source: Claytor and Schueler, 1996

- The filter media consists of an 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand or TxDOT Fine Aggregate Grade No. 1) on top of the underdrain system. Three inches of topsoil are placed over the sand bed. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. A proper fabric selection is critical. Choose a filter fabric with equivalent pore openings as to prevent clogging by sandy filler material. Figure 5.2.15-4 illustrates a typical media cross section.
- The filter bed is equipped with a 6-inch perforated PVC pipe (AASHTO M 252) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8-inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40% meeting the gradation listed below. Aggregate contaminated with soil shall not be used.

Gradation

Sieve Size	% Passing
2 ½"	100
2"	90 – 100
1 ½"	35 – 70
1"	0 – 15
½"	0 - 5

- The structure of the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media.

Perimeter Sand Filter

- The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQ_v prior to filtration. Figure 5.2.15-3 illustrates the distribution of the treatment volume (0.75 WQ_v) among the various components of the perimeter sand filter, including:
  - V_w – wet pool volume within the sedimentation basin
  - V_f – volume within the voids in the filter bed
  - V_{temp} – temporary volume stored above the filter bed
  - A_s – the surface area of the sedimentation basin
  - A_f – surface area of the filter media
  - h_f – average height of water above the filter media (1/2 h_{temp})
  - h_{temp} - depth of temporary volume
  - d_f – depth of filter media
- The sedimentation chamber must be sized to at least 50% of the computed WQ_v.
- The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.
- The filter media should consist of a 12- to 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand or TxDOT Fine Aggregate Grade No. 1) on top of the underdrain system. Figure 5.2.15-4 illustrates a typical media cross section.
- The perimeter sand filter is equipped with a 4 inch perforated PVC pipe (AASHTO M 252) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8 inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. A permeable filter fabric should be placed between the gravel layer and the filter media. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40% meeting the following gradation. Aggregate contaminated with soil shall not be used.

Gradation

Sieve Size	**% Passing**
2 ½"	100
2"	90 – 100
1 ½"	35 – 70
1"	0 – 15
½"	0 - 5

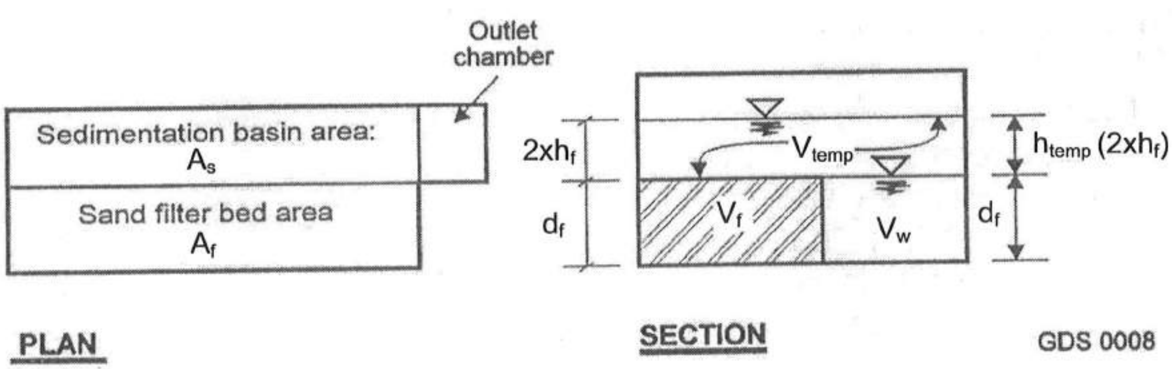


Figure 5.2.15-3 Perimeter Sand Filter Volumes
(Source: Claytor and Schueler, 1996)

D. PRETREATMENT / INLETS

- Pretreatment of runoff in a sand filter system is provided by the sedimentation chamber.
- Inlets to surface sand filters are to be provided with energy dissipaters. Exit velocities from the sedimentation chamber must be nonerosive.
- Figure 5.2.15-5 shows a typical inlet pipe from the sedimentation basin to the filter media basin for the surface sand filter.

E. OUTLET STRUCTURES

- Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways).

F. EMERGENCY SPILLWAY

- An emergency or bypass spillway must be included in the surface sand filter to safely pass flows that exceed the design storm flows. The spillway prevents filter water levels from overtopping the embankment and causing structural damage. The emergency spillway should be located so that downstream buildings and structures will not be impacted by spillway discharges.

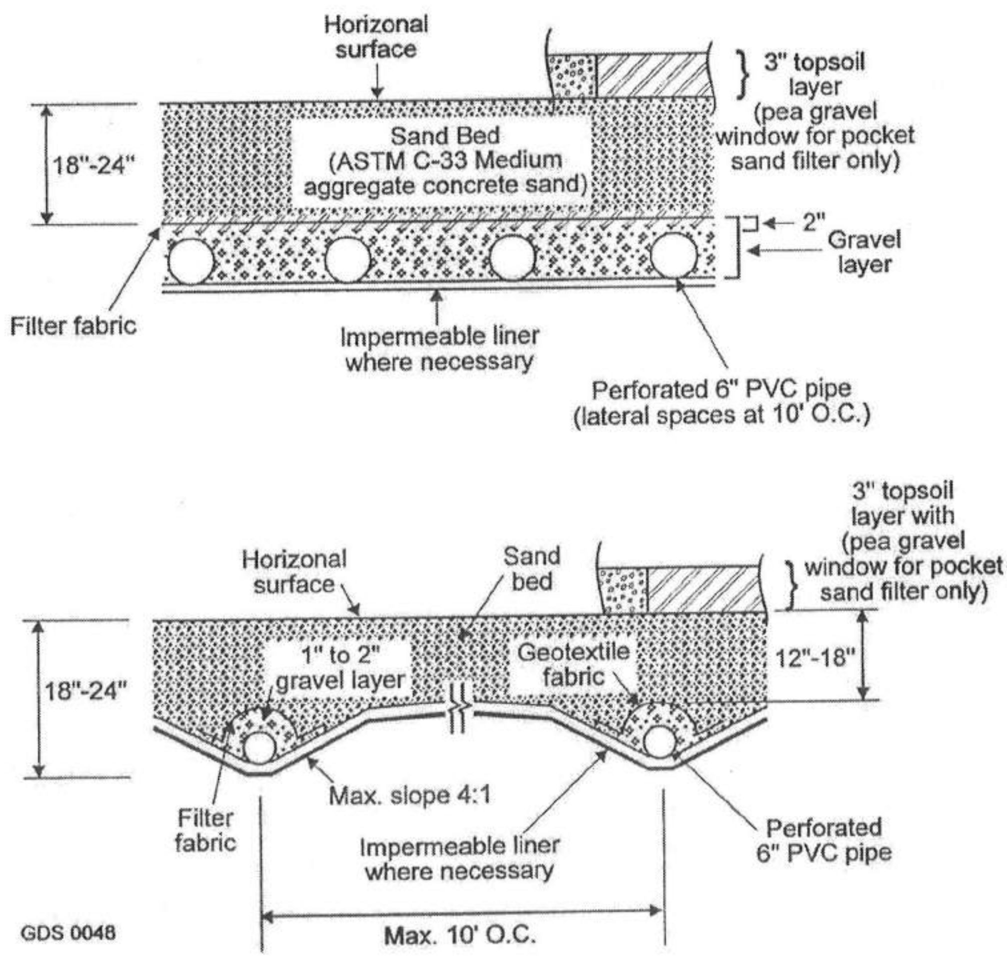


Figure 5.2.15-4 Typical Sand Filter Media Cross Sections
(Source: Claytor and Schueler, 1996)

G. MAINTENANCE ACCESS

- Adequate access must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. Access grates to the filter bed need to be included in a perimeter sand filter design. Facility designs must enable maintenance personnel to easily replace upper layers of the filter media.

H. SAFETY FEATURES

- Surface sand filter facilities can be fenced to prevent access. Inlet and access grates to perimeter sand filters may be locked.

I. LANDSCAPING

- Surface filters can be designed with a grass cover to aid in pollutant removal and prevent clogging. The grass should be capable of withstanding frequent periods of inundation and drought.

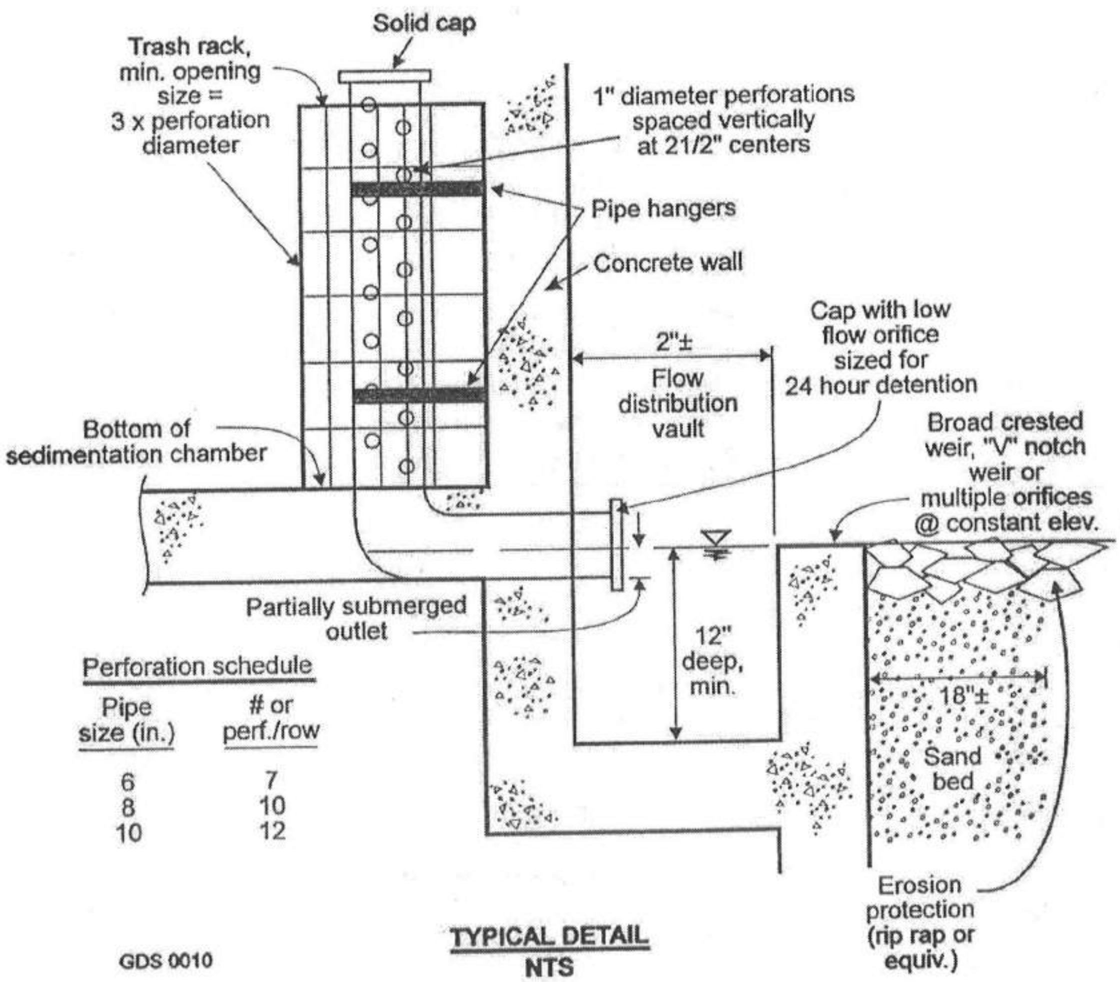


Figure 5.2.15-5 Surface Sand Filter Perforated Stand-Pipe
(Source: Claytor and Schueler, 1996)

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- Low Relief – Use of surface sand filter may be limited by low head
- High Relief – Filter bed surface must be level
- Karst – Use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure

Soils

- No restrictions

Special Downstream Watershed Considerations

- Stream Warming – Consideration should be given to the thermal influence on potential fish habitats downstream. If stream warming is significant, use shorter drain time (24 hours)
- Aquifer Protection – Use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure; no infiltration of filter runoff into groundwater

5.2.15.6 Design Procedures

Step 1. Compute runoff control volumes from the *integrated* Design Approach

Calculate the Water Quality Volume (WQ_v), Streambank Protection Volume (SP_v), On-Site Flood Control Volume (Q_p), and the Downstream Flood Control Volume (V_f).

Details on the *integrated* Design Approach are found in Section 1.2.

Step 2. Determine if the development site and conditions are appropriate for the use of a surface or perimeter sand filter.

Consider the Application and Site Feasibility Criteria in subsections 5.2.15.4 and 5.2.15.5-A (Location and Siting).

Step 3. Confirm local design criteria and applicability

Consider any special site-specific design conditions/criteria from subsection 5.2.15.5-J (Additional Site-Specific Design Criteria and Issues).

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 4. Compute WQ_v peak discharge (Q_{wq})

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures (see subsection 2.1.10).

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

Step 5. Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the sand filter facility.

Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 6. Size filtration basin chamber

The filter area is sized using the following equation (based on Darcy's Law):

$$A_f = (WQ_v)(d_f) / [(k)(h_f + d_f)(t_f)]$$

where:

A_f = surface area of filter bed (ft^2)
d_f = filter bed depth
(typically 18 inches, no more than 24 inches)
k = coefficient of permeability of filter media (ft/day)
(use 3.5 ft/day for sand)
h_f = average height of water above filter bed (ft)
(1/2 h_{max}, which varies based on site but h_{max} is typically $\leq$ 6 feet)
t_f = design filter bed drain time (days)
(1.67 days or 40 hours is recommended maximum)

Set preliminary dimensions of filtration basin chamber.

See subsection 5.2.15.5-C (Physical Specifications/Geometry) for filter media specifications.

Step 7. Size sedimentation chamber

Surface sand filter: The sedimentation chamber should be sized to at least 25% of the computed WQ_v and have a length-to-width ratio of 2:1. The Camp-Hazen equation is used to compute the required surface area:

$$A_s = -(Q_o/w) * \mathrm{Ln}(1-E)$$

Where:

A_s = sedimentation basin surface area (ft^2)
Q_o = rate of outflow = the WQ_v over a 24-hour period
w = particle settling velocity (ft/sec)
E = trap efficiency

Assuming:

- 90% sediment trap efficiency (0.9)
- particle settling velocity (ft/sec) = 0.0033 ft/sec for imperviousness < 75%
- particle settling velocity (ft/sec) = 0.0004 ft/sec for imperviousness $\geq$ 75%
- average of 24 hour holding period

Then:

A_s = (0.066) (WQ_v) ft^2 for I < 75%
A_s = (0.0081) (WQ_v) ft^2 for I $\geq$ 75%

Set preliminary dimensions of sedimentation chamber.

Perimeter sand filter: The sedimentation chamber should be sized to at least 50% of the computed WQ_v. Use same approach as for surface sand filter.

Step 8. Compute V_{min}

$$V_{min} = 0.75 * WQ_v$$

Step 9. Compute storage volumes within entire facility and sedimentation chamber orifice size

Surface sand filter:

$$\mathbf{V_{min} = 0.75\ WQ_v = V_s + V_f + V_{f\text{-}temp}}$$

(1) Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$
Where: n = porosity = 0.4 for most applications

(2) Compute $V_{f\text{-}temp}$ = temporary storage volume above the filter bed = $2 * h_f * A_f$

(3) Compute V_s = volume within sediment chamber = $V_{min} - V_f - V_{f\text{-}temp}$

(4) Compute h_s = height in sedimentation chamber = V_s/A_s

(5) Ensure h_s and h_f fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.

(6) Size orifice from sediment chamber to filter chamber to release V_s within 24-hours at average release rate with 0.5 h_s as average head.

(7) Design outlet structure with perforations allowing for a safety factor of 10 (see example)

(8) Size distribution chamber to spread flow over filtration media – level spreader weir or orifices.

Perimeter sand filter:

(1) Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$
Where: n = porosity = 0.4 for most applications

(2) Compute V_w = wet pool storage volume $A_s * 2$ feet minimum

(3) Compute V_{temp} = temporary storage volume = $V_{min} - (V_f + V_w)$

(4) Compute h_{temp} = temporary storage height = $V_{temp} / (A_f + A_s)$

(5) Ensure $h_{temp} \geq 2 * h_f$, otherwise decrease h_f and re-compute. Ensure dimensions fit available head and area – change as necessary in design iterations until all site dimensions fit.

(6) Size distribution slots from sediment chamber to filter chamber.

Step 10. Design inlets, pretreatment facilities, underdrain system, and outlet structures

See subsection 5.2.15-5-D through H for more details.

Step 11. Compute overflow weir sizes

Surface sand filter:

1. Size overflow weir at elevation h_s in sedimentation chamber (above perforated stand pipe) to handle surcharge of flow through filter system from storms producing more than 1.5 inches (see example in Appendix D).

2. Plan inlet protection for overflow from sedimentation chamber and size overflow weir at elevation h_f in filtration chamber (above perforated stand pipe) to handle surcharge of flow through filter system from storms producing more than 1.5 inches (see example).

Perimeter sand filter: Size overflow weir at end of sedimentation chamber to handle excess inflow, set at WQ_v elevation.

See Appendix D-3 for a Sand Filter Design Example

5.2.15.7 Inspection and Maintenance Requirements

Table 5.2.15-1 Typical Maintenance Activities for Sand Filters
(Source: WMI, 1997; Pitt, 1997)

Activity	Schedule
• Ensure that contributing area, facility, inlets, and outlets are clear of debris. • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Remove trash and debris. • Check to ensure that the filter surface is not clogging (also check after moderate and major storms). • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • If permanent water level is present (perimeter sand filter), ensure that the chamber does not leak and normal pool level is retained.	Monthly
• Check to see that the filter bed is clean of sediment, and the sediment chamber is not more than 50% full or 6 inches, whichever is less, of sediment. Remove sediment as necessary. • Stabilize disturbed area contributing to the heavy sediment load. • Make sure that there is no evidence of deterioration, spalling, or cracking of concrete. • Inspect grates (perimeter sand filter). • Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damaged structural parts. • Stabilize any eroded areas. • Ensure that flow is not bypassing the facility. • Ensure that no noticeable odors are detected outside the facility.	Annually
• If filter bed is clogged or partially clogged, manual manipulation of the surface layer of sand may be required. Remove the top few inches of sand, roto-till or otherwise cultivate the surface, and replace media with sand meeting the design specifications. • Replace any filter fabric that has become clogged.	As needed

Additional Maintenance Considerations and Requirements

- A record should be kept of the dewatering time for a sand filter to determine if maintenance is necessary.
- When the filtering capacity of the sand filter facility diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), then the top layers of the filter media (topsoil and 2 to 3 inches of sand) will need to be removed and replaced. This will typically need to be done every 3 to 5 years for low sediment applications, more often for areas of high sediment yield or high oil and grease.
- Removed sediment and media may usually be disposed of in a landfill.

Regular inspection and maintenance is critical to the effective operation of sand filter facilities as designed. Maintenance responsibility for a sand filter system should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

5.2.15.8 Example Schematics

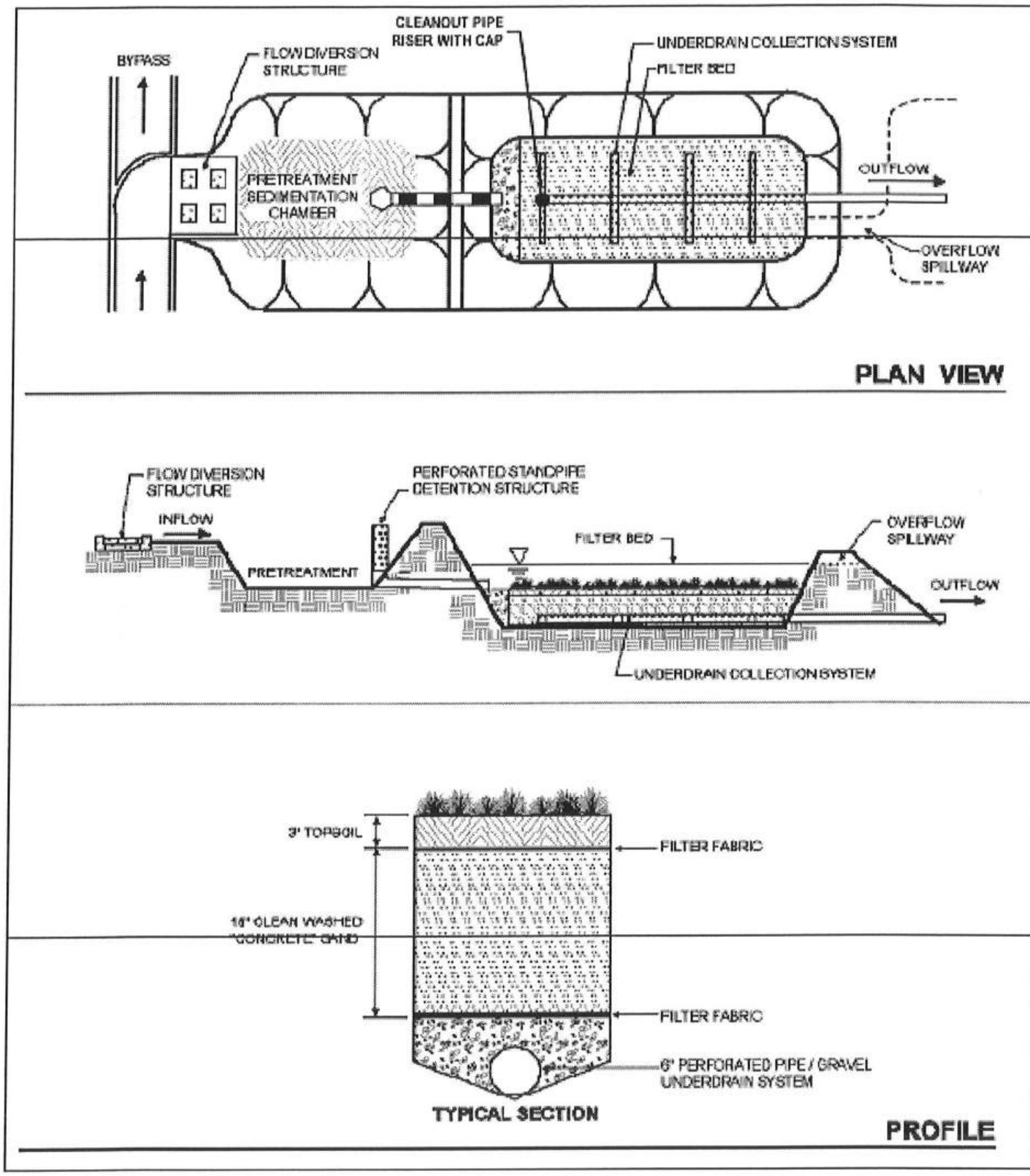


Figure 5.2.15-6 Schematic of Surface Sand Filter
(Source: Center for Watershed Protection)

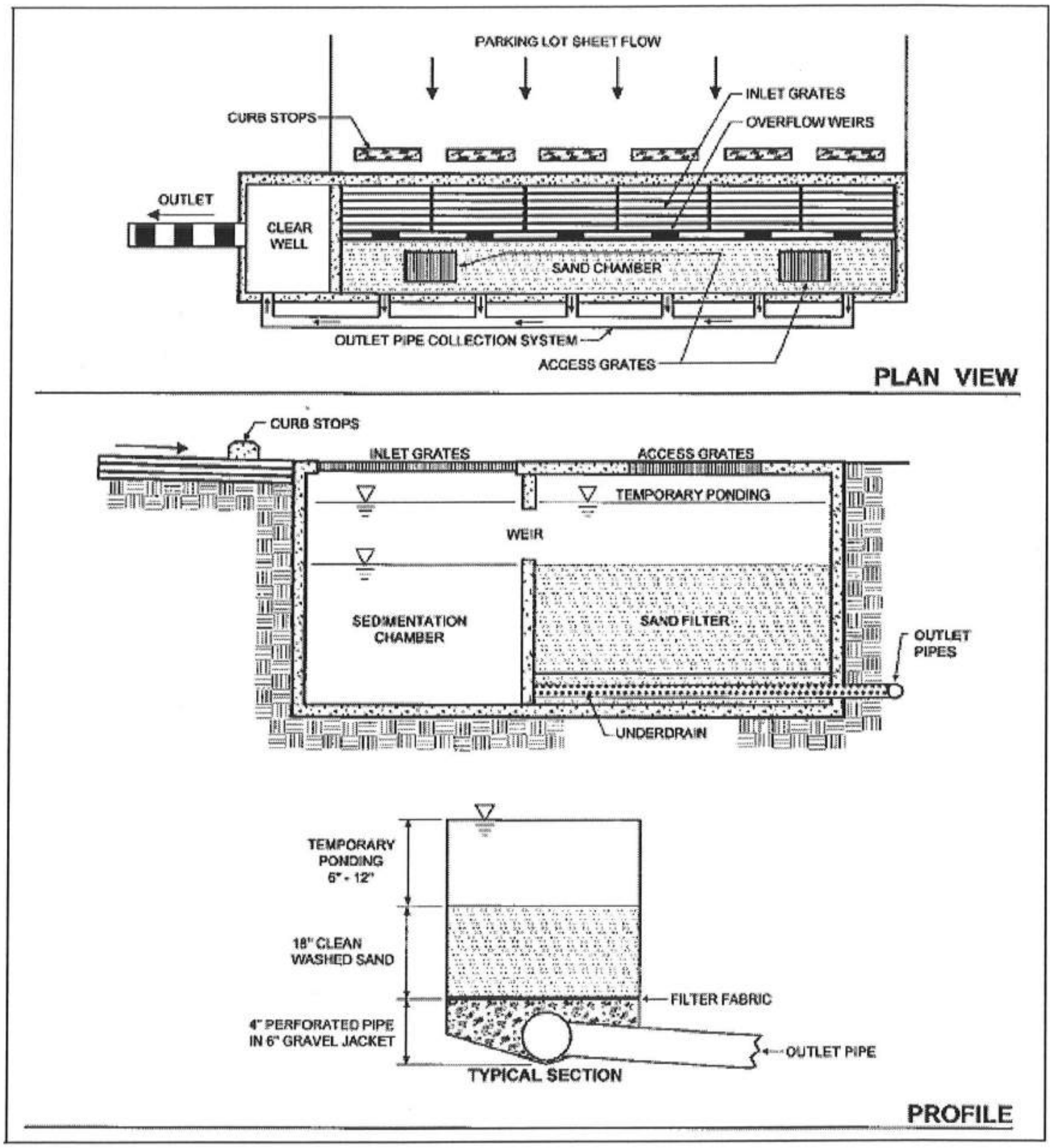


Figure 5.2.15-7 Schematic of Perimeter Sand Filter
(Source: Center for Watershed Protection)

5.2.15.9 Design Forms

Design Procedure Form: Sand Filters

PRELIMINARY HYDROLOGIC

1a. Compute WQ_v volume requirements	
Copute Runoff Coefficient, R_v	R_v = ________
Compute WQ_v	WQ_v = ________ acre-ft
1b. Compute SP_v	SP_v = ________ acre-ft
Copute average release rate	release rate = ________ cfs
Compute Q_p (100-year detention volume required)	Q_p = ________ acre-ft
Compute (as necessary) Q_f	Q_f = ________ cfs
SAND FILTER DESIGN	
2. Is the use of a sand fiilter appropriate?	Low Point in development area = ________
	Low Point at stream invert = ________
	Total available head = ________
	Average depth, h_f = ________
	See subsections 5.2.15.4 and 5.2.15.5-A
3. Confirm localdesign criteria and applicability.	***See subsection 5.2.15.5-J***
4. Compute WQ_v peak discharge (Q_{vq})	
Compute Curve Number	CN = ________
Compute Time of Concentration t_c	t_c = ________ hour
Compute Q_{wq}	Q_{wq} = ________ cfs
5. Size flow diversion structure	
Low flow orifice - Orifice equation	A = ________ ft^2
	diameter = ________ in
Overflow weir - Weir equation	Length = ________ ft
6. Size filtration bed chamber	
Compute area from Darcy's Law	A_f = ________ ft^2
Using length to width (2:1) ratio	L = ________ ft
	W = ________ ft
7. Size seidmentation chamber	
Compute area from Camp-Hazen equation	A_f = ________ ft^2
Given W from step 5, compute Length	L = ________ ft
8. Compute V_{min}	V_{min} = ________ ft^3
9. Compute volume within practice	
<u>Surface sand filter</u>	
Volume within filter bed	V_f = ________ ft^3
Temporary storage above filter bed	$V_{s\text{-}temp}$ = ________ ft^3
Sedimentation chamber (remaining volume)	V_s = ________ ft^3
Height in sedimentation chamber	h_s = ________ ft
Perforated stand pipe - Orifice equation	A = ________ ft^2
	diameter = ________ in
<u>Perimeter sand filter</u>	
Compute volume in filter bed	V_f = ________ ft^3
Compute wet pool storage	V_w = ________ ft^3
Compute temporary storage	V_{temp} = ________ ft^3
	h_{temp} = ________ ft
10. Compute overflow weir sizes	
Compute overflow - Orifice equation	Q = ________ cfs
Weir from sedimentation chamber - Weir equation	Length = ________ ft
Weir from filtration chamber - Weir equation	Length = ________ ft

Notes:

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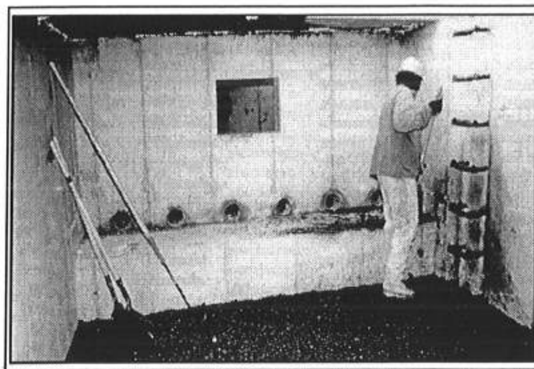
5.2.16 Underground Sand Filter

Limited Application
Structural Storm Water Control



Description: Design variant of the sand filter located in an underground vault.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for space-limited applications

ADVANTAGES / BENEFITS:

- High pollutant removal capability
- High removal rates for sediment, BOD, and fecal coliform bacteria
- Precast concrete shells available, which decrease construction costs

DISADVANTAGES / LIMITATIONS:

- High maintenance requirements

MAINTENANCE REQUIREMENTS:

- Filter may require more frequent maintenance than most of the other storm water controls

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
50/25%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
50%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
40%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Hotspot areas*

L=Low **M**=Moderate **H**=High

5.2.16.1 General Description

The underground sand filter is a design variant of the sand filter located in an underground vault designed for high-density land use or ultra-urban applications where there is not enough space for a surface sand filter or other structural storm water controls.

The underground sand filter is a three-chamber system. The initial chamber is a sedimentation (pretreatment) chamber that temporarily stores runoff and utilizes a wet pool to capture sediment. The sedimentation chamber is connected to the sand filter chamber by a submerged wall that protects the filter bed from oil and trash. The filter bed is 18 to 24 inches deep and may have a protective screen of gravel or permeable geotextile to limit clogging. The sand filter chamber also includes an underdrain system with inspection and clean out wells. Perforated drain pipes under the sand filter bed extend into a third chamber that collects filtered runoff. Flows beyond the filter capacity are diverted through an overflow weir.

Due to its location below the surface, underground sand filters have a high maintenance burden and should only be used where adequate inspection and maintenance can be ensured.

5.2.16.2 Pollutant Removal Capabilities

Underground sand filter pollutant removal rates are similar to those for surface and perimeter sand filters (see subsection 5.2.15, *Sand Filters*).

5.2.16.3 Design Criteria and Specifications

- Underground sand filters are typically used on highly impervious sites of 1 acre or less. The maximum drainage area that should be treated by an underground sand filter is 5 acres.
- Underground sand filters are typically constructed on-line, but can be constructed off-line. For off-line construction, the overflow between the second and third chambers is not included.
- The underground vault should be tested for water tightness prior to placement of filter layers.
- Adequate maintenance access must be provided to the sedimentation and filter bed chambers.
- Compute the minimum wet pool volume required in the sedimentation chamber as:

  $\mathbf{V_w = A_s * 3}$ **feet minimum**

- Consult the design criteria for the perimeter sand filter (see Section 5.2.15) for the rest of the underground filter sizing and design steps.

5.3.4.4 Inspection and Maintenance Requirements

Table 5.2.16-1 Typical Maintenance Activities for Underground Sand Filters
(Source: CWP, 1996)

Activity	Schedule
• Monitor water level in sand filter chamber.	Quarterly and following large storm events
• Sedimentation chamber should be cleaned out when the sediment depth reaches 12 inches.	As needed
• Remove accumulated oil and floatables in sedimentation chamber.	As needed, (typically every 6 months)

As a variant, organic material may be used instead of the sand media in the underground filter. Organic material has a higher cation exchange capacity and may remove more metals and other charged pollutants. Additional inspection and maintenance requirements for organic filters are similar to those for surface sand filter facilities (see subsection 5.2.15)

5.2.16.5 Example Schematic

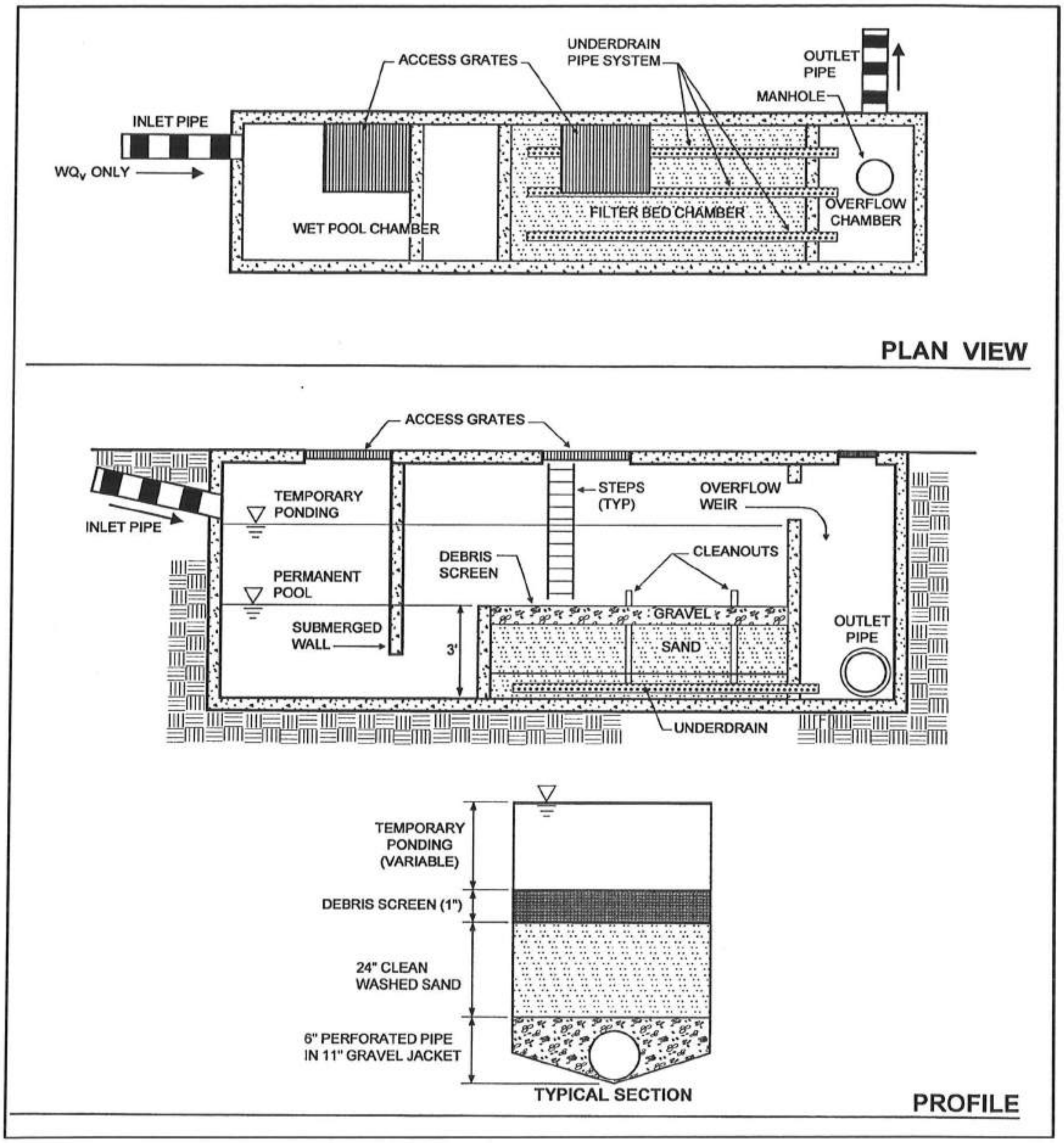


Figure 5.2.16-1 Schematic of Underground Sand Filter
(Source: Center for Watershed Protection)

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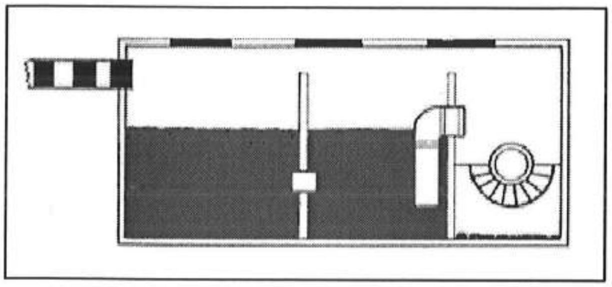
5.2.17 Gravity (Oil-Grit) Separator

Structural Storm Water Control



Description: Hydrodynamic separation device designed to remove settleable solids, oil and grease, debris, and floatables from storm water runoff through gravitational settling and trapping of pollutants.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for hotspot, space-limited, or pretreatment applications
- Intended for the removal of settleable solids (grit and sediment) and floatable matter, including oil and grease
- Performance dependent on design and frequency of inspection and cleanout of unit

DISADVANTAGES / LIMITATIONS:

- Cannot alone achieve the 80% TSS removal target
- Limited performance data
- Dissolved pollutants are not effectively removed

MAINTENANCE REQUIREMENTS:

- Frequent maintenance required

POLLUTANT REMOVAL

40%	**Total Suspended Solids**
5/5%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
No data	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *1 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Hotspot areas*
- *Pretreatment*

L=Low **M**=Moderate **H**=High

5.2.17.1 General Description

Gravity separators (also known as oil-grit separators) are hydrodynamic separation devices that are designed to remove grit and heavy sediments, oil and grease, debris, and floatable matter from storm water runoff through gravitational settling and trapping. Gravity separator units contain a permanent pool of water and typically consist of an inlet chamber, separation/storage chamber, a bypass chamber, and an access port for maintenance purposes. Runoff enters the inlet chamber where heavy sediments and solids drop out. The flow moves into the main gravity separation chamber, where further settling of suspended solids takes place. Oil and grease are skimmed and stored in a waste oil storage compartment for future removal. After moving into the outlet chamber, the clarified runoff is then discharged.

The performance of these systems is based primarily on the relatively low solubility of petroleum products in water and the difference between the specific gravity of water and the specific gravities of petroleum compounds. Gravity separators are not designed to separate other products such as solvents, detergents, or dissolved pollutants. The typical gravity separator unit may be enhanced with a pretreatment swirl concentrator chamber, oil draw-off devices that continuously remove the accumulated light liquids, and flow control valves regulating the flow rate into the unit.

Gravity separators are best used in commercial, industrial, and transportation land uses and are intended primarily as a pretreatment measure for high-density or ultra urban sites, or for use in hydrocarbon hotspots, such as gas stations and areas with high vehicular traffic. However, gravity separators cannot be used for the removal of dissolved or emulsified oils and pollutants such as coolants, soluble lubricants, glycols, and alcohols.

Since re-suspension of accumulated sediments is possible during heavy storm events, gravity separator units are typically installed off-line. Gravity separators are available as prefabricated proprietary systems from a number of different commercial vendors.

5.2.17.2 Pollutant Removal Capabilities

Testing of gravity separators has shown that they can remove between 40 and 50% of the TSS loading when used in an off-line configuration (Curran, 1996 and Henry, 1999). Gravity separators also provide removal of debris, hydrocarbons, trash and other floatables. They provide only minimal removal of nutrients and organic matter.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- **Total Suspended Solids – 40%**
- **Total Phosphorus – 5%**
- **Total Nitrogen – 5%**
- **Fecal Coliform – insufficient data**
- **Heavy Metals – insufficient data**

Actual field testing data and pollutant removal rates from an independent source should be obtained before using a proprietary gravity separator system.

5.2.17.3 Design Criteria and Specifications

- The use of gravity (oil-grit) separators should be limited to the following applications:
  - Pretreatment for other structural storm water controls
  - High-density, ultra urban or other space-limited development sites
  - Hotspot areas where the control of grit, floatables, and/or oil and grease are required
- Gravity separators are typically used for areas less than 5 acres. It is recommended that the contributing area to any individual gravity separator be limited to 1 acre or less of impervious cover.
- Gravity separator systems can be installed in almost any soil or terrain. Since these devices are underground, appearance is not an issue and public safety risks are low.

- Gravity separators are rate-based devices. This contrasts with most other storm water structural controls, which are sized based on capturing and treating a specific volume.
- Gravity separator units are typically designed to bypass runoff flows in excess of the design flow rate. Some designs have built-in high flow bypass mechanisms. Other designs require a diversion structure or flow splitter ahead of the device in the drainage system. An adequate outfall must be provided.
- The separation chamber should provide for three separate storage volumes:
  - a A volume for separated oil storage at the top of the chamber
  - b A volume for settleable solids accumulation at the bottom of the chamber
  - c A volume required to give adequate flow-through detention time for separation of oil and sediment from the storm water flow
- The total wet storage of the gravity separator unit should be at least 400 cubic feet per contributing impervious acre.
- The minimum depth of the permanent pools should be 4 feet.
- Horizontal velocity through the separation chamber should be 1 to 3 ft/min or less. No velocities in the device should exceed the entrance velocity.
- A trash rack should be included in the design to capture floating debris, preferably near the inlet chamber to prevent debris from becoming oil impregnated.
- Ideally, a gravity separator design will provide an oil draw-off mechanism to a separate chamber or storage area.
- Adequate maintenance access to each chamber must be provided for inspection and cleanout of a gravity separator unit.
- Gravity separator units should be watertight to prevent possible groundwater contamination.
- The design criteria and specifications of a proprietary gravity separator unit should be obtained from the manufacturer.

5.2.17.4 Inspection and Maintenance Requirements

Table 5.2.17-1 Typical Maintenance Activities for Gravity Separators

Activity	Schedule
• Inspect the gravity separator unit for structural problems, accumulated pollutants, and mosquito larvae.	Regularly (quarterly)
• Clean out sediment, oil and grease, and floatables, using catch basin cleaning equipment (vacuum pumps). Manual removal of pollutants may be necessary.	As Needed

Additional Maintenance Considerations and Requirements

- Additional maintenance requirements for a proprietary system should be obtained from the manufacturer.
- Failure to provide adequate inspection and maintenance can result in the re-suspension of accumulated solids. Frequency of inspection and maintenance is dependent on land use, climatological conditions, and the design of gravity separator.
- Proper disposal of oil, solids, and floatables removed from the gravity separator must be ensured.
- If mosquito larvae are present in the unit, treat with larvacide. (See sub-section 5.2.18.4)

5.2.17.5 Example Schematic

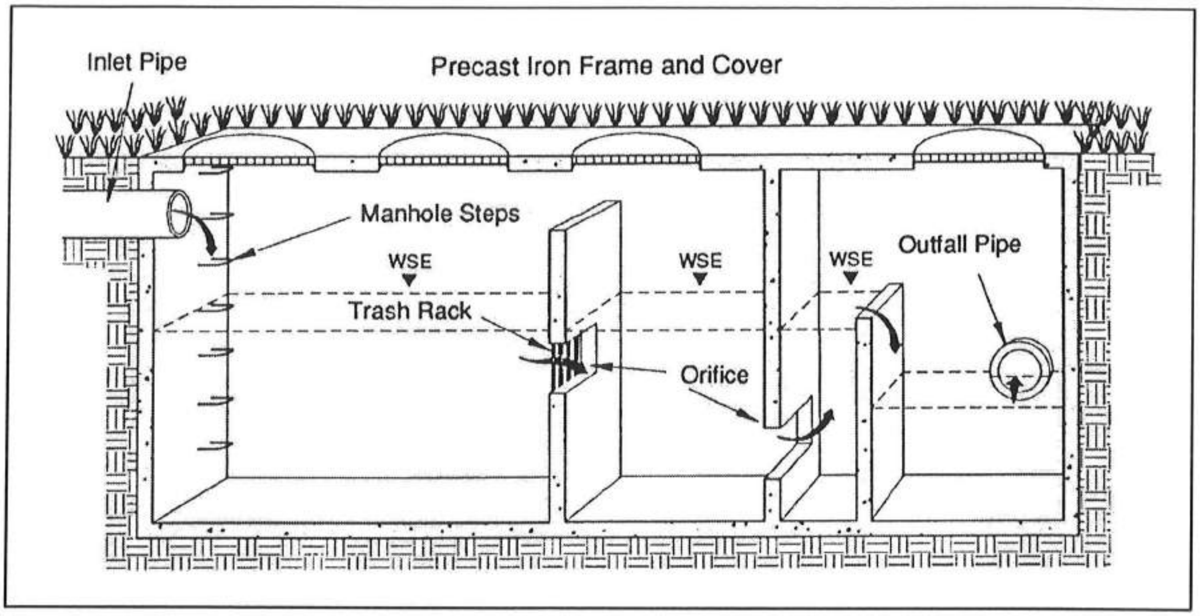
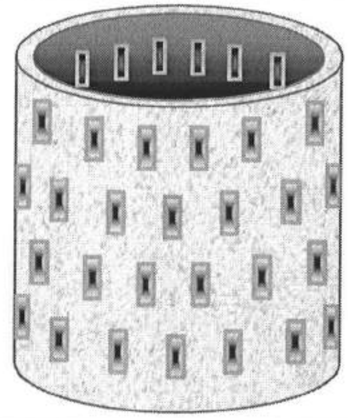


Figure 5.2.17-1 Schematic of an Example Gravity (Oil-Grit) Separator
(Source: NVRC, 1992[1])

5.2.18 Downspout Drywell

Structural Storm Water Control

Description: Drywells are essentially perforated manholes, but they can be manufactured in various sizes. Located underground, they allow storm water infiltration even in highly urbanized areas. They should be used in conjunction with some type of pretreatment devices where there are minimal risks of groundwater contamination.



KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for space-limited applications
- Like other infiltration devices, drywells should not be used for storm water containing high sediment loads to minimize clogging

ADVANTAGES / BENEFITS:

- Filtration provides pollutant removal capability in adjacent soil
- Decreases peak flow rates

DISADVANTAGES / LIMITATIONS:

- Subsurface structure considered an injection well and may require special permit

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
60/60%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
90%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
90%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
L	**Capital Cost**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions*

Soils: *Pervious soils required (0.5 in/hr or greater)*

L=Low **M**=Moderate **H**=High

5.2.18.1 General Description

Drywells are infiltration devices that have historically been used to dispose of excess runoff without extensive infrastructure. Its minimal land requirements allow it to be used in highly urbanized areas. Drywells used for storm water disposal are considered Class V injection devices by the EPA and fall under the Texas UIC program. Concerns about contaminating aquifers limit their application to "clean" runoff, such as roofdrains, and require pretreatment devices to remove sediments and other pollutants.

Drywells should not be used in areas near drinking water wells, with industrial land use, with high groundwater tables, a substrate of fractured rock, or slow-draining soils. Drywell design should be overseen by a licensed engineer.

5.2.18.2 Pollutant Removal Capabilities

Pollutant removal is similar to infiltration trenches (see Section 5.2.17), but care should be taken to avoid clogging with sediments.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 60%**
- **Total Nitrogen – 60%**
- **Fecal Coliform – 90%**
- **Heavy Metals – 90%**

5.2.18.3 Design Criteria and Specifications

- The drywell should be located at least 5 feet from the nearest property line and 10 feet away from an occupied building.
- Drywells shall be located at least 200 feet from the tops of slopes more than 10 feet high and steeper than 2h:1v.
- The drywell shall be excavated in native soil, uncompacted by heavy equipment.
- A qualified professional shall conduct infiltration testing. The surrounding soil should have a minimum infiltration rate of 0.5 inches per hour.
- The drywell shall be surrounded by a 12 inch thick layer of ¾" to 2 ½" round rock.
- There should be at least four feet between the bottom of the drywell and the seasonal high ground water table or bedrock.
- A pretreatment device should be installed upstream of the drywell to remove sediments and other pollutants.
- The drywell shall be sized in accordance with the simplified sizing criteria.
- The drywell should not be located next to trees, since roots may penetrate drywell and clog it.
- Access should be provided for drywell maintenance via a secured manhole or cleanout.

5.2.18.4 Inspection and Maintenance Requirements

The inspection and maintenance requirements for drywells are designed to maintain an adequate drainage rate through the drywell, while avoiding groundwater contamination.

Table 5.2.18-1 Typical Maintenance Activities for Drywells

Activity	Schedule
• Ensure that inflow is unimpeded. Clean out accumulated sediment/ debris and dispose of properly.	Quarterly and within 48 hours of major storms
• Inspect pretreatment device and clean if necessary. Cleaning shall be done without the used of detergents or solvents.	As needed, based on minimum annual inspection
• Inspect area surrounding the drywell for waterlogged soils at surface, indicating drywell failure. Clogged drywells must be replaced.	Inspect between 24 - 48 hours after major storms
• Pest control measures shall be taken if rodents or mosquitoes are found to be present. Holes in the ground around the drywell shall be filled and a low toxicity mosquito larvacide, such as Bacillus thuringiensis (Bti), Bacillus Sphearicus (Bsph) or Methoprene (insect growth regulator) applied by a licensed individual, if necessary.	As needed

5.2.18.5 Example Schematic

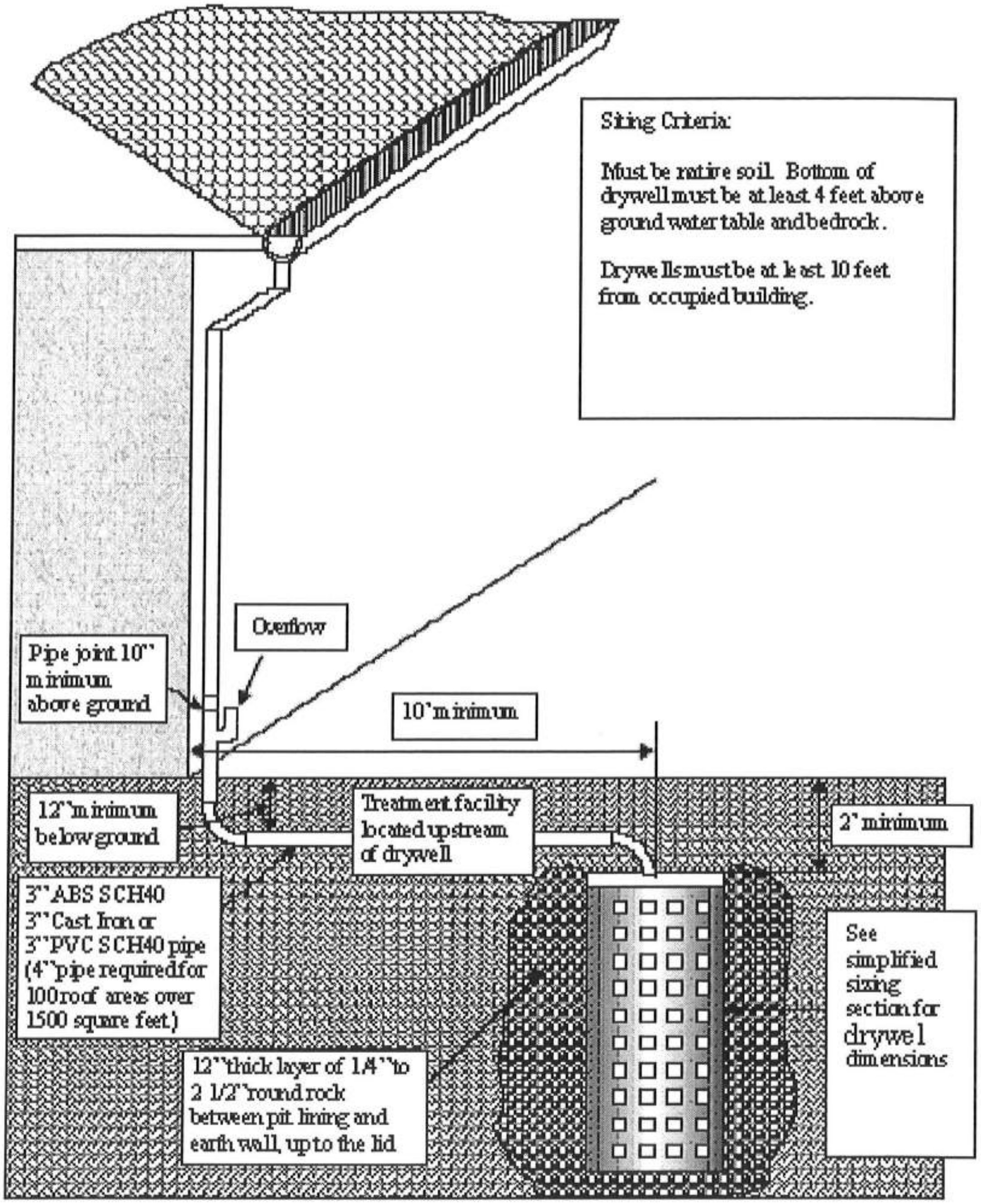
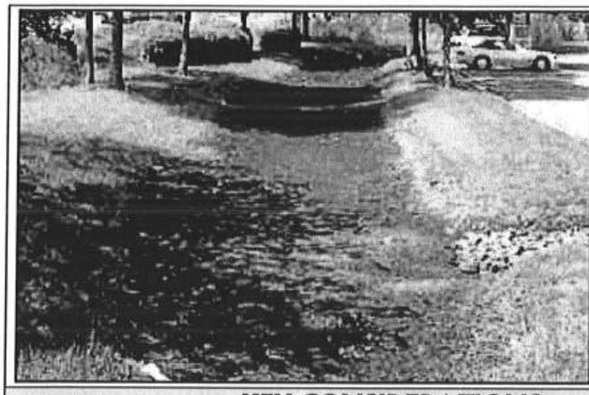


Figure 5.2.18-1 Schematic of Drywell System
(Source: City of Portland, Oregon)

5.2.19 Infiltration Trench

Structural Storm Water Control



Description: Excavated trench filled with stone aggregate used to capture and allow infiltration of storm water runoff into the surrounding soils from the bottom and sides of the trench.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Soil infiltration rate of 0.5 in/hr or greater required
- Excavated trench (3 to 8 foot depth) filled with stone media (1.5- to 2.5-inch diameter); pea gravel, and sand filter layers
- A sediment forebay and grass channel, or equivalent upstream pretreatment, must be provided
- Observation well to monitor percolation

ADVANTAGES / BENEFITS:

- Provides for groundwater recharge
- Good for small sites with porous soils

DISADVANTAGES / LIMITATIONS:

- Potential for groundwater contamination
- High clogging potential; should not be used on sites with fine-particled soils (clays or silts) in drainage area
- Significant setback requirements
- Restrictions in karst areas
- Geotechnical testing required, two borings per facility

MAINTENANCE REQUIREMENTS:

- Inspect for clogging
- Remove sediment from forebay
- Replace pea gravel layer as needed

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
S	**Streambank Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *Pervious soils required (0.5 in/hr or greater)*

Other Considerations:

- *Must not be placed under pavement or concrete*

L=Low M=Moderate H=High

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
60/60%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
90%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
90%	**Pathogens** - Coliform, Streptococci, E. Coli removal

5.2.19.1 General Description

Infiltration trenches are excavations typically filled with stone to create an underground reservoir for storm water runoff (see Figure 5.2.19-1). This runoff volume gradually filtrates through the bottom and sides of the trench into the subsoil over a 2-day period and eventually reaches the water table. By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Due to this fact, infiltration systems are limited to areas with highly porous soils where the water table and/or bedrock are located well below the bottom of the trench. In addition, infiltration trenches must be carefully sited to avoid the potential of groundwater contamination.

Infiltration trenches are not intended to trap sediment and must always be designed with a sediment forebay and grass channel or filter strip, or other appropriate pretreatment measures to prevent clogging and failure. Due to their high potential for failure, these facilities must only be considered for sites where upstream sediment control can be ensured.

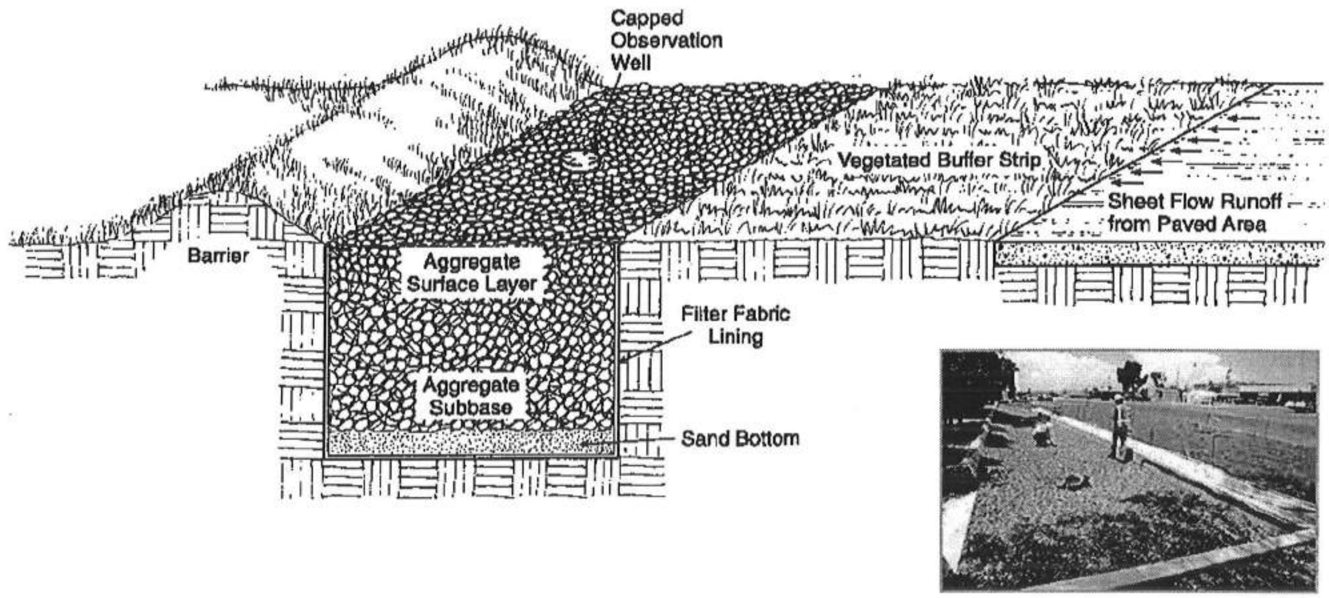


Figure 5.2.19-1 Infiltration Trench Example

5.2.19.2 Storm Water Management Suitability

Infiltration trenches are designed primarily for storm water quality, i.e. the removal of storm water pollutants. However, they can provide limited runoff quantity control, particularly for smaller storm events. For some smaller sites, trenches can be designed to capture and infiltrate the streambank protection volume (SP_v) in addition to WQ_v. An infiltration trench will need to be used in conjunction with another structural control to provide flood control, if required.

<u>Water Quality Protection</u>

Using the natural filtering properties of soil, infiltration trenches can remove a wide variety of pollutants from storm water through sorption, precipitation, filtering, and bacterial and chemical degradation. Sediment load and other suspended solids are removed from runoff by pretreatment measures in the facility that treats flows before they reach the trench surface.

Section 5.2.19.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Streambank Protection

For smaller sites, an infiltration trench may be designed to capture and infiltrate the entire streambank protection volume SP_v in either an off- or on-line configuration. For larger sites, or where only the WQ_v is diverted to the trench, another structural control must be used to provide SP_v extended detention.

Flood Control

Infiltration trench facilities must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the filter bed and facility.

The volume of runoff removed and treated by the infiltration trench may be taken in the on-site and/or downstream flood control calculations (see Section 5.1).

5.2.19.3 Pollutant Removal Capabilities

An infiltration trench is presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed infiltration trenches can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 60%**
- **Total Nitrogen – 60%**
- **Fecal Coliform – 90%**
- **Heavy Metals – 90%**

For additional information and data on pollutant removal capabilities for infiltration trenches, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Storm Water Best Management Practices (BMP) Database at www.bmpdatabase.org

5.2.19.4 Application and Site Feasibility Criteria

Infiltration trenches are generally suited for medium-to-high density residential, commercial, and institutional developments where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and the water table is low enough to prevent groundwater contamination. They are applicable primarily for impervious areas where there are not high levels of fine particulates (clay/silt soils) in the runoff and should only be considered for sites where the sediment load is relatively low.

Infiltration trenches can either be used to capture sheet flow from a drainage area or function as an off-line device. Due to the relatively narrow shape, infiltration trenches can be adapted to many different types of sites and can be utilized in retrofit situations. Unlike some other structural storm water controls, they can easily fit into the margin, perimeter, or other unused areas of developed sites.

To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Infiltration trenches should not be used for manufacturing and industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, infiltration should not be considered for areas with a high pesticide concentration. Infiltration trenches are also not suitable in areas with karst geology without adequate geotechnical testing by qualified individuals and in accordance with local requirements.

The following criteria should be evaluated to ensure the suitability of an infiltration trench for meeting storm water management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Storm Water Control – NO

Physical Feasibility - Physical Constraints at Project Site

- Drainage Area – 5 acres maximum
- Space Required – Will vary depending on the depth of the facility
- Site Slope – No more than 6% slope (for pre-construction facility footprint)
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 1 foot
- Minimum Depth to Water Table – 4 feet recommended between the bottom of the infiltration trench and the elevation of the seasonally high water table
- Soils – Infiltration rate greater than 0.5 inches per hour required (typically hydrologic group "A", some group "B" soils)

Other Constraints / Considerations

- Aquifer Protection – No hotspot runoff allowed; meet setback requirements in design criteria

5.2.19.5 Planning and Design Criteria

*The following criteria are to be considered **minimum** standards for the design of an infiltration trench facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

A. Location and Siting

- To be suitable for infiltration, underlying soils should have an infiltration rate (f_c) of 0.5 inches per hour or greater, as initially determined from NRCS soil textural classification and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Infiltration trenches cannot be used in fill soils.
- Infiltration trenches should have a contributing drainage area of 5 acres or less.
- Soils on the drainage area tributary to an infiltration trench should have a clay content of less than 20% and a silt/clay content of less than 40% to prevent clogging and failure.
- There should be at least 4 feet between the bottom of the infiltration trench and the elevation of the seasonally high water table.
- Clay lenses, bedrock or other restrictive layers below the bottom of the trench will reduce infiltration rates unless excavated.

- Minimum setback requirements for infiltration trench facilities (when not specified by local ordinance or criteria):
  - From a property line – 10 feet
  - From a building foundation – 25 feet
  - From a private well – 100 feet
  - From a public water supply well – 1,200 feet
  - From a septic system tank/leach field – 100 feet
  - From surface waters – 100 feet
  - From surface drinking water sources – 400 feet (100 feet for a tributary)
- When used in an off-line configuration, the water quality protection volume (WQ_v) is diverted to the infiltration trench through the use of a flow splitter. Storm water flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
- To reduce the potential for costly maintenance and/or system reconstruction, it is strongly recommended that the trench be located in an open or lawn area, with the top of the structure as close to the ground surface as possible. Infiltration trenches shall not be located beneath paved surfaces, such as parking lots.
- Infiltration trenches are designed for intermittent flow and must be allowed to drain and allow re-aeration of the surrounding soil between rainfall events. They must not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

B. GENERAL DESIGN

- A well-designed infiltration trench consists of:
  - Excavated shallow trench backfilled with sand, coarse stone, and pea gravel, and lined with a filter fabric
  - Appropriate pretreatment measures
  - One or more observation wells to show how quickly the trench dewaters or to determine if the device is clogged

Figure 5.2.19-2 provides a plan view and profile schematic for the design of an off-line infiltration trench facility. An example of an on-line infiltration trench is shown in Figure 5.2.19-1.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- The required trench storage volume is equal to the water quality protection volume (WQ_v). For smaller sites, an infiltration trench can be designed with a larger storage volume to include the streambank protection volume (SP_v).
- A trench must be designed to fully dewater the entire WQ_v within 24 to 48 hours after a rainfall event. The slowest infiltration rate obtained from tests performed at the site should be used in the design calculations.
- Trench depths should be between 3 and 8 feet, to provide for easier maintenance. The width of a trench must be less than 25 feet.
- Broader, shallow trenches reduce the risk of clogging by spreading the flow over a larger area for infiltration.
- The surface area required is calculated based on the trench depth, soil infiltration rate, aggregate void space, and fill time (assume a fill time of 2 hours for most designs).
- The bottom slope of a trench should be flat across its length and width to evenly distribute flows, encourage uniform infiltration through the bottom, and reduce the risk of clogging.

- The stone aggregate used in the trench should be washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40%. Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 should be used in calculations, unless aggregate specific data exist.
- A 6-inch layer of clean, washed sand is placed on the bottom of the trench to encourage drainage and prevent compaction of the native soil while the stone aggregate is added.
- The infiltration trench is lined on the sides and top by an appropriate geotextile filter fabric that prevents soil piping but has greater permeability than the parent soil. The top layer of filter fabric is located 2 to 6 inches from the top of the trench and serves to prevent sediment from passing into the stone aggregate. Since this top layer serves as a sediment barrier, it will need to be replaced more frequently and must be readily separated from the side sections.
- The top surface of the infiltration trench above the filter fabric is typically covered with pea gravel. The pea gravel layer improves sediment filtering and maximizes the pollutant removal in the top of the trench. In addition, it can easily be removed and replaced should the device begin to clog. Alternatively, the trench can be covered with permeable topsoil and planted with grass in a landscaped area.
- An observation well must be installed in every infiltration trench and should consist of a perforated PVC pipe, 4 to 6 inches in diameter, extending to the bottom of the trench (see Figure 5.2.19-3 for an observation well detail). The observation well will show the rate of dewatering after a storm, as well as provide a means of determining sediment levels at the bottom and when the filter fabric at the top is clogged and maintenance is needed. It should be installed along the centerline of the structure, flush with the ground elevation of the trench. A visible floating marker should be provided to indicate the water level. The top of the well should be capped and locked to discourage vandalism and tampering.
- The trench excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench so as not to jeopardize the stability of the trench sidewalls. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and should be scarified prior to placement of sand. The sides of the trench shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling. All infiltration trench facilities should be protected during site construction and should be constructed after upstream areas have been stabilized.

D. PRETREATMENT / INLETS

- Pretreatment facilities **must always** be used in conjunction with an infiltration trench to prevent clogging and failure.
- For a trench receiving sheet flow from an adjacent drainage area, the pretreatment system should consist of a vegetated filter strip with a minimum 25-foot length. A vegetated buffer strip around the entire trench is required if the facility is receiving runoff from both directions. If the infiltration rate for the underlying soils is greater than 2 inches per hour, 50% of the WQ_v should be pretreated by another method prior to reaching the infiltration trench.
- For an off-line configuration, pretreatment should consist of a sediment forebay, vault, plunge pool, or similar sedimentation chamber (with energy dissipaters) sized to 25% of the water quality protection volume (WQ_v). Exit velocities from the pretreatment chamber must be nonerosive for the 2-year design storm.

E. OUTLET STRUCTURES

- Outlet structures are not required for infiltration trenches.

F. EMERGENCY SPILLWAY

- Typically, for off-line designs, there is no need for an emergency spillway. However, a nonerosive overflow channel should be provided to pass safely flows that exceed the storage capacity of the trench to a stabilized downstream area or watercourse.

G. Maintenance Access

- Adequate access should be provided to an infiltration trench facility for inspection and maintenance.

H. Safety Features

- In general, infiltration trenches are not likely to pose a physical threat to the public and do not need to be fenced.

I. LANDSCAPING

- Vegetated filter strips and buffers should fit into and blend with surrounding area. Native grasses are preferable, if compatible. The trench may be covered with permeable topsoil and planted with grass in a landscaped area

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- Low Relief – No additional criteria
- High Relief – Maximum site slope of 6%
- Karst – Not suitable without adequate geotechnical testing

Special Downstream Watershed Considerations

No additional criteria

5.2.19.6 Design Procedures

Step 1 Compute runoff control volumes from the *integrated* Design Approach

Calculate the Water Quality Protection Volume (WQ_v), Streambank Protection Volume (SP_v), and the 100-Year Flood (Q_f).

Details on the *integrated* Design Approach are found in Section 1.2.

Step 2 Determine if the development site and conditions are appropriate for the use of an infiltration trench.

Consider the Application and Site Feasibility Criteria in subsections 5.2.19.4 and 5.2.19.5-A (Location and Siting).

Step 3 Confirm local design criteria and applicability

Consider any special site-specific design conditions/criteria from subsection 5.2.19.5-J (Additional Site-Specific Design Criteria and Issues).

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 4 Compute WQ_v peak discharge (Q_{wq})

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion (see subsection 2.1.7).

a Using WQ_v (or total volume to be infiltrated), compute CN
b Compute time of concentration using TR-55 method
c Determine appropriate unit peak discharge from time of concentration
d Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

Step 5 Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the infiltration trench.

Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 6 Size infiltration trench

The area of the trench can be determined from the following equation:

$$A = \frac{WQ_v}{(nd + kT/12)}$$

where:

A = Surface Area
WQ_v = Water Quality Protection Volume (or total volume to be infiltrated)
n = porosity
d = trench depth (feet)
k = percolation (inches/hour)
T = Fill Time (time for the practice to fill with water), in hours

A porosity value n = 0.32 should be used.

All infiltration systems should be designed to fully dewater the entire WQ_v within 24 to 48 hours after the rainfall event.

A fill time T=2 hours can be used for most designs

See subsection 5.2.19.5-C (Physical Specifications/Geometry) for more specifications.

Step 7 Determine pretreatment volume and design pretreatment measures

Size pretreatment facility to treat 25% of the water quality protection volume (WQ_v) for off-line configurations.

See subsection 5.2.19.5-D (Pretreatment / Inlets) for more details.

Step 8 Design spillway(s)

Adequate storm water outfalls should be provided for the overflow exceeding the capacity of the trench, ensuring nonerosive velocities on the down-slope.

See Appendix D-4 for an Infiltration Trench Design Example

5.2.19.7 Inspection and Maintenance Requirements

Table 5.2.19-1 Typical Maintenance Activities for Infiltration Trenches

Activity	Schedule
• Ensure that contributing area, facility, and inlets are clear of debris. • Ensure that the contributing area is stabilized. • Remove sediment and oil/grease from pretreatment devices, as well as overflow structures. • Mow grass filter strips as necessary. Remove grass clippings.	Monthly
• Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the trench.	Semi-annual Inspection
• Replace pea gravel/topsoil and top surface filter fabric (when clogged).	As needed
• Perform total rehabilitation of the trench to maintain design storage capacity. • Excavate trench walls to expose clean soil.	Upon Failure

(Source: EPA, 1999)

Additional Maintenance Considerations and Requirements

- A record should be kept of the dewatering time of an infiltration trench to determine if maintenance is necessary.
- Removed sediment and media may usually be disposed of in a landfill.

> Regular inspection and maintenance is critical to the effective operation of infiltration trench facilities as designed. Maintenance responsibility for an infiltration trench should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

5.2.19.8 Example Schematics

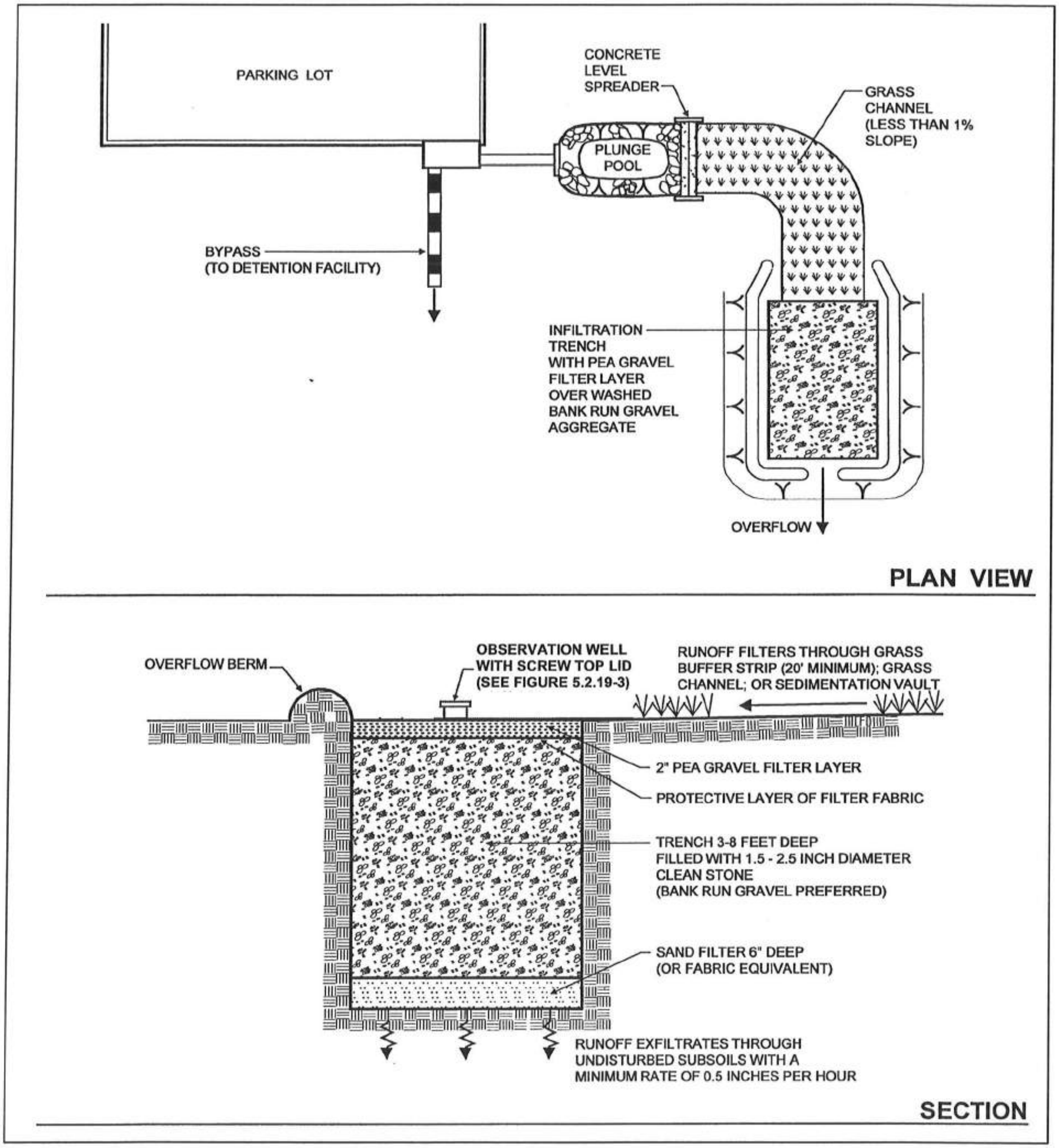


Figure 5.2.19-2 Schematic of Infiltration Trench
(Source: Center for Watershed Protection)

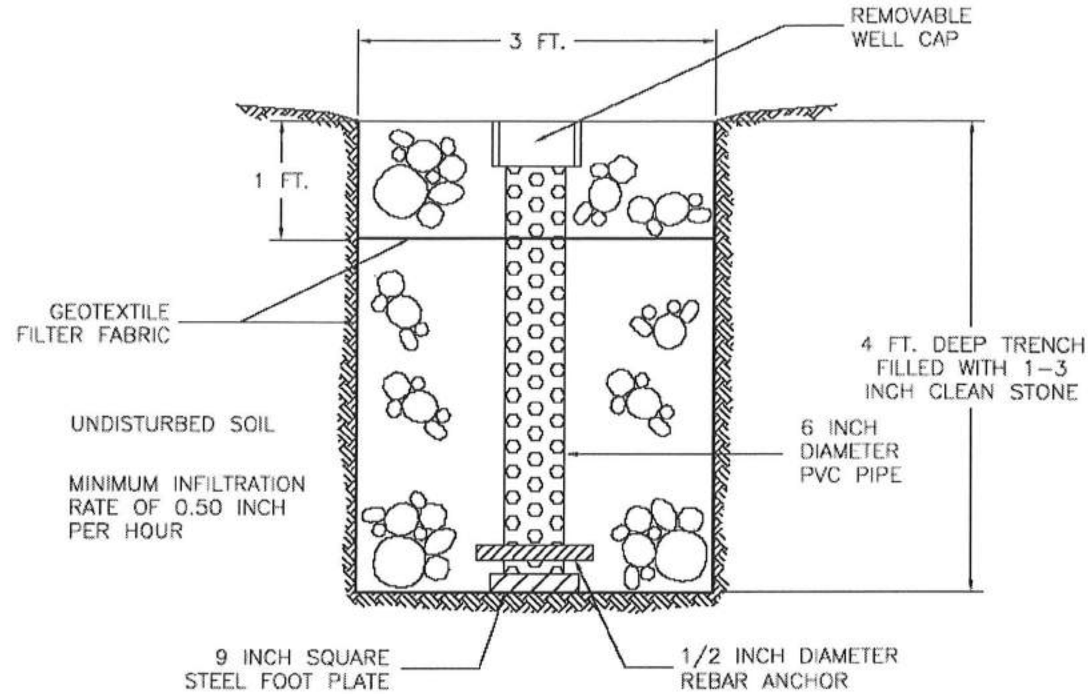


Figure 5.2.19-3 Observation Well Detail

- The aggregate material for the trench should consist of a clean aggregate with a maximum diameter of 3 inches and a minimum diameter of 1.5 inches.
- The aggregate should be graded such that there will be few aggregates smaller than the selected size. For design purposes, void space for these aggregates may be assumed to be in the range of 30 to 40%.
- A 6-inch layer of clean, washed sand is placed on the bottom of the trench to encourage drainage and prevent compaction of the native soil, while the stone aggregate is added.
- The aggregate should be completely surrounded with an engineering filter fabric. If the trench has an aggregate surface, filter fabric should surround all of the aggregate fill material except for the top 1 foot.
- The observation well should consist of perforated PVC pipe, 4 to 6 inches diameter, located in the center of the structure, and be constructed flush with the ground elevation of the trench.
- The PVC pipe should have a factory attached cast iron or high impact to prevent rotation when removing the screw top lid.
- The screw top lid should be cast iron and clearly labeled as an observation well.

5.2.19.9 Design Forms

Design Procedure Form: Infiltration Trench

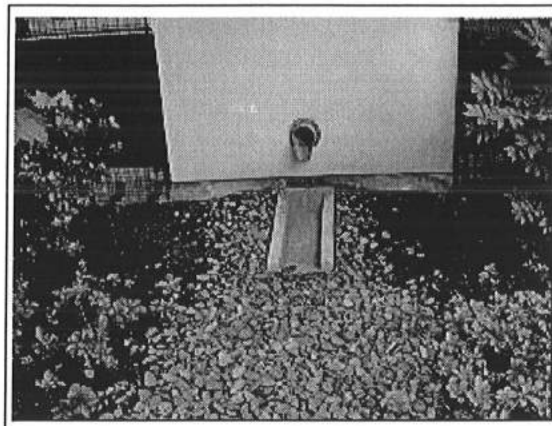
PRELIMINARY HYDROLOGIC CALCULATIONS	
1a. Compute WQ_v volume requirements	
Compute Runoff Coefficient, R_v	R_v = ________
Compute WQv	WQ_v = ________ acre-ft
1b. Compute **SP_v**	**SP_v** = ________ acre-ft
Compute average release rate	release rate = ________ cfs
Compute Q_p (100-year detention volume required)	Q_p = ________ acre-ft
Compute (as necessary) Q_f	Q_f = ________ cfs
INFILTRATION TRENCH DESIGN	
2. Is the use of a infiltration trench appropriate?	***See subsections 5.2.19.4 and 5.2.19.5 - A***
3. Confirm local design criteria and applicability.	***See subsection 5.2.19.5 - J***
4. Compute WQ_v peak discharge (Q_{wq})	
Compute Curve Number	CN = ________
Compute Time of Concentration t_c	t_c = ________ hour
Compute Q_{wq}	Q_{wq} = ________ cfs
5. Size infiltration trench	Area = ________ ft^2
Width must be less than 25 ft	Width = ________ ft
	Length = ________ ft
6. Size the flow diversion structures	
Low flow orifice from orifice equation	
$Q = CA(2gh)^{0.5}$	A = ________ ft^2
	diam. = ________ inch
Overflow weir from weir equation	
$Q = CLH^{3/2}$	Length = ________ ft
7. Pretreatment volume (for offine designs)	
$Vol_{pre} = 0.25(WQ_v)$	Vol_{pre} = ________ ft^3
8. Design spillway(s)	

Notes: ____

____

5.2.20 Soakage Trench

Structural Storm Water Control



Description: Soakage trenches are a variation of infiltration trenches. Soakage trenches drain through a perforated pipe buried in gravel. They are used in highly impervious areas where conditions do not allow surface infiltration and where pollutant concentrations in runoff are minimal (i.e. non-industrial rooftops. They may be used in conjunction with other storm water devices, such as draining downspouts or planter boxes.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for space-limited applications
- Like other infiltration devices, soakage trenches should not be used for storm water containing high sediment loads to minimize clogging

ADVANTAGES / BENEFITS:

- Filtration provides pollutant removal capability
- Reservoir decreases peak flow rates

DISADVANTAGES / LIMITATIONS:

- Subsurface pipe considered an injection well and may require special permit

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
60/60%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
90%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
90%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
S	**Streambank Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max*

Soils: *Pervious soils required (0.5 in/hr or greater)*

L=Low **M**=Moderate H=High

5.2.20.1 General Description

Soakage trenches represent a variation of infiltration trench. Regular infiltration trenches drain from the surface, but in highly urbanized areas there is not often a suitable area available for this type of setup. Soakage trenches utilize a perforated pipe embedded within the trench, thereby minimizing the surface area required for the device. They can even be located under pavement.

Soakage trenches used for storm water disposal are considered Class V injection devices by the EPA and fall under the Texas UIC program.

5.2.20.2 Pollutant Removal Capabilities

Pollutant removal is similar to infiltration trenches (see Section 5.2.12), but care should be taken to avoid clogging with sediments.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 60%**
- **Total Nitrogen – 60%**
- **Fecal Coliform – 90%**
- **Heavy Metals – 90%**

5.2.20.3 Design Criteria and Specifications

- The soakage trench should be located at least 5 feet from the nearest property line and 10 feet away from an occupied building (they may be closer to other structures, such as a parking garage or other structures on piers.
- The trench shall be excavated in native soil, uncompacted by heavy equipment.
- The trench should be at least 3 feet deep and 2.5 feet wide as shown in Figure 5.2.20-1. The exact dimensions will be dependent on the drainage characteristics of the surrounding soils.
- There should be at least four feet between the bottom of the trench and the seasonal high ground water table.
- A silt trap or similar device may be installed upstream of the perforated pipe if pretreatment is needed prior to discharge.
- The bottom of the trench should be filled with at least 18 inches of medium sand meeting TxDOT Fine Aggregate Grade No 1 and covered with a layer of filter fabric.
- A minimum of six inches of ¾" – 2 ½" round or crushed rock shall be placed on top of the fabric covered sand base.
- Piping should be 3" diameter prior to the perforated drainage pipe, 4" if serving greater than 1500 square feet of roof.
- The perforated pipe shall be an approved leach field pipe with holes oriented downward. It shall be covered with filter fabric, with at least 12" of backfill above the pipe.

5.2.20.4 Inspection and Maintenance Requirements

The inspection and maintenance requirements for soakage trenches are designed to maintain an adequate drainage rate through the trench, avoiding flooding.

Table 5.2.20-1 Typical Maintenance Activities for Soakage Trenches

Activity	Schedule
• Ensure that inflow is unimpeded.	Quarterly and within 48 hours of major storms
• Clean silt trap if it is more than 25% full of sediment	As needed, based on minimum annual inspection
• Inspect trench for waterlogged soils at surface.	Between 24 - 48 hours after major storms

5.2.20.5 Example Schematics

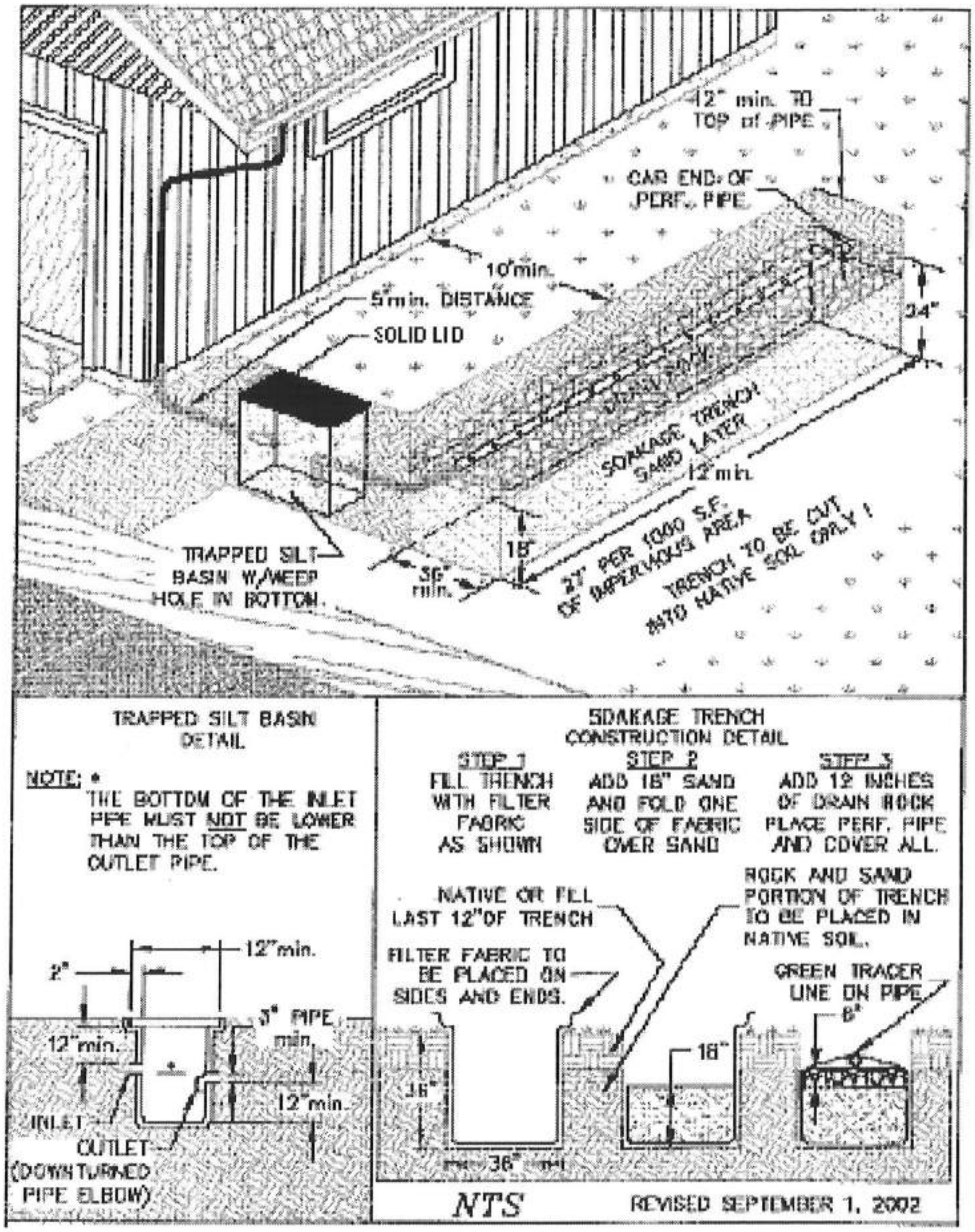


Figure 5.2.20-1 Schematic of a Soakage Trench
(Source: City of Portland, Oregon)

5.2.21 Storm Water Ponds

Storm Water Control

Description: Constructed storm water retention basin that has a permanent pool (or micropool). Runoff from each rain event is detained and treated in the pool primarily through settling and biological uptake mechanisms.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Minimum contributing drainage area of 25 acres; 10 acres for extended detention micropool pond
- A sediment forebay or equivalent upstream pretreatment must be provided
- Minimum length to width ratio for the pond is 1.5:1
- Maximum depth of the permanent pool should not exceed 8 feet
- Vegetated side slopes to the pond should not exceed 3:1 (h:v)

ADVANTAGES / BENEFITS:

- Moderate to high removal rate of urban pollutants
- High community acceptance
- Opportunity for wildlife habitat

DISADVANTAGES / LIMITATIONS:

- Potential for thermal impacts/downstream warming
- Dam height restrictions for high relief areas
- Pond drainage can be problematic for low relief terrain

MAINTENANCE REQUIREMENTS:

- Remove debris from inlet and outlet structures
- Maintain side slopes / remove invasive vegetation
- Monitor sediment accumulation and remove periodically
- Dam inspection and maintenance

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
50/30%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
50%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
70%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
P	**Streambank Protection**
P	**On-Site Flood Control**
P	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
L	**Capital Cost**
L-M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *10-25 acres min.*

Soils: *Hydrologic group 'A' and 'B' soils may require pond liner*

Other Considerations:

- *Outlet Clogging*
- *Safety Bench*
- *Landscaping*
- *Hotspot areas*

L=Low M=Moderate H=High

5.2.21.1 General Description

Storm water ponds (also referred to as *retention ponds, wet ponds, or wet extended detention ponds*) are constructed storm water retention basins that have a permanent (dead storage) pool of water throughout the year. They can be created by excavating an already existing natural depression or through the construction of embankments.

In a storm water pond, runoff from each rain event is detained and treated in the pool through gravitational settling and biological uptake until it is displaced by runoff from the next storm. The permanent pool also serves to protect deposited sediments from resuspension. Above the permanent pool level, additional temporary storage (live storage) is provided for runoff quantity control. The upper stages of a storm water pond are designed to provide extended detention of the 1-year storm for downstream streambank protection, as well as normal detention of larger storm events to meet Q_f requirements.

Storm water ponds are among the most cost-effective and widely used storm water practices. A well-designed and landscaped pond can be an aesthetic feature on a development site when planned and located properly.

There are several different variants of storm water pond design, the most common of which include the wet pond, the wet extended detention pond, and the micropool extended detention pond. In addition, multiple storm water ponds can be placed in series or parallel to increase performance or meet site design constraints. Below are descriptions of each design variant:

- **Wet Pond** – Wet ponds are storm water basins constructed with a permanent (dead storage) pool of water equal to the water quality volume. Storm water runoff displaces the water already present in the pool. Temporary storage (live storage) can be provided above the permanent pool elevation for larger flows.
- **Wet Extended Detention (ED) Pond** – A wet extended detention pond is a wet pond where the water quality volume is split evenly between the permanent pool and extended detention (ED) storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 24 hours. This design has similar pollutant removal to a traditional wet pond, but consumes less space.
- **Micropool Extended Detention (ED) Pond** – The micropool extended detention pond is a variation of the extended detention wet pond where only a small "micropool" is maintained at the outlet to the pond. The outlet structure is sized to detain the water quality volume for 24 hours. The micropool prevents resuspension of previously settled sediments and also prevents clogging of the low flow orifice.
- **Multiple Pond Systems** – Multiple pond systems consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The additional cells can create longer pollutant removal pathways and improved downstream protection.

Figure 5.2.21-1 shows a number of examples of storm water pond variants. Section 5.2.21.8 provides plan view and profile schematics for the design of a wet pond, wet extended detention pond, micropool extended detention pond, and multiple pond system.

Conventional dry detention basins do not provide a permanent pool and are **not recommended** for general application use to meet water quality criteria, as they fail to demonstrate an ability to meet the majority of the water quality goals. In addition, dry detention basins are prone to clogging and resuspension of previously settled solids and require a higher frequency of maintenance than wet ponds if used for untreated storm water flows. These facilities can be used in combination with appropriate water quality controls to provide streambank protection, and overbank and extreme flood storage. Please see a further discussion in subsection 5.2.9 (*Dry Detention Basins*).

Wet Pond

Wet ED Pond

Micropool ED Pond

Wet ED Pond

Figure 5.2.21-1 Storm Water Pond Examples

5.2.21.2 Storm Water Management Suitability

Storm water ponds are designed to control both storm water quantity and quality. Thus, a storm water pond can be used to address all of the *integrated storm water sizing criteria* for a given drainage area.

Water Quality

Ponds treat incoming storm water runoff by physical, biological, and chemical processes. The primary removal mechanism is gravitational settling of particulates, organic matter, metals, bacteria, and organics as storm water runoff resides in the pond. Another mechanism for pollutant removal is uptake by algae and wetland plants in the permanent pool – particularly of nutrients. Volatilization and chemical activity also work to break down and eliminate a number of other storm water contaminants such as hydrocarbons.

Section 5.2.21.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Streambank Protection

A portion of the storage volume above the permanent pool in a storm water pond can be used to provide control of the streambank protection volume (SP_v). This is accomplished by releasing the 1-year, 24-hour storm runoff volume over 24 hours (extended detention).

On-Site Flood Control

A storm water pond can also provide detention storage above the permanent pool to reduce the post-development peak flow to pre-development levels, if required.

Downstream Flood Control

In situations where it is required, storm water ponds can also be used to provide detention to control the 100-year storm peak flow downstream. Where this is not required, the pond structure is designed to safely pass extreme storm flows.

5.2.21.3 Pollutant Removal Capabilities

All of the storm water pond design variants are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed ponds can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 50%**
- **Total Nitrogen – 30%**
- **Fecal Coliform – 70% (if no resident waterfowl population present)**
- **Heavy Metals – 50%**

For additional information and data on pollutant removal capabilities for storm water ponds, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Storm Water Best Management Practices (BMP) Database at www.bmpdatabase.org

5.2.21.4 Application and Site Feasibility Criteria

Storm water ponds are generally applicable to most types of new development and redevelopment, and can be used in both residential and nonresidential areas. Ponds can also be used in retrofit situations. The following criteria should be evaluated to ensure the suitability of a storm water pond for meeting storm water management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra-Urban Areas – Land requirements may preclude use
- Regional Storm Water Control – YES
- Hotspot Runoff - YES

Physical Feasibility - Physical Constraints at Project Site

- Drainage Area – A minimum of 25 acres is needed for wet pond and extended detention wet pond to maintain a permanent pool, 10 acres minimum for extended detention micropool pond. A smaller drainage area may be acceptable with an adequate water balance and anti-clogging device.
- Space Required – Approximately 2 to 3% of the tributary drainage area

- Site Slope – There should not be more than 15% slope across the pond site.
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 6 to 8 feet
- Minimum Depth to Water Table – If used on a site with an underlying water supply aquifer or when treating a hotspot, a separation distance of 2 feet is required between the bottom of the pond and the elevation of the seasonally high water table.
- Soils – Underlying soils of hydrologic group "C" or "D" should be adequate to maintain a permanent pool. Most group "A" soils and some group "B" soils will require a pond liner. *Evaluation of soils should be based upon an actual subsurface analysis and permeability tests.*

Other Constraints / Considerations

- Local Aquatic Habitat – Consideration should be given to the thermal influence of storm water pond outflows on downstream local aquatic habitats.

5.2.21.5 Planning and Design Criteria

The following criteria are to be considered ***minimum*** *standards for the design of a storm water pond facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

A. LOCATION AND SITING

- Storm water ponds should have a minimum contributing drainage area of 25 acres or more for wet pond or extended detention wet pond to maintain a permanent pool. For an extended detention micropool pond, the minimum drainage area is 10 acres. A smaller drainage area can be considered when water availability can be confirmed (such as from a groundwater source or areas with a high water table). In these cases a water balance may be performed (see subsection 2.1.11 for details). Ensure that an appropriate anti-clogging device is provided for the pond outlet.
- A storm water pond should be sited such that the topography allows for maximum runoff storage at minimum excavation or construction costs. Pond siting should also take into account the location and use of other site features such as buffers and undisturbed natural areas and should attempt to aesthetically "fit" the facility into the landscape. Bedrock close to the surface may prevent excavation.
- Storm water ponds should not be located on steep (>15%) or unstable slopes.
- Storm water ponds cannot be located within a stream or any other navigable waters of the U.S., including wetlands, without obtaining a Section 404 permit under the Clean Water Act, and any other applicable State permit.
- Minimum setback requirements for storm water pond facilities measured from the easement line that defines the pond site (when not specified by local ordinance or criteria):
  - From a property line – 10 feet
  - From a private well – 100 feet; if well is downgradient from a hotspot land use then the minimum setback is 250 feet
  - From a septic system tank/leach field/spray area – 50 feet
- All utilities should be located outside of the pond/basin site.

B. GENERAL DESIGN

- A well-designed storm water pond consists of:
  1. Permanent pool of water,
  2. Overlying zone in which runoff control volumes are stored, and
  3. Shallow littoral zone (aquatic bench) along the edge of the permanent pool that acts as a biological filter.

- In addition, all storm water pond designs need to include a sediment forebay at all major inflows to the basin to allow heavier sediments to drop out of suspension before the runoff enters the permanent pool. (A sediment forebay schematic can be found in Appendix C)
- Additional pond design features include an emergency spillway, maintenance access, safety bench, pond buffer, and appropriate native landscaping.

Figures 5.2.21-4 thru 5.2.21-7 in subsection 5.2.21.8 provide plan view and profile schematics for the design of a wet pond, extended detention wet pond, extended detention micropool pond and multiple pond system.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

In general, pond designs are unique for each site and application. However, there are number of geometric ratios and limiting depths for pond design that must be observed for adequate pollutant removal, ease of maintenance, and improved safety.

- Permanent pool volume is typically sized as follows:
  - Standard wet ponds: 100% of the water quality treatment volume (1.0 WQ_v)
  - Extended detention wet ponds: 50% of the water quality treatment volume (0.5 WQ_v)
  - extended detention micropool ponds: Approximately 0.1 inch per impervious acre
- Proper geometric design is essential to prevent hydraulic short-circuiting (unequal distribution of inflow), which results in the failure of the pond to achieve adequate levels of pollutant removal. The minimum length-to-width ratio for the permanent pool shape is 1.5:1, and should ideally be greater than 3:1 to avoid short-circuiting. In addition, ponds should be wedge-shaped when possible so that flow enters the pond and gradually spreads out, improving the sedimentation process. Baffles, pond shaping or islands can be added within the permanent pool to increase the flow path.
- Maximum depth of the permanent pool should generally not exceed 8 feet to avoid stratification and anoxic conditions. Minimum depth for the pond bottom should be 3 to 4 feet. Deeper depths near the outlet will yield cooler bottom water discharges that may mitigate downstream thermal effects.
- Side slopes to the pond should not usually exceed 3:1 (h:v) without safety precautions or if mowing is anticipated and should terminate on a safety bench (see Figure 5.2.21-2). The safety bench requirement may be waived if slopes are 4:1 or gentler. All side slopes should be verified with a geotechnical evaluation to ensure slope stability.
- The perimeter of all deep pool areas (4 feet or greater in depth) should be surrounded by two benches: safety and aquatic. For larger ponds, a safety bench extends approximately 15 feet outward from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench should be 6%. An aquatic bench extends inward from the normal pool edge (15 feet on average) and has a maximum depth of 18 inches below the normal pool water surface elevation (see Figure 5.2.21-2).

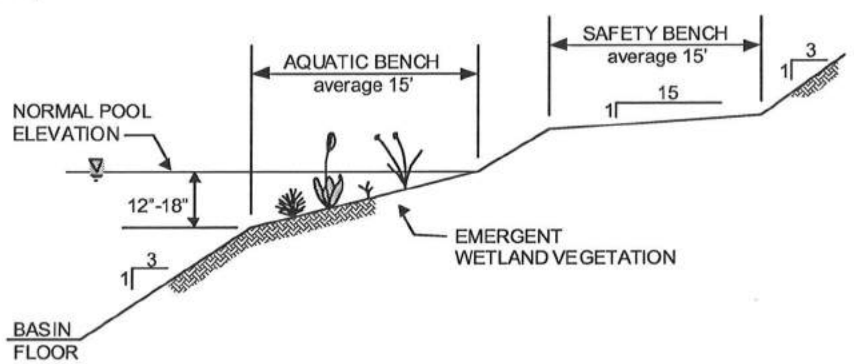


Figure 5.2.21-2 Typical Storm Water Pond Geometry Criteria

- The contours and shape of the permanent pool should be irregular to provide a more natural landscaping effect.

D. PRETREATMENT / INLETS

- Each pond should have a sediment forebay or equivalent upstream pretreatment. A sediment forebay is designed to remove incoming sediment from the storm water flow prior to dispersal in a larger permanent pool. The forebay should consist of a separate cell, formed by an acceptable barrier. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. In some design configurations, the pretreatment volume may be located within the permanent pool.
- The forebay is sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The pretreatment storage volume is part of the total WQ_v requirement and may be subtracted from WQ_v for permanent pool sizing.
- A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.
- Inflow channels are to be stabilized with flared riprap aprons, or the equivalent. Inlet pipes to the pond can be partially submerged. Inflow pipe, channel velocities, and exit velocities from the forebay must be nonerosive.

E. OUTLET STRUCTURES

- Flow control from a storm water pond is typically accomplished with the use of a concrete or corrugated aluminum, aluminized steel, or HDPE riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the bottom of the pond with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see Figure 5.2.21-3). The riser should be located within the embankment for maintenance access, safety and aesthetics.

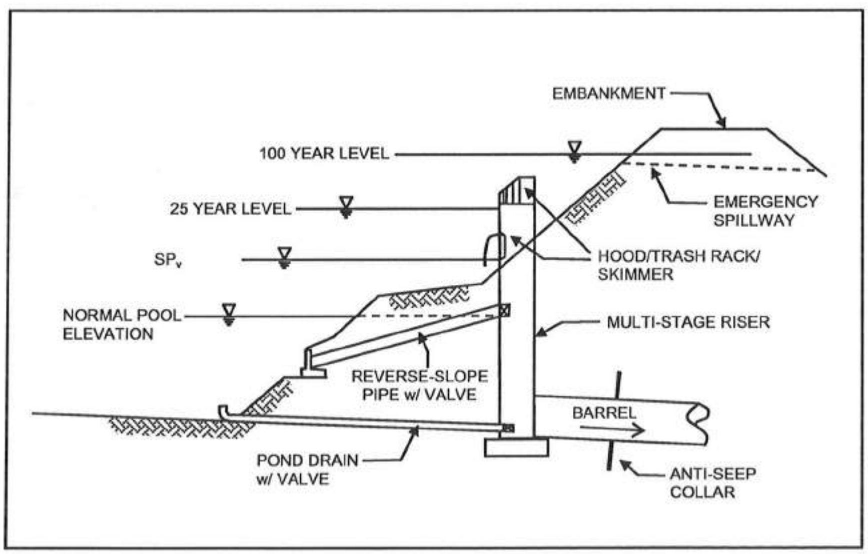


Figure 5.2.21-3 Typical Pond Outlet Structure

- A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality, streambank protection, and on-site flood control runoff volumes. The number of orifices can vary and is usually a function of the pond design.
- Embankments 6 feet in height or greater shall be designed per Texas Commission on Environmental Quality guidelines for Dam Safety. See Appendix H.

- For example, a wet pond riser configuration is typically comprised of a streambank protection outlet (usually an orifice) and on-site flood control outlet (often a slot or weir). The streambank protection orifice is sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams). Since the water quality volume is fully contained in the permanent pool, no orifice sizing is necessary for this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the streambank protection orifice. Thus an off-line wet pond providing *only* water quality treatment can use a simple overflow weir as the outlet structure.
- In the case of an extended detention wet pond or extended detention micropool pond, there is generally a need for an additional outlet (usually an orifice) that is sized to pass the extended detention water quality volume that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to release the water quality extended detention volume in 24 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next outlet is sized for the release of the streambank protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention water quality volume and is sized to release the streambank protection storage volume over a 24-hour period.
- Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch, proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the normal pool.
- The water quality outlet (if design is for an extended detention wet or extended detention micropool pond) and streambank protection outlet should be fitted with adjustable gate valves or other mechanism that can be used to adjust detention time.
- Higher flows (On-Site and Downstream Flood Control) pass through openings or slots protected by trash racks further up on the riser.
- After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.
- Riprap, plunge pools, or pads, or other energy dissipators are to be placed at the outlet of the barrel to prevent scouring and erosion. If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. See Section 4.7 (*Energy Dissipation Design*) for more guidance.
- Each pond must have a bottom drain pipe with an adjustable valve that can completely or partially drain the pond within 24 hours.
- The pond drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

See the design procedures in 5.2.21.6 as well as Section 2.2 (*Storage Design*) and Section 4.6 (*Outlet Structures*) for additional information and specifications on pond routing and outlet works.

F. EMERGENCY SPILLWAY

- An emergency spillway is to be included in the storm water pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges. All local and state dam safety requirements should be met.

- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood to the lowest point of the dam embankment, not counting the emergency spillway.

G. MAINTENANCE ACCESS

- A maintenance right of way or easement must be provided to a pond from a public road or easement. Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser is to be provided by lockable manhole covers, and manhole steps should be within easy reach of valves and other controls.

H. SAFETY FEATURES

- All embankments and spillways must be designed to State of Texas guidelines for dam safety (see Appendix H).
- Fencing of ponds is not generally desirable, but may be required by the local review authority. A preferred method is to manage the contours of the pond through the inclusion of a safety bench (see above) to eliminate dropoffs and reduce the potential for accidental drowning. In addition, the safety bench may be landscaped to deter access to the pool.
- The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent access. Warning signs should be posted near the pond to prohibit swimming and fishing in the facility.

I. LANDSCAPING

- Aquatic vegetation can play an important role in pollutant removal in a storm water pond. In addition, vegetation can enhance the appearance of the pond, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris. Therefore, wetland plants should be encouraged in a pond design, along the aquatic bench (fringe wetlands), the safety bench and side slopes (ED ponds), and within shallow areas of the pool itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within 6 inches (plus or minus) of the normal pool elevation. Additional information on establishing wetland vegetation and appropriate wetland species for North Central Texas can be found in Appendix F (*Landscaping and Aesthetics Guidance*).
- Woody vegetation may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.
- A pond buffer should be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall storm water management concept plan. No structures should be located within the buffer, and an additional setback to permanent structures may be provided.
- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.
- The soils of a pond buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration and therefore may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites and backfill these with uncompacted topsoil.

- Fish such as Gambusia affinis can be stocked in a pond to aid in mosquito prevention.
- A fountain or solar-powered aerator may be used for oxygenation of water in the permanent pool.
- Compatible multi-objective use of storm water pond locations is strongly encouraged.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- Low Relief – Maximum normal pool depth is limited; providing pond drain can be problematic
- High Relief – Embankment heights restricted
- Karst – Requires poly or clay liner to sustain a permanent pool of water and protect aquifers; limits on ponding depth; geotechnical tests may be required

Soils

- Hydrologic group "A" soils generally require pond liner; group "B" soils may require infiltration testing

Special Downstream Watershed Considerations

- Local Aquatic Habitat – extended detention micropool pond best alternative; design wet ponds and extended detention wet ponds offline and provide shading to minimize thermal impact; limit WQ_v-ED to 12 hours
- Aquifer Protection – Reduce potential groundwater contamination by preventing infiltration of hotspot runoff. May require liner for type "A" and "B" soils; pretreat hotspots; 2 to 4 foot separation distance from water table
- Swimming Area/Shellfish – Design for geese prevention (see Appendix F); provide 48-hour extended detention for maximum coliform dieoff.

Dams

Dam construction for storm water ponds can take a variety of forms. Large dams that are over six feet in height are regulated by the State of Texas (See Appendix H). Small dams are not as tightly regulated, but require careful attention to design and construction details to ensure that they function properly throughout their designed economic life.

The most commonly used material for small dam construction is earth fill, but structural concrete can also be used. For on-site storm water controls in high density areas of development or where land values are very costly, the use of a structural concrete dam can save significant amounts of land while making a much more aesthetically appealing outfall structure that the typical riser and barrel assembly.

- **General**
  - The dam area shall be cleared, grubbed and stripped of all vegetative material and topsoil prior to dam construction.
- **Earth Dams**
  - The dam construction plans shall indicate allowable soil materials to be used, compaction required, locations of core trenches if used, any sub-drainage facilities to be installed to control seepage, plus horizontal and vertical dimensions of the earthen structure.
  - The sub-grade of the dam shall be scarified prior to the placement and compaction of the first lift of soil backfill to ensure a good bond between the existing soil and the earthen dam.
  - Placement of earth fill shall be in controlled lifts with proper compaction.
  - Placement of spillway or outflow pipes through the dam shall be per the plan details, with proper backfill and compaction of any excavated trenches. Hydraulic flooding or other compaction methods of saturated soil shall not be allowed.

  - Topsoil and soil additives necessary for the establishment of permanent ground cover above the normal water surface elevation and on the downstream side of the dam shall be installed and seeded as soon as practical to avoid rilling and erosion of the dam's earthen embankment.
  - Do not plant trees or large shrubs on the earth dam, as their root systems cause seepage and damage to the structure.
- **Concrete Dams**
  - Concrete dams shall be designed and built in accordance with the American Concrete Institute's (ACI) latest guidelines for Environmental Engineering Concrete Structures. Particular attention shall be paid to water tightness, crack control, concrete materials and construction practices.
  - The construction plans shall indicate materials, plus horizontal and vertical dimensions necessary for the construction of the dam. Details and information shall be provided on joint types and spacing to be used.
  - At least one-half of the water surface perimeter of the pond at normal pool elevation shall be constructed with a vegetated earthen embankment.
  - Principal and emergency spillways can be incorporated into a weir overflow over the dam if splash pads or another type of control structure is provided to protect the downstream toe of the concrete structure.
  - Placement of drain valves, overflow controls and other penetrations of the concrete wall shall not be located on the same vertical line to prevent creating a weakened plane where uncontrolled cracks can form. Locations should also anticipate operation during storm events when overflow weirs will be operating.

5.2.21.6 Design Procedures

Step 1. Compute runoff control volumes from the *integrated* Design Approach

Calculate the Water Quality Volume (WQ_v), Streambank Protection Volume (SP_v), and the Flood Protection Storm (Q_f). Design volume should be increased by 15% for extended detention ponds.

Details on the *integrated* Design Approach are found in Section 1.2.

Step 2. Determine if the development site and conditions are appropriate for the use of a storm water pond

Consider the Application and Site Feasibility Criteria in subsections 5.2.21.4 and 5.2.21.5-A (Location and Siting).

Step 3. Confirm local design criteria and applicability

Consider any special site-specific design conditions/criteria from subsection 5.2.21.5-J. (Additional Site-Specific Design Criteria and Issues).

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 4. Determine pretreatment volume

A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The forebay storage volume counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.

Step 5. Determine permanent pool volume (and water quality extended detention volume)

Wet Pond: Size permanent pool volume to 1.0 WQ_v

Extended Detention Wet Pond: Size permanent pool volume to 0.5 WQ_v. Size extended detention volume to 0.5 WQ_v.

Extended Detention Micropool Pond: Size permanent pool volume to 25 to 30% of WQ_v. Size extended detention volume to remainder of WQ_v.

Step 6. Determine pond location and preliminary geometry. Conduct pond grading and determine storage available for permanent pool (and water quality extended detention if extended detention wet pond or extended detention micropool pond)

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond.

- Include safety and aquatic benches.
- Set WQ_v permanent pool elevation (and WQ_v-ED elevation for extended detention wet and extended detention micropool pond) based on volumes calculated earlier.

See subsection 5.2.21.5-C (Physical Specifications / Geometry) for more details.

Step 7. Compute extended detention orifice release rate(s) and size(s), and establish SP_v elevation

Wet Pond: The SP_v elevation is determined from the stage-storage relationship and the orifice is then sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams). The streambank protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an over-perforated vertical stand pipe with ½-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.

Extended Detention Wet Pond and Extended Detention Micropool Pond: Based on the elevations established in Step 6 for the extended detention portion of the water quality volume, the water quality orifice is sized to release this extended detention volume in 24 hours. The water quality orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter. The SP_v elevation is then determined from the stage-storage relationship. The invert of the streambank protection orifice is located at the water quality extended detention elevation, and the orifice is sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams).

Step 8. Calculate Q_p release rate and water surface elevation

Set up a stage-storage-discharge relationship for the control structure for the extended detention orifice(s) and the deisgn storm.

Step 9. Design embankment(s) and spillway(s)

Size emergency spillway, calculate 100-year water surface elevation, set top of embankment elevation, and analyze safe passage of the 100-year flood.

At final design, provide safe passage for the 100-year event.

Step 10. Investigate potential pond hazard classification

The design and construction of storm water management ponds are required to follow the latest version of the State of Texas Administrative Code for dams and reservoirs (see Appendix H).

Step 11. Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features.

See subsection 5.2.21.5-D through H for more details.

Step 12. Prepare Vegetation and Landscaping Plan

A landscaping plan for a storm water pond and its buffer should be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation.

See subsection 5.2.21.5-I (Landscaping) and Appendix F for more details.

See Appendix D-1 for a Storm Water Pond Design Example

5.2.21.7 Inspection and Maintenance Requirements

Table 5.2.21-1 Typical Maintenance Activities for Ponds
(Source: WMI, 1997)

Activity	Schedule
• Clean and remove debris from inlet and outlet structures. • Mow side slopes. • Check visually for illegal dumping or other pollutants.	Monthly
• If wetland components are included, inspect for invasive vegetation.	Semiannual Inspection
• Inspect for damage, paying particular attention to the control structure. • Check for signs of eutrophic conditions. • Note signs of hydrocarbon build-up, and remove appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational. • Check all control gates, valves or other mechanical devices. • Check downstream face of dam for seepage (earth and concrete), settling (earth) and cracking (concrete).	Annual Inspection
• Repair undercut or eroded areas.	As Needed
• Perform wetland plant management and harvesting.	Annually (if needed)
• Remove sediment from the forebay.	5 to 7 years or after 50% of the total forebay capacity has been lost
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, or the pond becomes eutrophic.	10 to 20 years or after 25% of the permanent pool volume has been lost

Additional Maintenance Considerations and Requirements

- A sediment marker should be located in the forebay to determine when sediment removal is required.
- Sediments excavated from storm water ponds that do not receive runoff from designated hotspots are not considered toxic or hazardous material and can be safely disposed of by either land application or landfilling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present.
- Periodic mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.
- Care should be exercised during pond drawdowns to prevent downstream discharge of sediments, anoxic water, or high flows with erosive velocities. The approving jurisdiction should be notified before draining a storm water pond.

Regular inspection and maintenance is critical to the effective operation of storm water ponds as designed. Maintenance responsibility for a pond and its buffer should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

5.2.21.8 Example Schematics

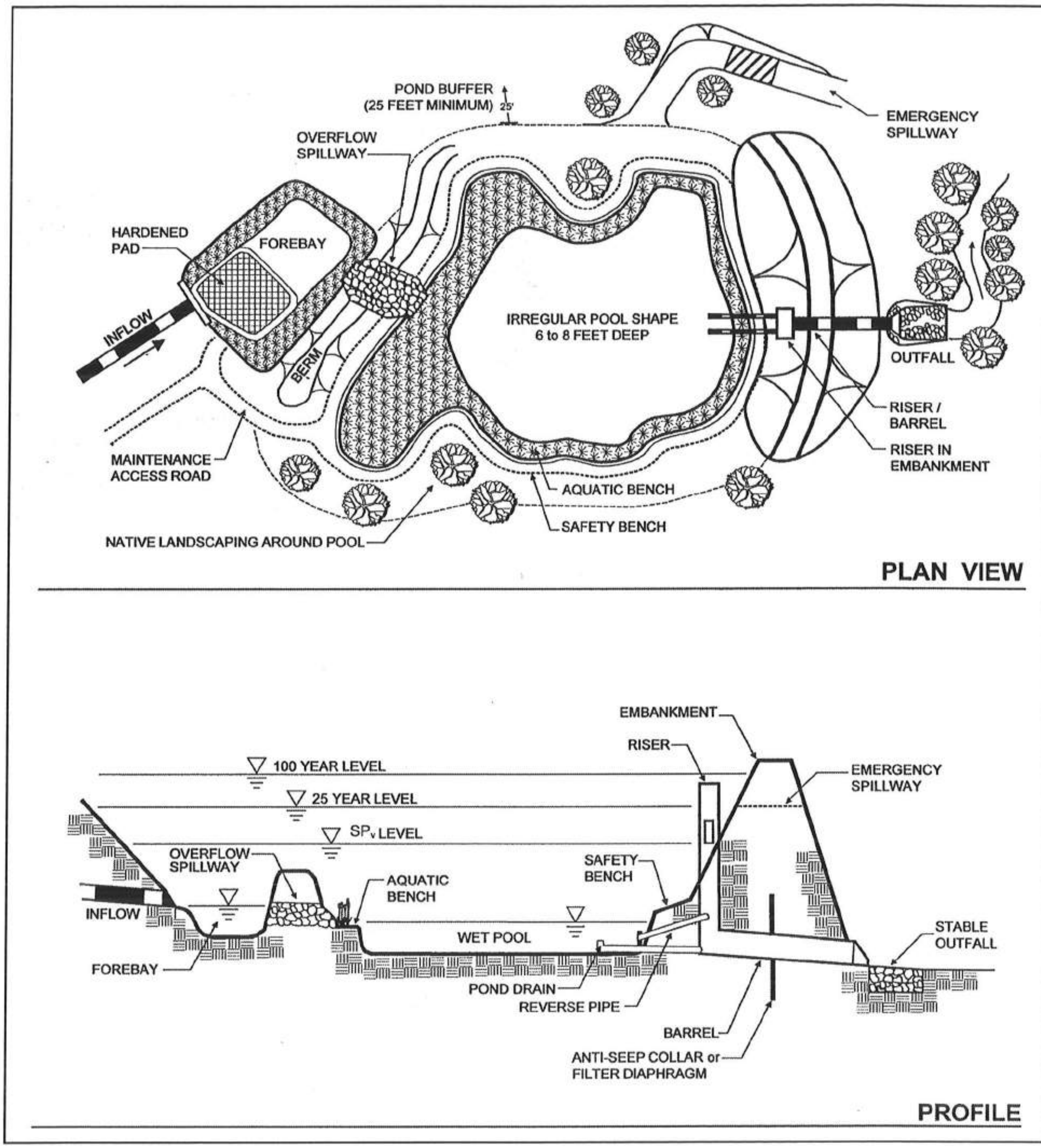


Figure 5.2.21-4 Schematic of Wet Pond
(Source: Center for Watershed Protection)

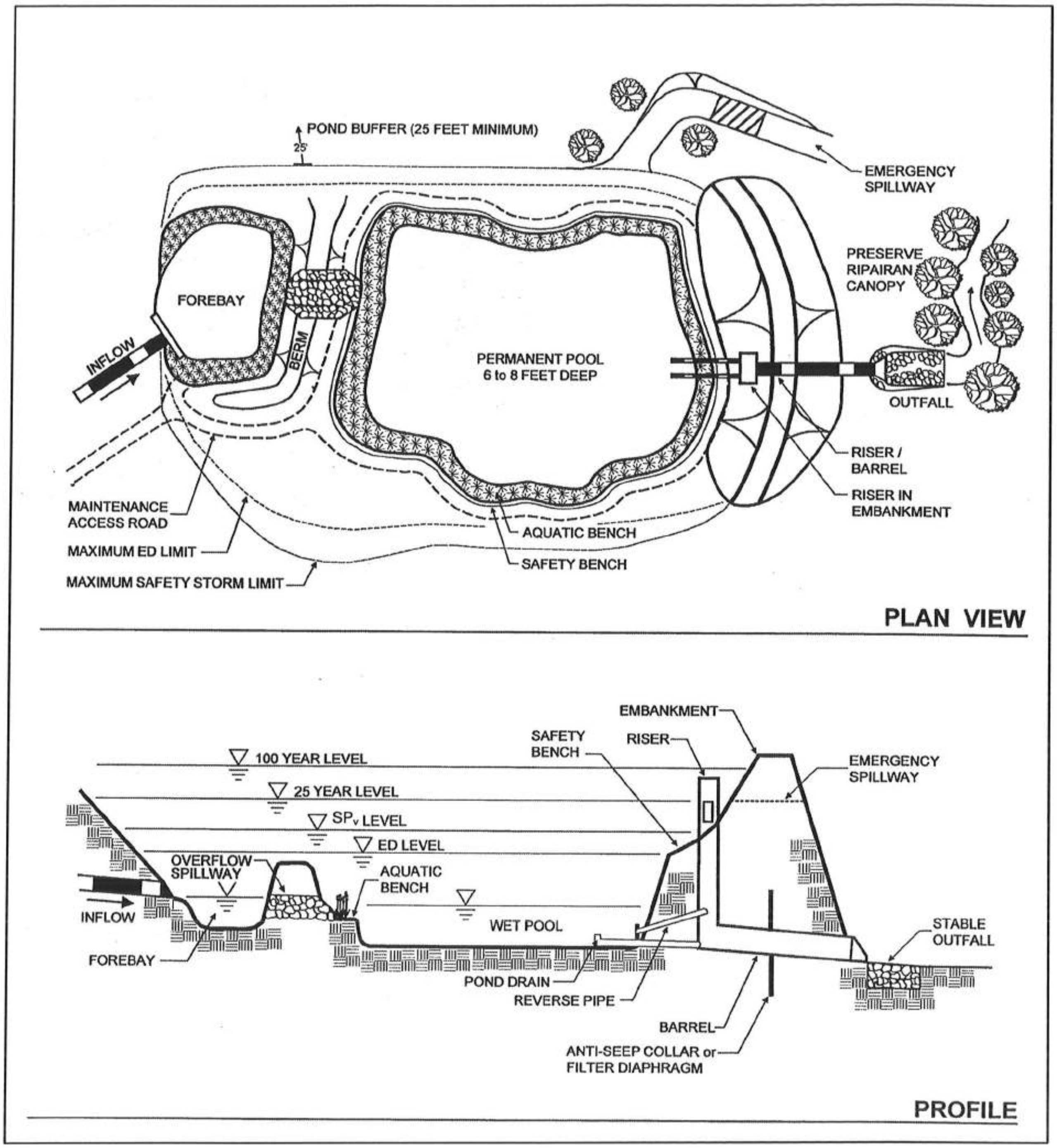


Figure 5.2.21-5 Schematic of Wet Extended Detention Pond
(Source: Center for Watershed Protection)

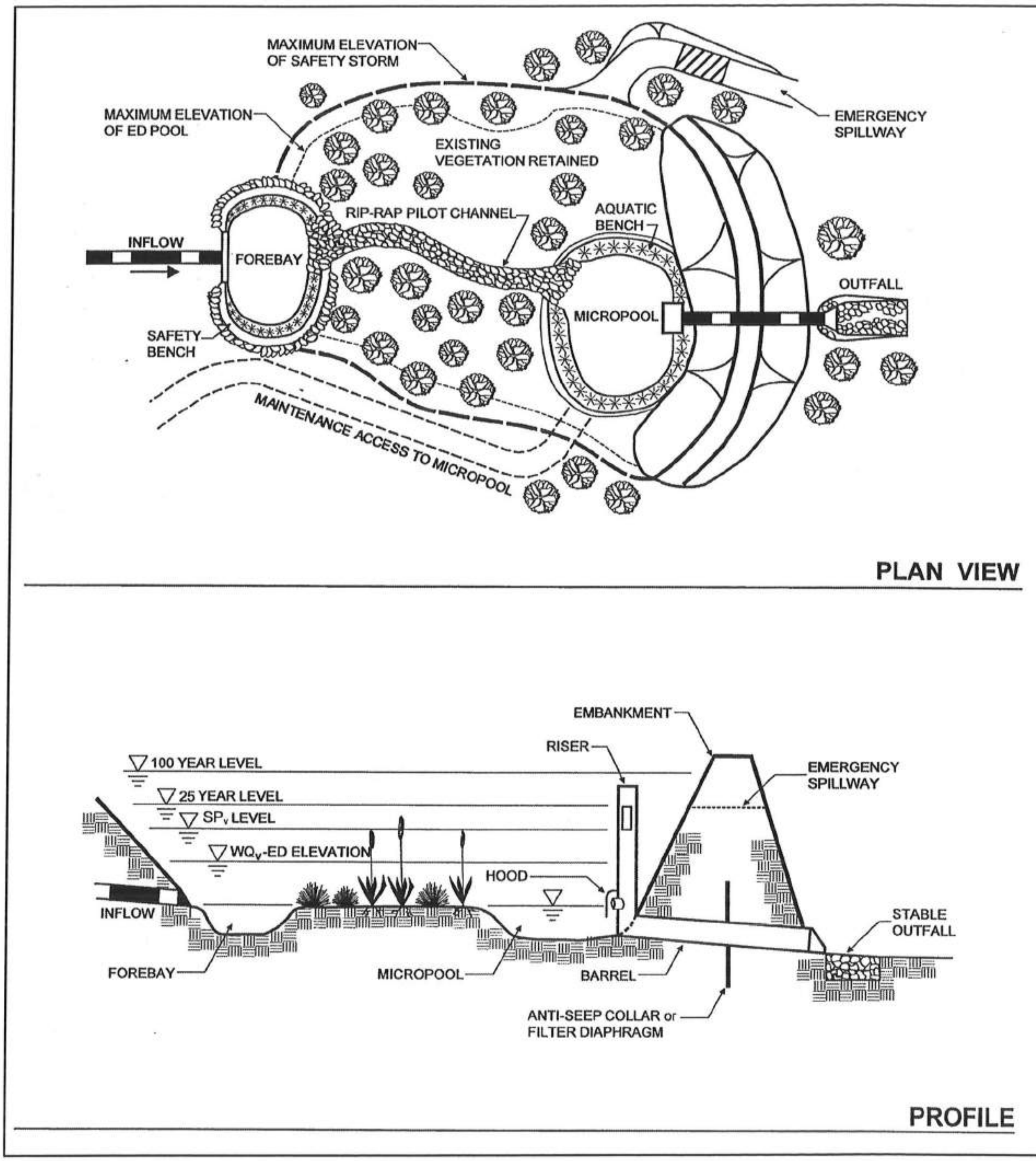


Figure 5.2.21-6 Schematic of Micropool Extended Detention Pond
(Source: Center for Watershed Protection)

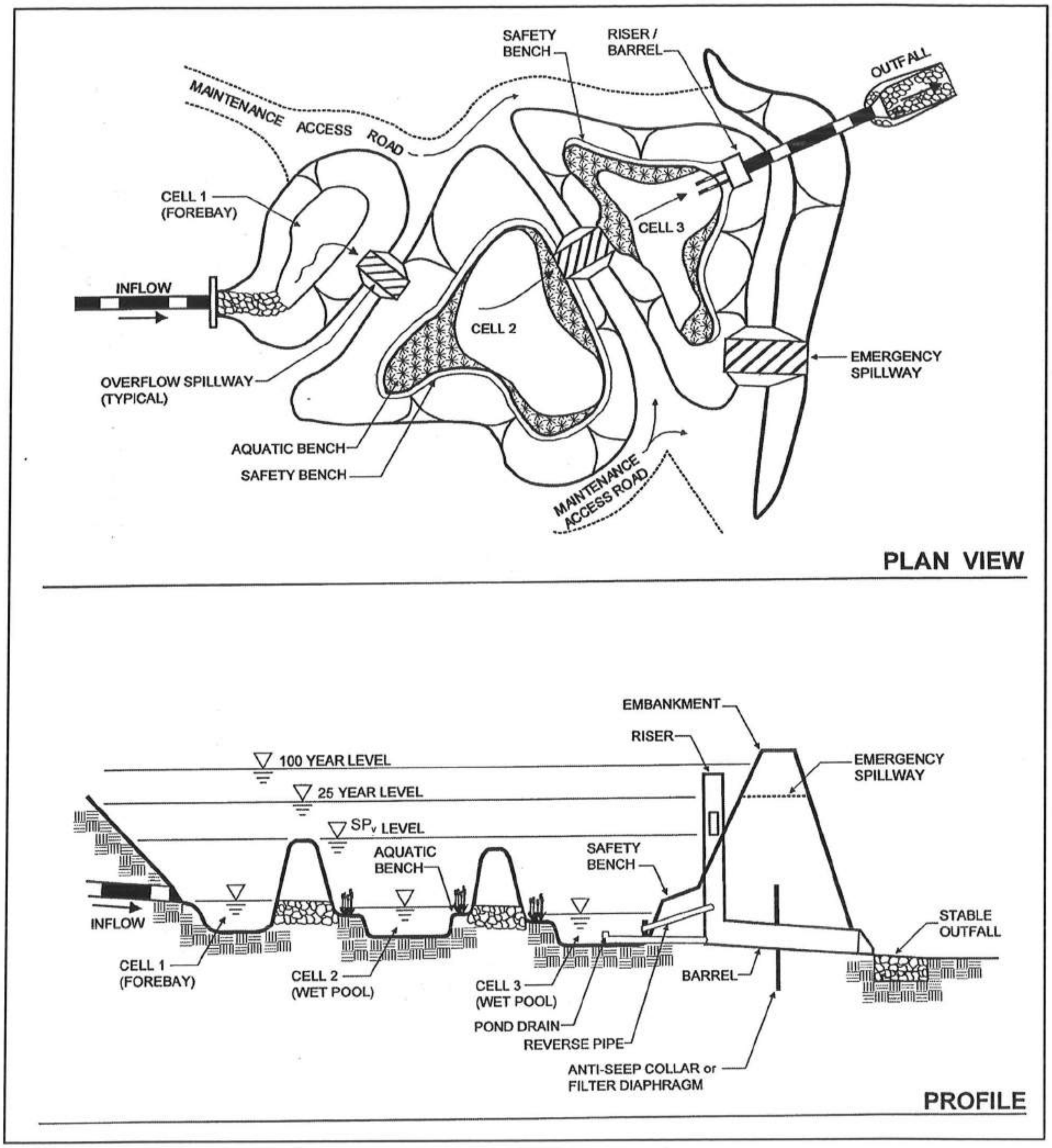


Figure 5.2.21-7 Schematic of Multiple Pond System
(Source: Center for Watershed Protection)

5.2.21.9 Design Forms

Design Procedure Form: Storm Water Ponds

PRELIMINARY HYDROLOGIC CALCULATIONS

1a. Compute WQ_v Volume requirements
Compute Runoff Coefficient, R_v — R_v = ______
Compute WQ_v Volume requirements — WQ_v = ______ acre-ft

1b. Compute SP_v — SP_v = ______ acre-ft
Compute average release rate — release rate = ______ cfs
Compute Q_p (Required 100-year detention volume) — Q_p = ______ acre-ft
Add 15% to the required Q_p volume (if ED) — Q_p* 15% = ______ acre-ft
Compute (as necessary) Q_f — Q_f = ______ cfs

STORM WATER POND DESIGN

2. Is the use of storm water pond appropriate? — **See subsection 5.2.21.4 and 5.2.21.5-A**

3. Confirm local design criteria and applicability

4. Pretretament volume
$Vol_{pre} = I(0.1")(1'/12")$ — Vol_{pre} = ______ acre-ft

5. Allocation of Permanent Pool Volume and ED Volume
Wet Pond: $Vol_{pool} = WQ_v$ — Vol_{pool} = ______ acre-ft
Wet ED Pond: $Vol_{pool} = 0.5(WQ_v)$ — Vol_{pool} = ______ acre-ft
$Vol_{ED} = 0.5(WQ_v)$ — Vol_{ED} = ______ acre-ft
Micropool ED Pond: $Vol_{pool} = 0.25(WQ_v)$ — Vol_{pool} = ______ acre-ft
$Vol_{ED} = 0.75(WQ_v)$ — Vol_{ED} = ______ acre-ft

6. Conduct grading and determine storage available for permanent pool (and WQ_v-ED volume if applicable) — Prepare an elevation-storage table and curve using the average area method for computing volumes.

Elevation MSL	Area ft^2	Average Area ft^2	Depth ft	Volume ft^3	Cumulative Volume ft^3	Cumulative Volume acre-ft	Volume above Permanent Pool acre-ft

7. WQ_v Orifice Computations
Average ED release rate (if applicable) — release rate = ________ cfs
Average head, h = (ED elev. - Permanent pool elev.) / 2 — h = ________ ft
Area of orifice from orifice equation — A = ________ ft^2
$Q = CA(2gh)^{0.5}$ — diameter = ________ in
factor = ________ $(h)^{0.5}$

Discharge equation $Q = (h)^{0.5}$

Compute release rate for SP_v-ED control and establish SP_v elevation — WSEL = ________ ft-NGVD
Release rate = — release rate = ________ cfs
Aerage head, h = SP_velev. - Permanent pool elev.) / 2 — h = ________ ft-NGVD
Area of orifice from orifice equatin — A = ________ ft^2
$Q = CA(2gh)^{0.5}$ — diameter = ________ in
Discharge equation $Q = (h)^{0.5}$ — factor = ________ $(h)^{0.5}$

8. Calculate Qp release rate and WSEL

Set up a stage-storage-discharge relationship

Elevation	Storage	Low Flow	Riser				Barrel		Emergency	Total
		WQv-ED	SPv-ED	High Storage			Inlet	Pipe	Spillway	Storage
				Orif.	Weir					
MSL	ac-ft	H(ft) Q(cfs)	H(ft) Q(cfs)	HQ	HQ		H(ft) Q(cfs)	H(ft) Q(cfs)	H(ft) Q(cfs)	Q(cfs)

Q_p = pre-dev. Peak discharge - (WQ_v-ED release + SP_v-ED release) — Q_p = ________ cfs

Maximum head = — H = ________ ft
Use weir equation for slot length ($Q = CLH^{3/2}$) — L = ________ ft

Check inlet condition
Check outlet condition

Use culvert charts (section 4.3)

9. Size emergency spillway, calculate 100-year WSEL and set top of embankment elevation
$WSEL_{25}$ = ________ ft
$WSEL_{100}$ = ________ ft
Q_{ES} = ________ cfs
Q_{PS} = ________ cfs

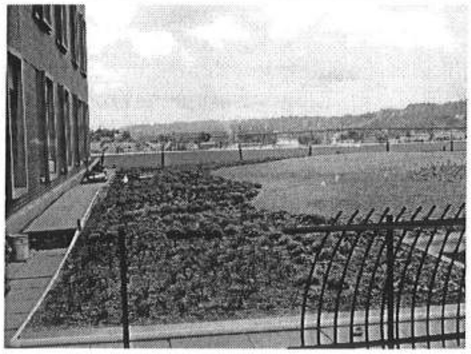
10. Investigate potential pond hazard classification — **See Appendix H**

11. Design inlets, sediment forebays, outlet structures, maintenance access, and safety features. — **See subsection 3.2.15 - D through H**

12. Attach landscaping plan — **See Appendix F**

5.2.22 Green Roof

Structural Storm Water Control



Description: A green roof uses a small amount of substrate over an impermeable membrane to support a covering of plants. The green roof slows down runoff from the otherwise impervious roof surface as well as moderating rooftop temperatures. With the right plants, a green roof will also provide aesthetic or habitat benefits. Green roofs have been used in Europe for decades.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Relatively new in North America
- Potential for high failure rate if poorly designed, poorly constructed, not adequately maintained Minimum length to width ratio for the pond is 1.5:1

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume
- Higher initial cost when compared to conventional roofs, but potential for lower life cycle costs through longevity

DISADVANTAGES / LIMITATIONS:

- Requires additional roof support
- Requires more maintenance than regular roofs
- Special attention to design and construction needed
- Requires close coordination with plant specialists
- Potential for leakage due to plant roots penetrating membrane.

POLLUTANT REMOVAL

85%	**Total Suspended Solids**
95%/16%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
25%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
S	**Streambank Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *No restrictions*

Other Considerations:

- *Hotspot Areas*

L=Low **M**=Moderate **H**=High

5.2.22.1 General Description

Green roofs (also referred to as *ecoroofs, roof gardens, or roof meadows*) are vegetated roofs used in place of conventional roofing, such as gravel-ballasted roofs. They are used as part of sustainable development initiatives, along with narrow streets, permeable pavement, and various infiltration devices. There are two main types of green roofs. The first is what is called roof gardens or intensive green roofs. They may be thought of as a garden on the roof. They have a greater diversity of plants, including trees and shrubs, but require deeper soil, increased load bearing capacity, and require more maintenance. The second has been referred to as roof meadows or extensive green roofs. The vegetation is limited and similar to an alpine meadow, requiring less soil depth and minimal maintenance. Due to the considerably greater costs and structural design requirements, only the second type of green roof, the roof meadow or extensive type is discussed in this manual.

The extensive green roof is designed to control low-intensity storms by intercepting and retaining or storing water until the peak storm event has passed. The plants intercept and delay runoff by capturing and holding precipitation in the foliage, absorbing water in the root zone, and slowing the velocity of direct runoff by increasing retardance to flow and extending the flowpath through the vegetation. Water is also stored and evaporated from the growing media. Green roofs can capture and evaporate up to 100 percent of the incident precipitation, depending on the roof design and the storm characteristics.

Monitoring in Pennsylvania, for instance, showed reductions of approximately 2/3 in runoff from a green roof (15.5 inches runoff from 44 inches of rainfall). Furthermore, runoff was negligible for storm events of less than 0.6 inches. A study done for Portland, Oregon, indicated a reduction in storm water discharges from the downtown area of between 11 and 15% annually if half of the roofs in the downtown area were retrofitted as green roofs.

Green roofs also:

- reduce the temperature of runoff,
- reduce the "heat island" effect of urban buildings,
- help insulate the building,
- improve visual aesthetics,
- protect roofs from weather,
- improve building insulation,
- reduce noise,
- and provide habitat for wildlife.

As with a conventional roof, a green roof must safely drain runoff from the roof. It may be desirable to drain the runoff to a rainwater harvesting system such as (rainbarrels or cisterns), or other storm water facilities such as planters and swales.

Significant removals of heavy metals by green roofs have been reported, but there is not enough evidence to include removal rates at this time.

5.2.22.2 Design Criteria and Specifications

- For either new installations or retrofits, an architect or structural engineer must be consulted to determine whether the building can provide the structural support needed for a green roof.
- Generally, the building structure must be adequate to hold an additional 10 to 25 pounds per square foot (psf) saturated weight, depending on the vegetation and growth medium that will be used. (This is in addition to snow load requirements.) An existing rock ballast roof may be structurally sufficient to hold a 10-12 psf green roof, since ballast typically weighs 10-12 psf.

- Green roofs can be used on flat or pitched roofs up to 40 percent. Although, on a roof slope greater than 20 degrees, the green roof installer needs to ensure that the plant layer does not slip or slump through its own weight, especially when it becomes wet. Horizontal strapping, wood, plastic, or metal, may be necessary. Some commercial support grid systems are also available for this purpose.
- A green roof typically consists of several layers, as shown in Figure 5.2.22-1. A waterproof membrane is placed over the roof's structure. A root barrier is placed on top of the membrane to prevent roots from penetrating the membrane and causing leaks. A layer for drainage is installed above this, followed by the growth media. The vegetation is then planted to form the top layer. Details of the various layers are given below.
- Waterproof membranes are made of various materials, such as synthetic rubber (EPDM), hypolan (CPSE), reinforced PVC, or modified asphalts (bitumens). The membranes are available in various forms, liquid, sheets, or rolls. Check with the manufacturer to determine their strength and functional characteristics of the membrane under consideration.
- Root barriers are made of dense materials or are treated with copper or other materials that inhibit root penetration, protecting the waterproof membrane from being breached. A root barrier may not be necessary for synthetic rubber or reinforced PVC membranes, but will likely be needed for asphalt mixtures. Check with the manufacturer to determine if a root barrier is required for a particular product.
- The drainage layer of a green roof is usually constructed of various forms of plastic sheeting, a layer of gravel, or in some cases, the growth medium.
- The growth medium is generally 2 to 6 inches thick and made of a material that drains relatively quickly. Commercial mixtures containing coir (coconut fiber), pumice, or expanded clay are available. Sand, gravel, crushed brick, and peat are also commonly used. Suppliers recommend limiting organic material to less than 33% to reduce fire hazards. The City of Portland, Oregon has found a mix of 1/3 topsoil, 1/3 compost, and 1/3 perlite may be sufficient for many applications. Growth media can weigh from 16 to 35 psf when saturated depending on the type (intensive/extensive), with the most typical range being from 10-25 psf.
- When dry, all of the growth media are light-weight and prone to wind erosion. It is important to keep media covered before planting and ensure good coverage after vegetation is established.
- Selecting the right vegetation is critical to minimize maintenance requirements. Due to the shallowness of the growing medium and the extreme desert-like microclimate on many roofs, plants are typically alpine, dryland, or indigenous. Ideally, the vegetation should be:
  - Drought-tolerant, requiring little or no irrigation after establishment
  - Self-sustaining, without fertilizers, pesticides, or herbicides
  - Able to withstand heat, cold, and high winds
  - Shallow root structure
  - Low growing, needing little or no mowing or trimming
  - Fire resistant
  - Perennial or self propagating, able to spread and cover blank spots by itself

  Visit www.txsmartscape.com to look up plants meeting the above criteria.
- A mix of sedum/succulent plant communities is recommended because they possess many of these attributes. Certain wildflowers, herbs, forbs, grasses, mosses, and other low groundcovers can also be used to provide additional habitat benefits or aesthetics; however, these plants need more watering and maintenance to survive and keep their appearance.
- Green roof vegetation is usually established by one or more of the following methods: seeding, cuttings, vegetation mats, and plugs/potted plants.
  - Seeds can be either hand sown or broadcast in a slurry (hydraseeded). Seeding takes longer to establish and requires more weeding, erosion control, and watering than the other methods.

  - Cuttings or sprigs are small plant sections. They are hand sown and require more weeding, erosion control, and watering than mats.
  - Vegetation mats are sod-like mats that achieve full plant coverage very quickly. They provide immediate erosion control, do not need mulch, and minimize weed intrusion. They generally require less ongoing maintenance than the other methods.
  - Plugs or potted plants may provide more design flexibility than mats. However, they take longer to achieve full coverage, are more prone to erosion, need more watering during establishment, require mulching, and more weeding.

- Green roof vegetation is most easily established during the spring or fall.
- Irrigation is necessary during the establishment period and possibly during drought conditions, regardless of the planting method used. The goal is to minimize the need for irrigation by paying close attention to plant selection, soil, and various roof characteristics.
- Installation costs for green roofs generally run from $10 to $25 per square foot, as compared to $3 to $20 per square foot for a conventional roof. However, the longer lifespan of a green roof (reportedly 40 years or up to twice as long as a conventional roof) and lower maintenance costs offset this.
- Provide controlled overflow point(s) to prevent overloading of roof.

5.2.22.3 Inspection and Maintenance Requirements

Table 5.2.22-1 Typical Maintenance Activities for Green Roofs

Activity	Schedule
• Watering to help establish vegetation	As needed
• Replant to cover bare spots or dead plants	Monthly
• Weeding (as needed, based on inspection)	Two or three times yearly
• Water and mowing to prevent fire hazards (if grasses or similar plants are used)	As needed
• Inspect drains for clogging	Twice per year
• Inspect the roof for leakage	Annually, or as needed
• If leaks occur, remove and stockpile vegetation, growth media, and drainage layer. Replace membrane and root barrier, followed by stockpiled material.	Upon failure

5.2.22.4 Example Schematic

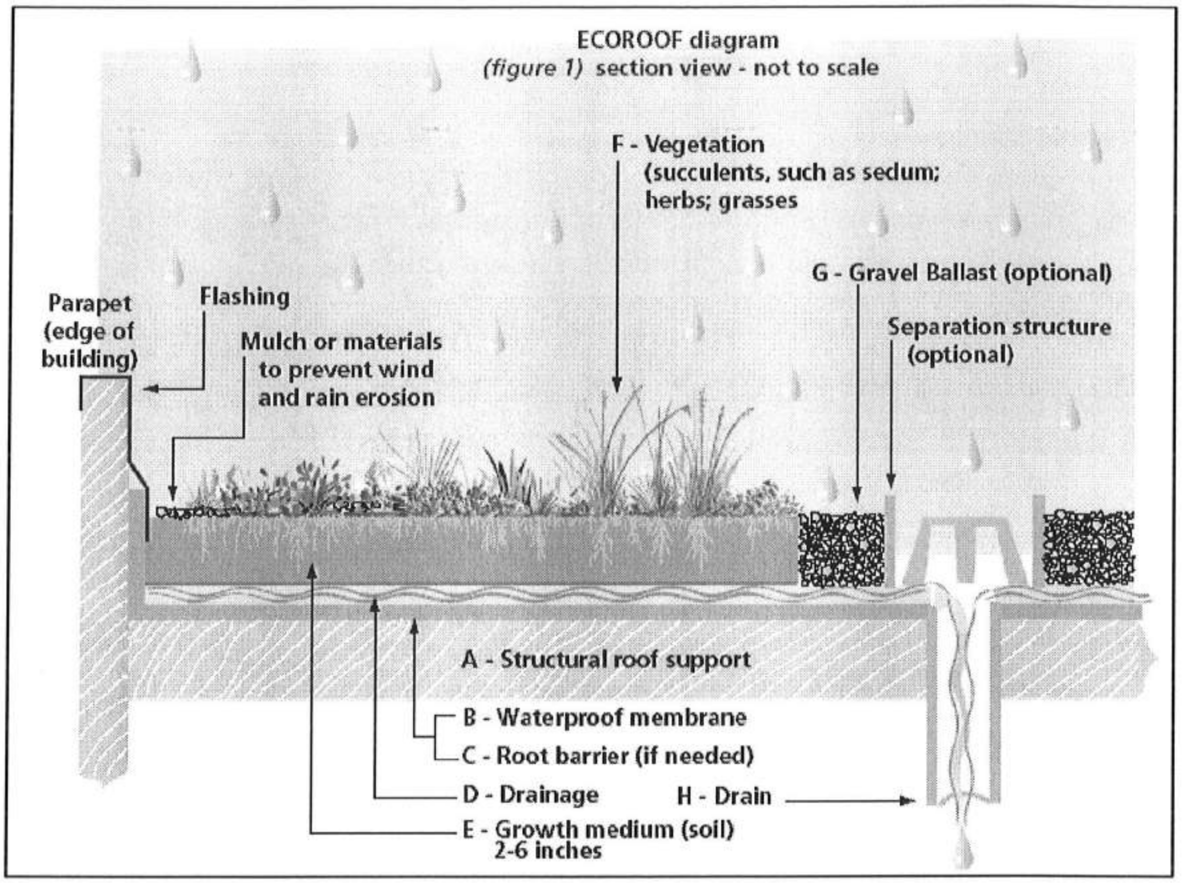


Figure 5.2.22-1 Green Roof Cross Section (from City of Portland, Oregon)

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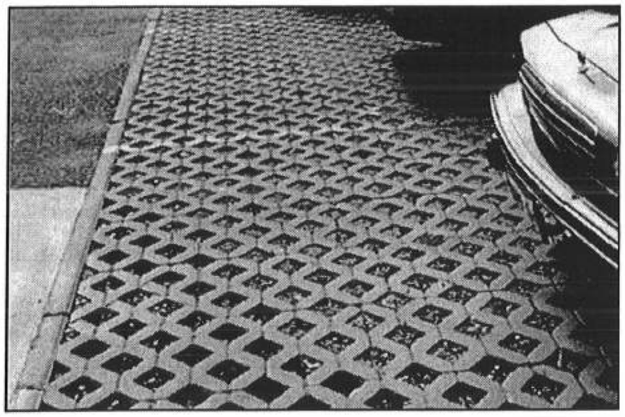
5.2.23 Modular Porous Paver Systems

Structural Storm Water Control



Description: A pavement surface composed of structural units with void areas that are filled with pervious materials such as sand or grass turf. Porous pavers are installed over a gravel base course that provides storage as runoff infiltrates through the porous paver system into underlying permeable soils.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for low traffic areas, or for residential or overflow parking applications
- Soil infiltration rate of 0.5 in/hr or greater required

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume
- High level of pollutant removal
- Available from commercial vendors

DISADVANTAGES / LIMITATIONS:

- High maintenance requirements
- High cost compared to conventional pavements
- Potential for high failure rate if not adequately maintained or used in unstabilized areas
- Potential for groundwater contamination

POLLUTANT REMOVAL

NA	**Total Suspended Solids**
80/80%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
90%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
S	**Streambank Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
M	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *Soil infiltration rate of 0.5 in/hr or greater required*

L=Low **M**=Moderate **H**=High

5.2.23.1 General Description

Modular porous pavers are structural units, such as concrete blocks, bricks, or reinforced plastic mats, with regularly interspersed void areas used to create a load-bearing pavement surface. The void areas are filled with pervious materials (gravel, sand, or grass turf) to create a system that allows for the infiltration of storm water runoff. Porous paver systems provide water quality benefits in addition to groundwater recharge and a reduction in storm water volume. The use of porous paver systems results in a reduction of the effective impervious area on a site.

There are many different types of modular porous pavers available from different manufacturers, including both pre-cast and mold in-place concrete blocks, concrete grids, interlocking bricks, and plastic mats with hollow rings or hexagonal cells (see Figure 5.2.23-1).

Modular porous pavers are typically placed on a gravel (stone aggregate) base course. Runoff infiltrates through the porous paver surface into the gravel base course, which acts as a storage reservoir as it infiltrates to the underlying soil. The infiltration rate of the soils in the subgrade must be adequate to support drawdown of the entire runoff capture volume within 24 to 48 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils, which could affect the soils' infiltration capability.

Modular porous paver systems are typically used in low-traffic areas such as the following types of applications:

- Parking pads in parking lots
- Overflow parking areas
- Residential driveways
- Residential street parking lanes
- Recreational trails
- Golf cart and pedestrian paths
- Emergency vehicle and fire access lanes

A major drawback is the cost and complexity of modular porous paver systems compared to conventional pavements. Porous paver systems require a very high level of construction workmanship to ensure that they function as designed and do not settle unevenly. In addition, there is the difficulty and cost of rehabilitating the surfaces should they become clogged. Therefore, consideration of porous paver systems should include the construction and maintenance requirements and costs.

5.2.23.2 Pollutant Removal Capabilities

As they provide for the infiltration of storm water runoff, porous paver systems have a high removal of both soluble and particulate pollutants, where they become trapped, absorbed, or broken down in the underlying soil layers. Due to the potential for clogging, porous paver surfaces should not be used for the removal of sediment or other coarse particulate pollutants.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- **Total Suspended Solids – not applicable**
- **Total Phosphorus – 80%**
- **Total Nitrogen – 80%**
- **Fecal Coliform – insufficient data**

- **Heavy Metals – 90%**

5.2.23.3 Design Criteria and Specifications

- Porous paver systems can be used where the underlying in-situ subsoils have an infiltration rate of between 0.5 and 3.0 inches per hour. Therefore, porous paver systems are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the soils.
- Porous paver systems should ideally be used in applications where the pavement receives tributary runoff only from impervious areas. The ratio of the contributing impervious area to the porous paver surface area should be no greater than 3:1.
- If runoff is coming from adjacent pervious areas, it is important that those areas be fully stabilized to reduce sediment loads and prevent clogging of the porous paver surface.
- Porous paver systems are not recommended on sites with a slope greater than 2%.
- A minimum of 2 feet of clearance is required between the bottom of the gravel base course and underlying bedrock or the seasonally high groundwater table.
- Porous paver systems should be sited at least 10 feet downgradient from buildings and 100 feet away from drinking water wells.
- An appropriate modular porous paver should be selected for the intended application. A minimum of 40% of the surface area should consist of open void space. If it is a load bearing surface, then the pavers should be able to support the maximum load.
- The porous paver infill is selected based upon the intended application and required infiltration rate. Masonry sand (such as ASTM C-33 concrete sand or TxDOT item 421 Fine Aggregate) has a high infiltration rate (8 in/hr) and should be used in applications where no vegetation is desired. A sandy loam soil has a substantially lower infiltration rate (1 in/hr), but will provide for growth of a grass ground cover.
- A 1-inch top course (filter layer) of sand (ASTM C-33 concrete sand or TxDOT item 421 Fine Aggregate) underlain by filter fabric is placed under the porous pavers and above the gravel base course.
- The gravel base course should be designed to store at a minimum the water quality protection volume (WQ_v). The stone aggregate used should be washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40% (ASTM C-33 Size No. 3 Coarse Aggregate). Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 should be used in calculations.
- The gravel base course must have a minimum depth of 9 inches. The following equation can be used to determine if the depth of the storage layer (gravel base course) needs to be greater than the minimum depth:

  $$\mathbf{d = V / A * n}$$

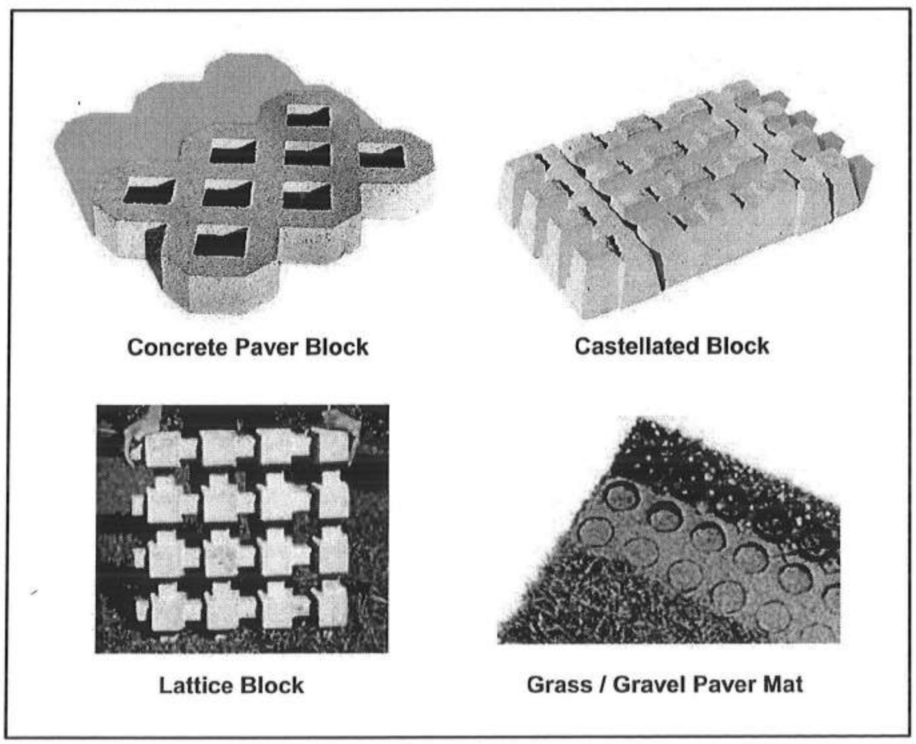
  where:
  - d = Gravel Layer Depth (feet)
  - V = Water Quality Protection Volume –or– Total Volume to be Infiltrated (cubic feet)
  - A = Surface Area (square feet)
  - n = Porosity (use n=0.32)
- The surface of the subgrade should be lined with filter fabric or an 8-inch layer of sand (ASTM C-33 concrete sand or TxDOT item 421 Fine Aggregate) and be completely flat to promote infiltration across the entire surface.

- Porous paver system designs must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that are too large to be infiltrated by the porous paver system, or if the surface clogs.
- For the purpose of sizing downstream conveyance and structural control system, porous paver surface areas can be assumed to be 35% impervious. In addition, a reduction in water quality volume requirements can be obtained for the runoff volume infiltrated from other impervious areas using the methodology in Section 1.2.

5.2.23.4 Inspection and Maintenance Requirements

Table 5.2.23-1 Typical Maintenance Activities for Modular Porous Paver Systems

Activity	Schedule
• Ensure that the porous paver surface is free of extraneous sediment. • Check to make sure that the system dewaters between storms.	Monthly
• Clear debris from contributing area and porous paver surface. • Stabilize and mow contributing adjacent areas and remove clippings.	As needed, based on inspection
• Vacuum sweep porous paver surface to keep free of sediment.	Typically three to four times a year
• Inspect the surface for deterioration or spalling.	Annually
• Totally rehabilitate the porous paver system, including the top and base course.	Upon failure



Concrete Paver Block

Castellated Block

Lattice Block

Grass / Gravel Paver Mat

Figure 5.2.23-1 Examples of Modular Porous Pavers

5.2.23.5 Example Schematics

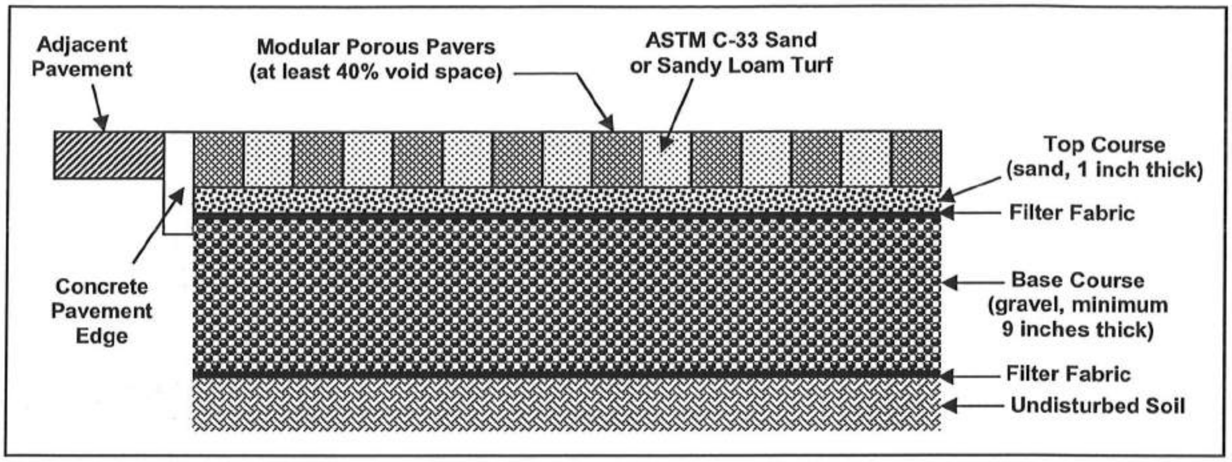


Figure 5.2.23-2 Modular Porous Paver System Section

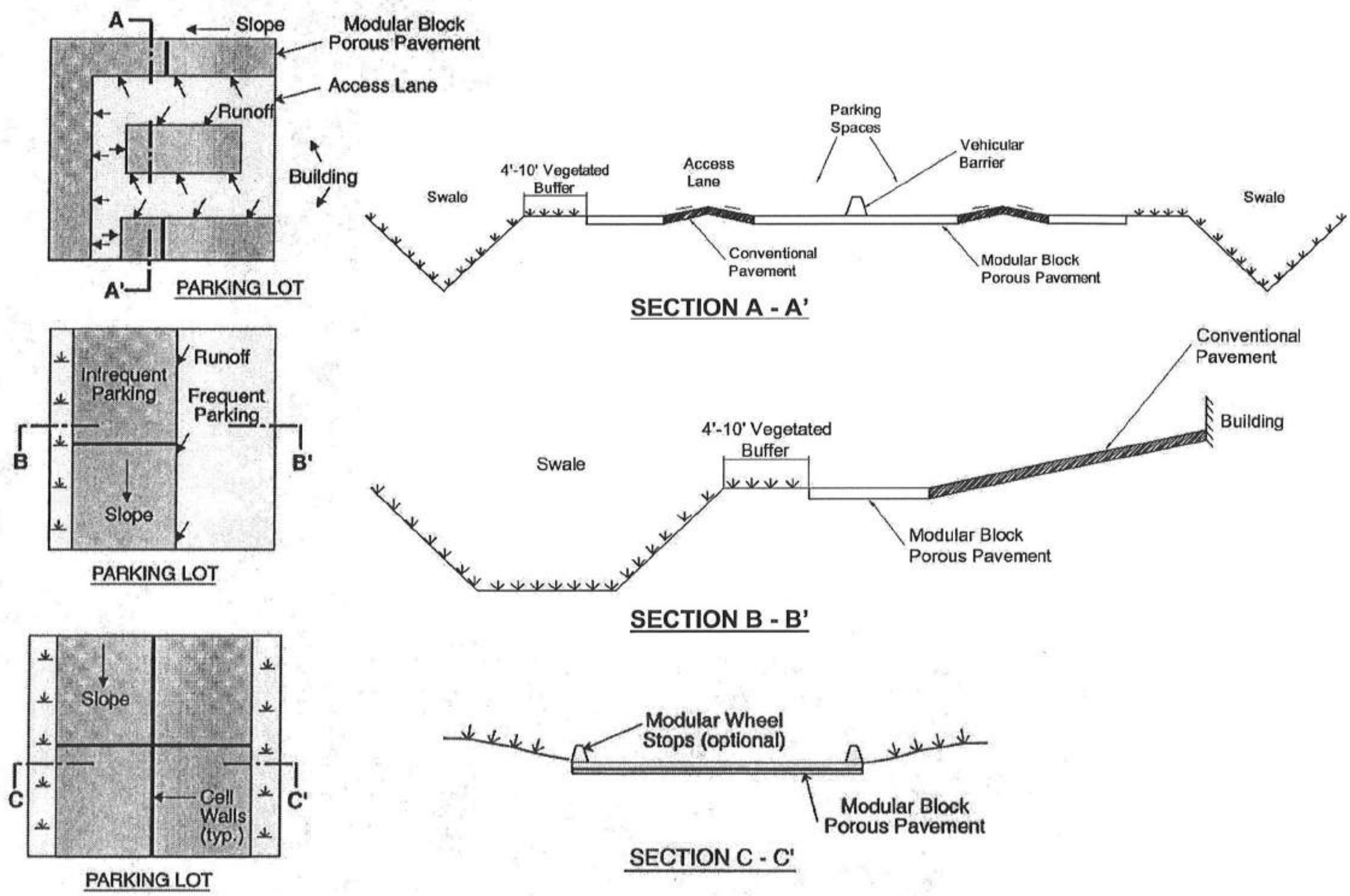


Figure 5.2.23-3 Typical Modular Porous Paver System Applications
(Source: UDFCD, 1999)

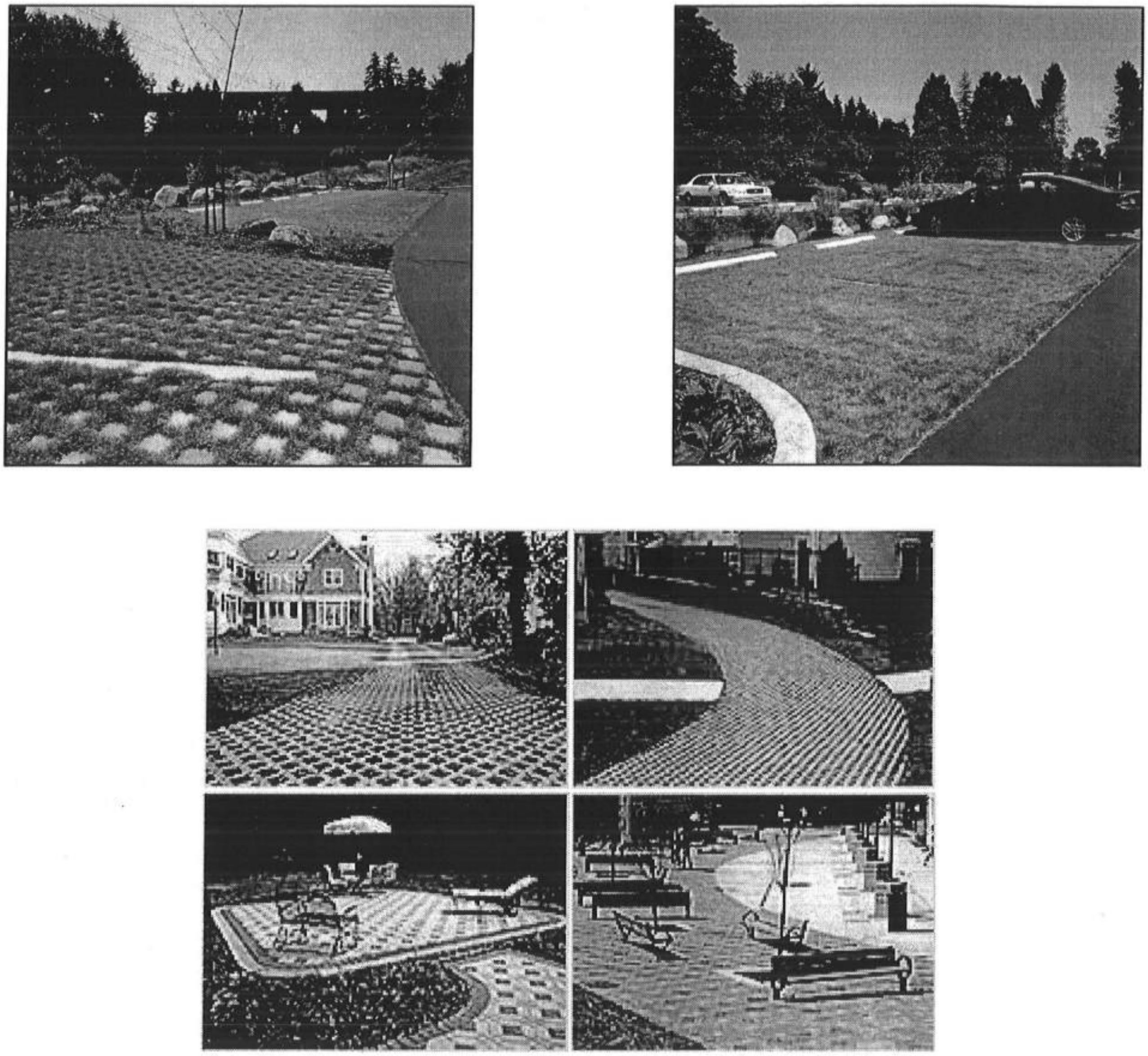
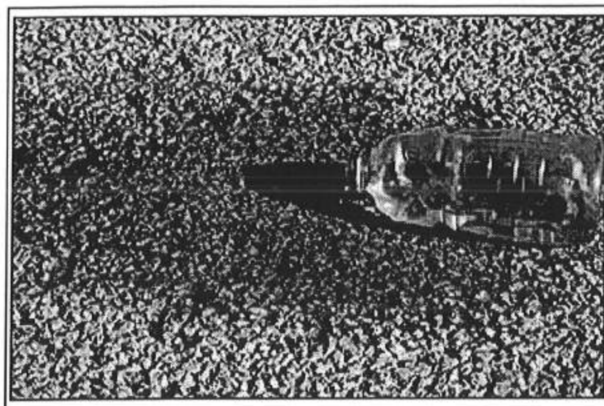


Figure 5.2.23-4 Examples of Porous Paver Surfaces
(Sources: Invisible Structures, Inc.; EP Henry Corp.)

5.2.24 Porous Concrete

Limited Application
Structural Storm Water Control



Description: Porous concrete is the term for a mixture of coarse aggregate, portland cement and water that allows for rapid infiltration of water and overlays a stone aggregate reservoir. This reservoir provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an underdrain system.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for low volume auto traffic areas, or for overflow parking applications
- Should not be used in areas of soils with low permeability, wellhead protection zones, or recharge areas of water supply aquifer recharge areas.
- Soil infiltration rate of 0.5 in/hr or greater required
- Excavated area filled with stone media; gravel and sand filter layers with observation well

ADVANTAGES / BENEFITS:

- Pre-treat runoff if sediment present
- Provides reduction in runoff volume

DISADVANTAGES / LIMITATIONS:

- Restrictions on use by heavy vehicles
- High maintenance requirements
- Special attention to design and construction needed
- Somewhat higher cost when compared to conventional pavements
- Potential for high failure rate if poorly designed, poorly constructed, not adequately maintained, or used in unstabilized areas
- Potential for groundwater contamination

POLLUTANT REMOVAL

NA	**Total Suspended Solids**
50/65%	**Nutrients** - Total Phosphorus / Total Nitrogen removal
60%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
No data	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
S	**Streambank Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Overflow Parking, driveway*

L=Low **M**=Moderate **H**=High

5.2.24.1 General Description

Porous concrete (also referred to as *enhanced porosity concrete*, *porous concrete*, *portland cement pervious pavement*, and *pervious pavement*) is a subset of a broader family of pervious pavements including porous asphalt, and various kinds of grids and paver systems. Porous concrete is thought to have a greater ability than porous asphalt to maintain its porosity in hot weather and thus is provided as a limited application control in this manual. Although, porous concrete has seen growing use, there is still very limited practical experience with this measure. According to the U.S. EPA, porous pavement sites have had a high failure rate – approximately 75 percent. Failure has been attributed to poor design, inadequate construction techniques, soils with low permeability, heavy vehicular traffic, and poor maintenance. This measure, if used, should be carefully monitored over the life of the development.

Porous concrete consists of a specially formulated mixture of portland cement; uniform, open graded course aggregate; and water. The concrete layer has a high permeability often many times that of the underlying permeable soil layer which allows rapid percolation of rainwater through the surface and into the layers beneath. The void space in porous concrete is in the 15% to 22% range compared to three to five percent for conventional pavements. The permeable surface is placed over a layer of open-graded gravel and crushed stone. The void spaces in the stone act as a storage reservoir for runoff.

Porous concrete is designed primarily for storm water quality, i.e. the removal of storm water pollutants. However, it can provide limited runoff quantity control, particularly for smaller storm events. For some smaller sites, trenches can be designed to capture and infiltrate the streambank protection volume (SP_v) in addition to WQ_v. Porous concrete will need to be used in conjunction with another structural control to provide downstream flood control, if required.

Modifications or additions to the standard design have been used to pass flows and volumes in excess of the water quality volume, or to increase storage capacity or treatment. These include:

- Placing a perforated pipe near the top of the crushed stone reservoir to pass excess flows after the reservoir is filled
- Providing surface detention storage in a parking lot, adjacent swale, or detention pond with suitable overflow conveyance
- Connecting the stone reservoir layer to a stone filled trench
- Adding a sand layer and perforated pipe beneath the stone layer for filtration of the water quality volume
- Placing an underground detention tank or vault system beneath the layers

The infiltration rate of the soils in the subgrade should be adequate to support drawdown of the entire runoff capture volume within 24 to 48 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils which could affect the soils' infiltration capability.

Porous concrete systems are typically used in low-traffic areas such as the following types of applications:

- Parking pads in parking lots
- Overflow parking areas
- Residential street parking lanes
- Recreational trails
- Golf cart and pedestrian paths
- Emergency vehicle and fire access lanes

Slopes should be flat or gentle to facilitate infiltration versus runoff and the seasonally high water table or bedrock should be a minimum of two feet below the bottom of the gravel layer if infiltration is to be relied on to remove the stored volume.

Porous concrete has the positive characteristics of volume reduction due to infiltration, groundwater recharge, and an ability to blend into the normal urban landscape relatively unnoticed. It also allows a reduction in the cost of other storm water infrastructure, a fact that may offset the greater placement cost somewhat.

A drawback is the cost and complexity of porous concrete systems compared to conventional pavements. Porous concrete systems require a very high level of construction workmanship to ensure that they function as designed. They experience a high failure rate if they are not designed, constructed, and maintained properly.

Like other infiltration controls, porous concrete should not be used in areas that experience high rates of wind erosion, where highly erosive soils are present, or in drinking water aquifer recharge areas. Also it cannot be used in traffic areas where sanding is used during winter weather.

5.2.24.2 Pollutant Removal Capabilities

As they provide for the infiltration of storm water runoff, porous concrete systems have a high removal of both soluble and particulate pollutants. These pollutants become trapped, absorbed, or broken down in the underlying soil layers. Due to the potential for clogging, porous concrete surfaces should not be used for the removal of sediment or other coarse particulate pollutants.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- **Total Suspended Solids – not applicable**
- **Total Phosphorus – 50%**
- **Total Nitrogen – 65%**
- **Fecal Coliform – insufficient data**
- **Heavy Metals – 60%**

Pollutant removal can be improved through routine vacuum sweeping and high pressure washing, insuring a drainage time of at least 24 hours, pretreating the runoff, having organic material in the subsoil, and using clean washed aggregate (EPA, 1999).

5.2.24.3 Design Criteria and Specifications

- Porous concrete systems can be used where the underlying in-situ subsoils have an infiltration rate greater than 0.5 inches per hour. Therefore, porous concrete systems are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the underlying soils.
- Porous concrete systems should typically be used in applications where the pavement receives tributary runoff only from impervious areas. Actual pervious surface area sizing will depend on achieving a 24 hour minimum and 48 hour maximum draw down time for the design storm volume.
- If runoff is coming from adjacent pervious areas, it is important that those areas be fully stabilized to reduce sediment loads and prevent clogging of the porous paver surface. Pretreatment using filter strips or vegetated swales for removal of course sediments is recommended. (see sections 5.2.12 and 5.2.3)

- Porous concrete systems should not be used on slopes greater than 5% with slopes of no greater than 2% recommended. For slopes greater than 1% barriers perpendicular to the direction of drainage should be installed in sub-grade material to keep it from washing away, or filter fabric should be placed at the bottom and sides of the aggregate to keep soil from migrating into the aggregate and reducing porosity.
- A minimum of four feet of clearance is recommended between the bottom of the gravel base course and underlying bedrock or the seasonally high groundwater table.
- Porous concrete systems should be sited at least 10 feet down-gradient from buildings and 100 feet away from drinking water wells.
- To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Porous concrete should not be used for manufacturing and industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, porous concrete should not be considered for areas with a high pesticide concentration. Porous concrete is also not suitable in areas with karst geology without adequate geotechnical testing by qualified individuals and in accordance with local requirements.
- Porous concrete system designs must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that are too large to be infiltrated by the porous concrete system, or if the surface clogs.
- For the purpose of sizing downstream conveyance and structural control system, porous concrete surface areas can be assumed to 35% impervious. In addition, reduction in water quality volume requirements can be obtained for the runoff volume infiltrated from other impervious areas using the methodology in Section 1.2.
- For treatment control, the design volume should be, at a minimum, equal to the water quality volume. The water quality storage volume is contained in the surface layer, the aggregate reservoir, and the sub-grade above the seasonal high water table – if the sub-grade is sandy. The storm duration (fill time) is normally short compared to the infiltration rate of the sub-grade, a duration of two hours can be used for design purposes. The total storage volume in a layer is equal to the percent of voids times the volume of the layer. Alternately storage may be created on the surface through temporary ponding, though this would tend to accelerate clogging if course sediment or mud settles out on the surface.
- The cross-section typically consists of four layers, as shown in Figure 5.2.24-1. The aggregate reservoir can sometimes be avoided or minimized if the sub-grade is sandy and there is adequate time to infiltrate the necessary runoff volume into the sandy soil without by-passing the water quality volume. Descriptions of each of the layers is presented below:

  Porous Concrete Layer – The porous concrete layer consists of an open-graded concrete mixture usually ranging from depths of 2 to 4 inches depending on required bearing strength and pavement design requirements. Porous concrete can be assumed to contain 18 percent voids (porosity = 0.18) for design purposes. Thus, for example, a 4 inch thick porous concrete layer would hold 0.72 inches of rainfall. The omission of the fine aggregate provides the porosity of the porous pavement. To provide a smooth riding surface and to enhance handling and placement a coarse aggregate of 3/8 inch maximum size is normally used. Use coarse aggregate (3/8 to No. 16) per ASTM C 33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448.

  Top Filter Layer – Consists of a 0.5 inch diameter crushed stone to a depth of 1 to 2 inches. This layer serves to stabilize the porous concrete layer. It can be combined with reservoir layer using suitable stone.

  Reservoir Layer – The reservoir gravel base course consists of washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40% meeting the gradation listed below. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void spaces, but typically ranges from two to four feet. The layer must have a minimum depth of nine inches. The layer should be designed to drain completely in 48 hours. and stored at a minimum the water quality volume (WQ_v). Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 should be used in calculations unless aggregate specific data exist.

Gradation

Sieve Size	% Passing
2 ½"	100
2"	90 – 100
1 ½"	35 – 70
1"	0 – 15
½"	0 - 5

Bottom Filter Layer – The surface of the subgrade should be an 6 inch layer of sand (ASTM C-33 concrete sand or TxDOT Fine Aggregate Grade No. 1) or a 2 inch thick layer of 0.5 inch crushed stone, and be completely flat to promote infiltration across the entire surface. This layer serves to stabilize the reservoir layer, to protect the underlying soil from compaction, and act as the interface between the reservoir layer and the filter fabric covering the underlying soil.

Filter Fabric – It is very important to line the entire trench area, including the sides, with filter fabric prior to placement of the aggregate. The filter fabric serves a very important function by inhibiting soil from migrating into the reservoir layer and reducing storage capacity. Fabric should be MIRIFI # 14 N or equivalent.

Underlying Soil – The underlying soil should have an infiltration capacity of at least 0.5 in/hr, but preferably greater than 0.50 in/hr. as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Infiltration trenches cannot be used in fill soils. Soils at the lower end of this range may not be suited for a full infiltration system. Test borings are recommended to determine the soil classification, seasonal high ground water table elevation, and impervious substrata, and an initial estimate of permeability. Often a double-ring infiltrometer test is done at subgrade elevation to determine the infiltration rate of the least permeable layer, and, for safety, one-half that measured value is taken for infiltration calculations.

- The pit excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench as not to jeopardize the stability of the trench sidewalls. The bottom of the excavated trench should not be loaded so as to cause compaction, and should be scarified prior to placement of sand. The sides of the trench shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling. All infiltration trench facilities should be protected during site construction, and should be constructed after upstream areas have been stabilized.
- An observation well consisting of perforated PVC pipe 4 to 6 inches in diameter should be placed at the downstream end of the facility and protected. The well should be used to determine actual infiltration rates.
- A warning sign should be placed at the facility that states, "Porous Paving used on this site to reduce pollution. Do not resurface with non-porous material or sand during icy weather. Call the local jurisdiction for more information."
- Details of construction of the concrete layer are beyond the scope of this manual. However, construction of porous concrete is exacting, and requires special handling, timing, and placement to perform adequately (LACDPW, 2000, Paine, 1992, Maryland, 1984).

5.2.24.4 Inspection and Maintenance Requirements

Table 5.2.24-1 Typical Maintenance Activities for Porous Concrete Systems

Activity	Schedule
• Initial inspection	Monthly for three months after installation
• Ensure that the porous paver surface is free of sediment	Monthly
• Ensure that the contributing and adjacent area is stabilized and mowed, with clippings removed	As needed, based on inspection
• Vacuum sweep porous concrete surface followed by high pressure hosing to keep pores free of sediment	Four times a year
• Inspect the surface for deterioration or spalling • Check to make sure that the system dewaters between storms	Annually
• Spot clogging can be handled by drilling half-inch holes through the pavement every few feet • Rehabilitation of the porous concrete system, including the top and base course as needed	Upon failure

To ensure proper maintenance of porous pavement, a carefully worded maintenance agreement is essential. It should include specific the specific requirements and establish the responsibilities of the property owner and provide for enforcement.

5.2.24.5 Example Schematics

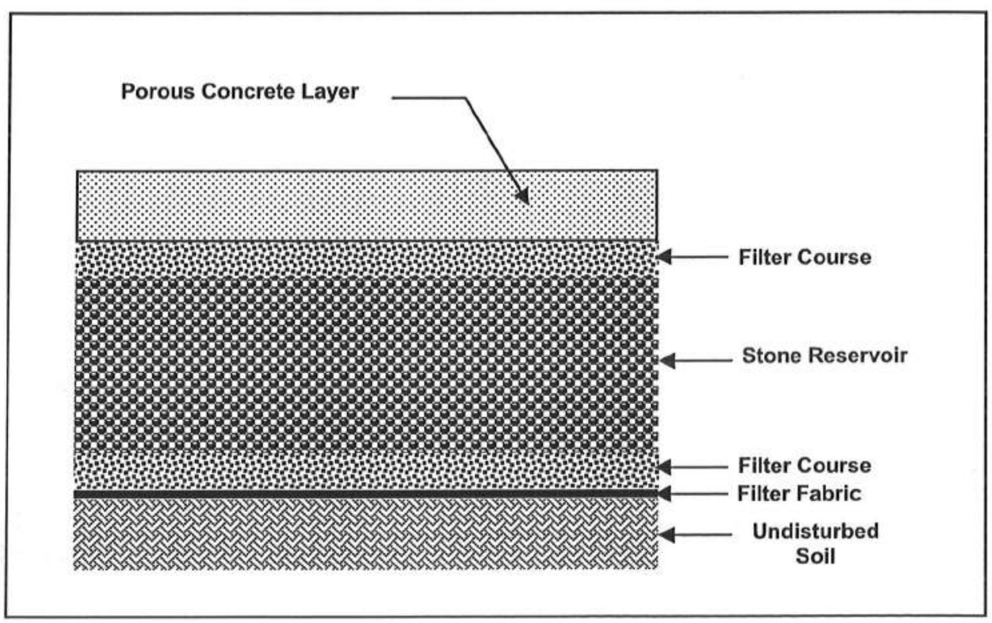


Figure 5.2.24-1 Porous Concrete System Section
(Modified From: LAC 2000)

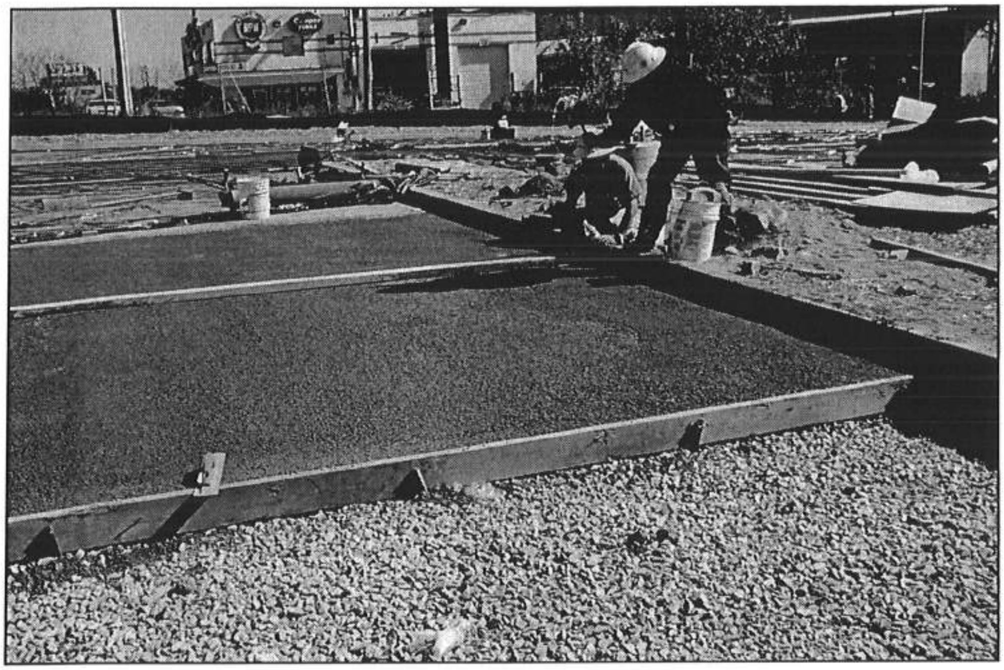


Figure 5.2.24-2 Porous Concrete System Installation

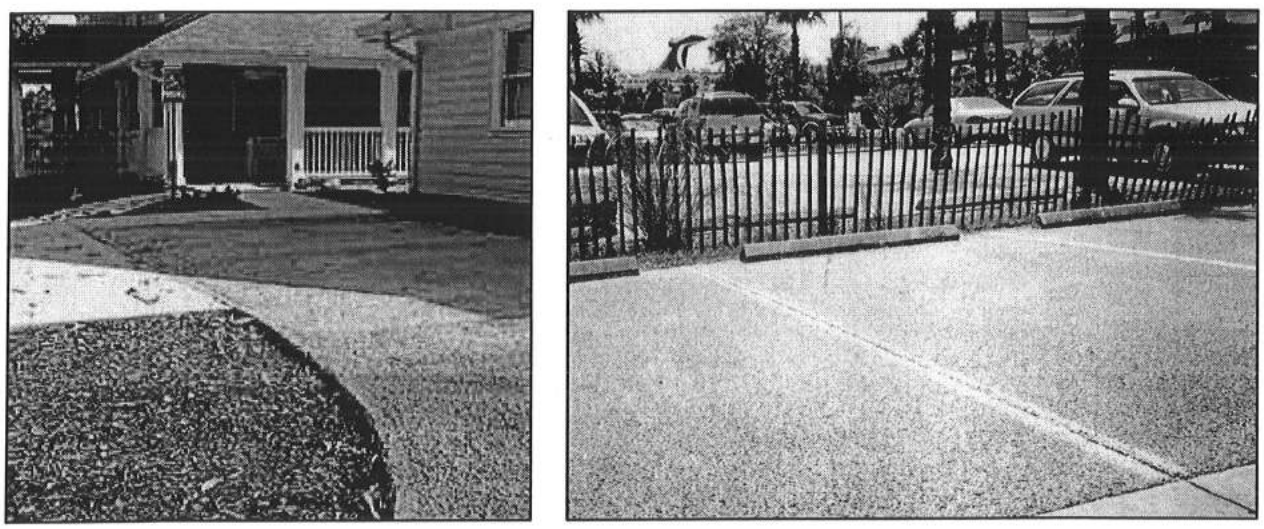


Figure 5.2.24-3 Typical Porous Concrete System Applications
(Photos by Bruce Ferguson, Don Wade)

5.2.24.6 Design Example

Data

A 1.5 acre overflow parking area is to be designed to provide water quality treatment using porous concrete to handle the runoff from the whole overflow parking area. Initial data shows:

- Rainfall depth for treatment is up to 1.5 inches
- Borings show depth to water table is 5.0 feet
- Boring and infiltrometer tests show sand-loam with percolation rate (k) of 1.02 inches/hr

- Structural design indicates the thickness of the porous concrete must be at least three inches

Water Quality Volume

R_v = 0.05 + 0.009 I (where I = 100 percent)
= 0.95

WQ_v = 1.5 R_v A / 12 = 1.5 * 0.95 * 1.5/12 = 0.178 acre-feet
= (0.178 ac-ft) (43,560 cu-ft/ac-ft) = 7,759 cubic feet

Surface Area

A porosity value n = 0.32 should be used for the gravel and 0.18 for the concrete layer.

All infiltration systems should be designed to fully de-water the entire WQ_v within 24 to 48 hours after the rainfall event at the design percolation rate.

A fill time T=2 hours can be used for most designs

Chose a depth of gravel pit of three feet (including layer under concrete) which fits the site with a two foot minimum to water table (other lesser depths could be chosen, making the surface area larger). The minimum surface area of the trench can be determined, in a manner similar to the infiltration trench, from the following equation:

$$A = WQ_v/(n_g d_g + kT/12 + n_p d_p)$$

$$= 7{,}759/(0.32*3 + 1.02*2/12 + 0.18 * 3/12)$$

$$= 6{,}604 \text{ square feet}$$

Where:

A	= Surface Area
WQv	= Water Quality Volume (or total volume to be infiltrated)
n	= porosity (g of the gravel, p of the concrete layer)
d	= depth or gravel layer (feet) (g of the gravel, p of the concrete layer)
k	= percolation (inches/hour)
T	= Fill Time (time for the practice to fill with water), in hours

Check of drain time:
depth = 3*12 + 3 inches to sand layer = 39 inches @ 1.02 in/hr = 38 hours (ok)

Overflow will be carried across the porous concrete and tied into the drainage system for the rest of the site.

5.2.25 Proprietary Structural Controls

Limited Application
Structural Storm Water Control

Description: Manufactured structural control systems available from commercial vendors designed to treat storm water runoff and/or provide water quantity control

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Independent performance data must be available to prove a demonstrated capability of meeting storm water management goal(s)
- System or device must be appropriate for use in North Central Texas conditions, and specifically for the community in question
- Pre-treat runoff if sediment present

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume

DISADVANTAGES / LIMITATIONS:

- Depending on the proprietary system, there may be:
  - Limited performance data
  - Application constraints
  - High maintenance requirements
  - Higher costs than other structural control alternatives
- Installation and operations/maintenance requirements must be understood by all parties approving and using the system or device in question

STORM WATER MANAGEMENT SUITABILITY

S	**Water Quality Protection**
S	**Streambank Protection**
S	**On-Site Flood Control**
S	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential
Subdivision Use: *Depends on the specific proprietary structural control*

High Density/Ultra-Urban: *Yes*

Drainage Area: *Depends on the specific proprietary structural control.*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

Note: It is the policy of this Manual not to recommend any specific commercial vendors for proprietary systems. However, this subsection is being included in order to provide communities with a rationale for approving the use of a proprietary system or practice in their jurisdictions.

5.2.25.1 General Description

There are many types of commercially-available proprietary storm water structural controls available for both water quality treatment and quantity control. These systems include:

- Hydrodynamic systems such as gravity and vortex separators
- Filtration systems
- Catch basin media inserts
- Chemical treatment systems

- Package treatment plants
- Prefabricated detention structures

Many proprietary systems are useful on small sites and space-limited areas where there is not enough land or room for other structural control alternatives. Proprietary systems can often be used in pretreatment applications in a treatment train. However, proprietary systems are often more costly than other alternatives and may have high maintenance requirements. Perhaps the largest difficulty in using a proprietary system is the lack of adequate independent performance data, particularly for use in North Central Texas conditions. Below are general guidelines that should be followed before considering the use of a proprietary commercial system.

5.2.25.2 Guidelines for Using Proprietary Systems

In order for use as a limited application control, a proprietary system must have a demonstrated capability of meeting the storm water management goals for which it is being intended. This means that the system must provide:

1. Independent third-party scientific verification of the ability of the proprietary system to meet water quality treatment objectives and/or to provide water quantity control (streambank or flood control)
2. Proven record of longevity in the field
3. Proven ability to function in North Central Texas conditions (e.g., climate, rainfall patterns, soil types, etc.)
4. Maintainability - Documented procedures for required maintenance including collection and removal of pollutants or debris.

For a proprietary system to meet (1) above for water quality goals, the following monitoring criteria should be met for supporting studies:

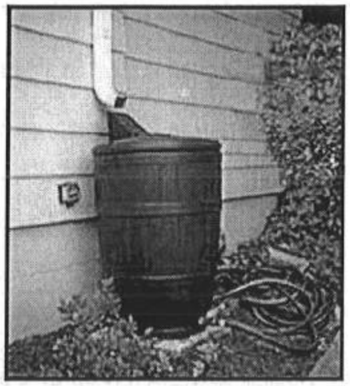
- At least 15 storm events must be sampled
- The study must be independent or independently verified (i.e., may not be conducted by the vendor or designer without third-party verification)
- The study must be conducted in the field, as opposed to laboratory testing
- Field monitoring must be conducted using standard protocols which require proportional sampling both upstream and downstream of the device
- Concentrations reported in the study must be flow-weighted
- The propriety system or device must have been in place for at least one year at the time of monitoring

Although local data is preferred, data from other regions can be accepted as long as the design accounts for the local conditions.

Local governments may submit a proprietary system to further scrutiny based on the performance of similar practices. A poor performance record or high failure rate is valid justification for not allowing the use of a proprietary system or device. Consult your local review authority for more information in regards to the use of proprietary structural storm water controls.

5.2.26 Rain Harvesting (Tanks/Barrels)

Storm Water Control



Description: Rain harvesting is a container or system designed to capture and store rainwater discharged from a roof. The rain harvesting system consists of a storage container, a downspout diversion, a sealed lid, and an overflow system. Typical rain harvesting systems hold between 50 and 500 gallons of water, and may work in series to provide larger volumes of storage.

KEY CONSIDERATIONS

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume
- Low-cost, effective, and easy to maintain
- Offers flexibility with volume of water to capture
- Potential water savings
- Healthier for plants and gardens due to non-chlorinated water

DISADVANTAGES / LIMITATIONS:

- Small storage capacity
- Requires some attention
- If not attended to after a rain, leaking can cause damage to adjacent building foundation
- High construction cost when compared to the low cost of municipal water supply
- Certain roofing materials can cause runoff contamination (re-use)

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
	Streambank Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirement**
L	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *depends on manufacture's model*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

5.2.26.1 General Description

Rain harvesting (also referred to as *rain pails* and *rain savers*) are used as a water conservation practice and a storm water management strategy. Capturing water in a rain tank/barrel prevents runoff from flowing down a driveway or across a parking lot and picking up soil, pesticides, and other pollutants before entering the storm sewer system.

Rain tanks/barrels not only store water, but also help to decrease the water supply demand during the sweltering summer months. Only 1/4 inch of rainfall runoff from the average roof will completely fill the typical barrel. Collection of water from rooftop runoff can provide an ample supply of free 'soft water' containing no chlorine, lime, or calcium. Because it tends to have fewer sediments and dissolved salts than municipal water, rain water is ideal for a multitude of applications, including organic vegetable gardens, planter beds for botanicals, indoor plants, automobile washing, and cleaning household windows. Saving water in this manner will reduce the demand for treated tap water, and save money by lowering the homeowner's monthly bill. Rain water diversion will also help decrease the burden on water treatment facilities and municipal drainage systems during storm events.

A typical rain harvesting design will include a storage container with a hole at the top to allow for flow from a downspout, a sealed lid, an overflow pipe and a spigot at or near the bottom of the barrel. The spigot can be left partially open to detain water or closed to fill the barrel. A screen is often included to control mosquitoes and other insects. Rain tanks/barrels can be connected in series to provide larger volumes of storage. Larger systems for commercial or industrial use can include pumps and filtration systems.

For every inch of rain that falls on a catchment area of 1,000 square feet, approximately 600 gallons of rainwater can be collected. Ten inches of rain falling on a 1,000 square foot catchment area will generate approximately 6,000 gallons of rainwater.

5.2.26.2 Design Criteria and Specifications

- The required capacity of a rain barrel is a function of the rooftop surface area that drains to it, the inches of rainfall required to fill the barrel, and water losses due primarily to evaporation. The general rule of thumb to utilize in the sizing of rain barrels is 1 inch of rainfall on a 1000 square foot roof will yield approximately 600 gallons.

Sample Calculation	
Rain barrel volume can be determined by calculating the roof top water yield for any given rainfall, using the following general equation:	
Equation 1. $V = A^2 \times R \times 0.90 \times 7.5$ *gals./ ft.*^{3} where:	
V	= volume of rain barrel (gallons)
A^2	= surface area roof (square feet)
R	= rainfall (feet)
0.90	= losses to system (no units)
7.5	= conversion factor (gallons per cubic foot)
Example: one 60-gallon barrel would provide runoff storage from a rooftop area of approximately 212 square feet for a 1.5 inch (0.125 ft.) of rainfall. $V = 212\ ft.^2 \times 0.125\ ft. \times 0.90 \times 7.5\ gallons/ft.^3 = 179\ gallons$	

- Homeowners and manufacturers typically use a flexible plastic downspout elbow to direct water from the downspout into the rain tank/barrel. It is best to use the downspout connector only for smaller drainage areas or to use a diverter that can be engaged either automatically or with physical contact.
- The use of screens should be considered on gutters and downspouts to remove sediment and particles as the water enters the barrel.
- Containers should be opaque to discourage bacteria/algae growth.
- Most rain barrels are equipped with tight covers and screens to prevent accidents involving children and pets and to keep debris out of the barrels. To combat concerns regarding mosquitoes and West Nile virus, tight fitting screens should be inspected and maintained on a routine basis or nontoxic mosquito control agent (Bti) placed in water.
- A half-barrel design will allow the barrel to sit flush against a building and may prove to be more aesthetically pleasing.
- A typical rain barrel will include spigot at the top to accommodate overflow (this should be directed away from the foundation of the building) and a gravity-fed hose bib at the bottom to connect a hose for redistribution of the rainwater.
- Inexpensive rain barrels can be made from food grade plastic barrels or heavy-duty trash cans, for as little as $15 or they can be purchased pre-made from numerous non-profit organizations, commercial manufacturers, and retailers, in prices ranging from $25 to $150.

5.2.26.3 Example Schematics

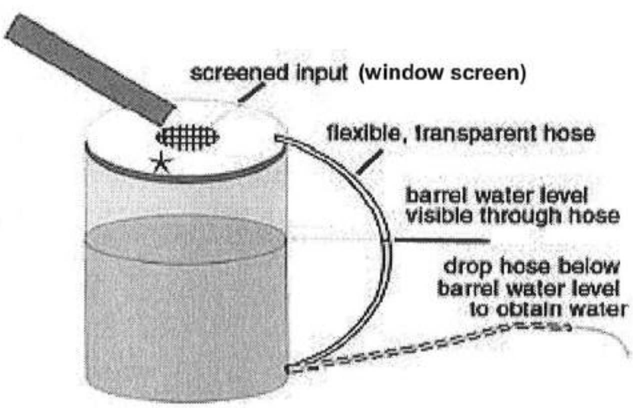


Figure 5.2.26-1 Simple Rain Barrel Design (from Maryland DNR Green Building Program)

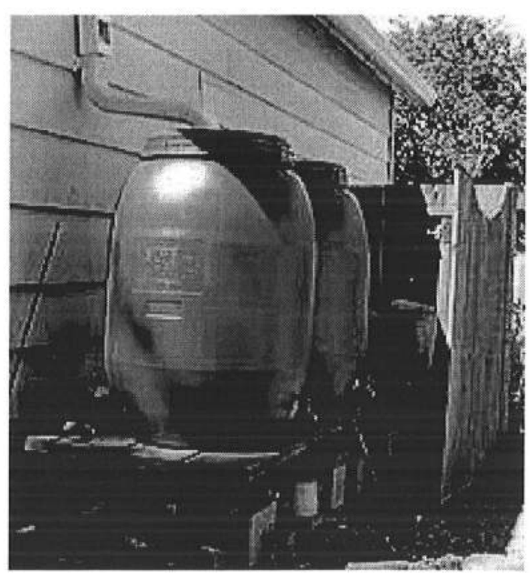


Figure 5.2.26-2 Rain barrels in series

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5.2.27 Storm Water Wetlands

Storm Water Control

Description: Constructed wetland systems used for storm water management. Runoff volume is both stored and treated in the wetland facility.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Minimum contributing drainage area of 25 acres; 5 acres for pocket wetland
- Minimum dry weather flow path of 2:1 (length: width) should be provided from inflow to outflow
- Minimum of 35% of total surface area should have a depth of 6 inches or less; 10 to 20% of surface area should be deep pool (1.5- to 6-foot depth)

ADVANTAGES / BENEFITS:

- Good nutrient removal
- Provides natural wildlife habitat
- Relatively low maintenance costs

DISADVANTAGES / LIMITATIONS:

- Requires large land area
- Needs continuous baseflow for viable wetland
- Sediment regulation is critical to sustain wetlands
- Large commitment to establish vegetation in the first 3 years

MAINTENANCE REQUIREMENTS:

- Replace wetland vegetation to maintain at least 50% surface area coverage
- Remove invasive vegetation
- Monitor sediment accumulation and remove periodically

POLLUTANT REMOVAL

80%	**Total Suspended Solids**
40/30%	***Nutrients** - Total Phosphorus / Total Nitrogen removal
50%	**Metals** - Cadmium, Copper, Lead, and Zinc removal
70%	**Pathogens** - Coliform, Streptococci, E.Coli removal

STORM WATER MANAGEMENT SUITABILITY

P	**Water Quality Protection**
P	**Streambank Protection**
P	**On-Site Flood Control***
P	**Downstream Flood Control***

**Does not apply to Submerged Gravel Wetland Systems*

Accepts Hotspot Runoff: *Yes*
(2 feet of separation distance required to water table)

IMPLEMENTATION CONSIDERATIONS

M-H	**Land Requirement**
M	**Capital Cost**
	Maintenance Burden:
M	Shallow Wetland
M	ED Shallow Wetland
H	Pocket Wetland
M	Pond/Wetland

Residential Subdivision Use: *Yes*

High-Density/Ultra-Urban: *No*

Drainage Area: *25 acres min.*

Soils: *Hydrologic group 'A' and 'B' soils may require a liner*

L=Low M=Moderate H=High

5.2.27.1 General Description

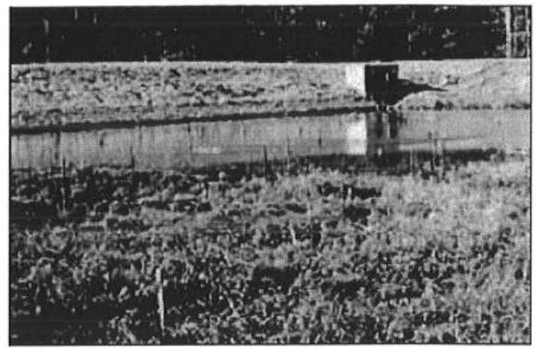
Storm water wetlands (also referred to as constructed wetlands) are constructed shallow marsh systems that are designed to both treat urban storm water and control runoff volumes. As storm water runoff flows through the wetland facility, pollutant removal is achieved through settling and uptake by marsh vegetation.

Wetlands are among the most effective storm water practices in terms of pollutant removal and also offer aesthetic value and wildlife habitat. Constructed storm water wetlands differ from natural wetland systems in that they are engineered facilities designed specifically for the purpose of treating storm water runoff and typically have less biodiversity than natural wetlands both in terms of plant and animal life. However, as with natural wetlands, storm water wetlands require a continuous base flow or a high water table to support aquatic vegetation.

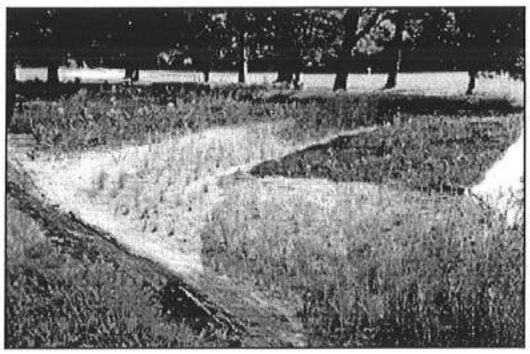
There are several design variations of the storm water wetland, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. These include the shallow wetland, the extended detention shallow wetland, pond/wetland system, and pocket wetland. Figure 5.2.27-1 contains photos of various wetlands. Below are descriptions of each design variant:

- **Shallow Wetland** – In the shallow wetland design, most of the water quality treatment volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland, and the micropool at the outlet. One disadvantage of this design is that, since the pool is very shallow, a relatively large amount of land is typically needed to store the water quality volume.
- **Extended Detention (ED) Shallow Wetland** – The extended detention (ED) shallow wetland design is the same as the shallow wetland; however, part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24 hours. This design can treat a greater volume of storm water in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate both wet and dry periods need to be specified in the extended detention zone.
- **Pond/Wetland Systems** – The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland where storm water flows receive additional treatment. Less land is required for a pond/wetland system than for the shallow wetland or the extended detention shallow wetland systems.
- **Pocket Wetland** – A pocket wetland is intended for smaller drainage areas of 5 to 10 acres and typically requires excavation down to the water table for a reliable water source to support the wetland system.
- **Submerged Gravel -** Also known as subsurface flow wetlands, this wetland consists of one or more cells filled with crushed rock designed to support wetland plants. Storm water flows subsurface through the root zone of the constructed wetland where pollutant removal takes place. *This type of wetland is not recommended for use to meet storm water management goals due to limited performance data.* They may be applicable in special or retrofit situations where there are severe limitations on what can be implemented.

Shallow Wetland

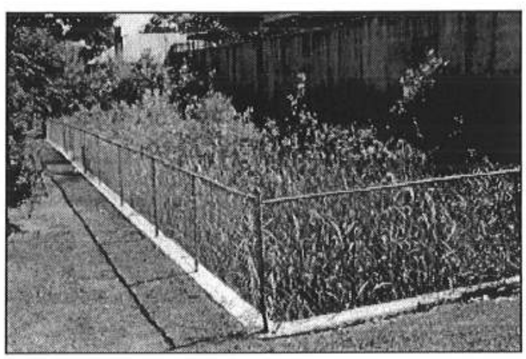


Shallow ED Wetland



Newly Constructed Shallow Wetland

Pocket Wetland



Submerged Gravel Wetland

Figure 5.2.27-1 Storm Water Wetland Examples

5.2.27.2 Storm Water Management Suitability

Similar to storm water ponds, storm water wetlands are designed to control both storm water quantity and quality. Thus, a storm water wetland can be used to address all of the integrated storm water sizing criteria for a given drainage area.

Water Quality

Pollutants are removed from storm water runoff in a wetland through uptake by wetland vegetation and algae, vegetative filtering, and through gravitational settling in the slow moving marsh flow. Other pollutant removal mechanisms are also at work in a storm water wetland including chemical and biological decomposition and volatilization. Section 5.2.27.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Streambank Protection

The storage volume above the permanent pool/water surface level in a storm water wetland is used to provide control of the streambank protection volume (SP_v). This is accomplished by releasing the 1-year, 24-hour storm runoff volume over 24 hours (extended detention). It is best to do this with minimum vertical water level fluctuation, as extreme fluctuation may stress vegetation.

Flood Control

In situations where it is required, storm water wetlands can also be used to provide detention to control the 100-year storm peak flow. Where 100-year peak control is not required, a storm water wetland must be designed to safely pass the 100-year storm flows.

5.2.27.3 Pollutant Removal Capabilities

All of the storm water wetland design variants are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed wetland facilities can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 40%**
- **Total Nitrogen – 30%**
- **Fecal Coliform – 70% (if no resident waterfowl population present)**
- **Heavy Metals – 50%**

For additional information and data on pollutant removal capabilities for storm water wetlands, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Storm Water Best Management Practices (BMP) Database at www.bmpdatabase.org

Submerged Gravel Wetland

The pollution removal efficiency of the submerged gravel wetland is similar to a typical wetland. Recent data show a TSS removal rate in excess of the 80% goal. This reflects the settling environment of the gravel media. These systems also exhibit removals of about 60% TP, 20% TN, and 50% Zn. The growth of algae and microbes among the gravel media has been determined to be the primary removal mechanism of the submerged gravel wetland.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- **Total Suspended Solids – 80%**
- **Total Phosphorus – 50%**
- **Total Nitrogen – 20%**
- **Fecal Coliform – 70%**

- **Heavy Metals – 50%**

Although gravel wetlands are fairly effective at removing total phosphorus, they have a tendency to contribute small amounts of soluble phosphorus.

5.2.27.4 Application and Site Feasibility Criteria

Storm water wetlands are generally applicable to most types of new development and redevelopment, and can be utilized in both residential and nonresidential areas. However, due to the large land requirements, wetlands may not be practical in higher density areas. The following criteria should be evaluated to ensure the suitability of a storm water wetland for meeting storm water management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – Land requirements may preclude use
- Regional Storm Water Control – YES
- Hot Spot Runoff - YES

Physical Feasibility - Physical Constraints at Project Site

- <u>Drainage Area</u> – A minimum of 25 acres and a positive water balance is needed to maintain wetland conditions; 5 acres for pocket wetland
- <u>Space Required</u> – Approximately 3 to 5% of the tributary drainage area
- <u>Site Slope</u> – There should be no more than 8% slope across the wetland site
- <u>Minimum Head</u> – Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet; 2 to 3 feet for pocket wetland
- <u>Minimum Depth to Water Table</u> – If used on a site with an underlying water supply aquifer or when treating a hotspot, a separation distance of 2 feet is recommended between the bottom of the wetland and the elevation of the seasonally high water table; pocket wetland is typically below water table.
- <u>Soils</u> – Permeable soils are not well suited for a constructed storm water wetland without a high water table. Underlying soils of hydrologic group "C" or "D" should be adequate to maintain wetland conditions. Most group "A" soils and some group "B" soils will require a liner. *Evaluation of soils should be based upon an actual subsurface analysis and permeability tests.*

5.2.27.5 Planning and Design Criteria

*The following criteria are to be considered **minimum** standards for the design of a storm water wetland facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

A. LOCATION AND SITING

- Storm water wetlands should normally have a minimum contributing drainage area of 25 acres or more. For a pocket wetland, the minimum drainage area is 5 acres.
- A continuous base flow or high water table is required to support wetland vegetation. A water balance must be performed to demonstrate that a storm water wetland can withstand a 30-day drought at summer evaporation rates without completely drawing down (see subsection 2.1.8 for details).
- Wetland siting should also take into account the location and use of other site features such as natural depressions, buffers, and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape. Bedrock close to the surface may prevent excavation.

- Storm water wetlands cannot be located within navigable waters of the U.S., including natural wetlands, without obtaining a Section 404 permit under the Clean Water Act, and any other applicable State permit. In some isolated cases, a wetlands permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts.
- If a wetland facility is not used for flood control less than the 100 year event, it should be designed as an off-line system to bypass higher flows rather than passing them through the wetland system.
- Minimum setback requirements for storm water wetland facilities (when not specified by local ordinance or criteria):
  - From a property line – 10 feet
  - From a private well – 100 feet; if well is downgradient from a hotspot land use then the minimum setback is 250 feet
  - From a septic system tank/leach field/spray area – 50 feet
- All utilities should be located outside of the wetland site.

B. GENERAL DESIGN

- A well-designed storm water wetland consists of:
  1. Shallow marsh areas of varying depths with wetland vegetation,
  2. Permanent micropool, and
  3. Overlying zone in which runoff control volumes are stored.

Pond/wetland systems also include a storm water pond facility (see Section 5.2.21, *Storm Water Ponds*, for pond design information).

- In addition, all wetland designs must include a sediment forebay at the inflow to the facility to allow heavier sediments to drop out of suspension before the runoff enters the wetland marsh.
- Additional wetland design features include an emergency spillway, maintenance access, safety bench, wetland buffer, and appropriate wetland vegetation and native landscaping.

Figures 5.2.27-3 through 5.2.27-6 in subsection 5.2.27.8 provide plan view and profile schematics for the design of a shallow wetland, extended detention shallow wetland, pond/wetland system, and pocket wetland, respectively.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

In general, wetland designs are unique for each site and application. However, there are a number of geometric ratios and limiting depths for the design of a storm water wetland that must be observed for adequate pollutant removal, ease of maintenance, and improved safety. Table 5.2.27-1 provides the recommended physical specifications and geometry for the various storm water wetland design variants.

Table 5.2.27-1 Recommended Design Criteria for Storm Water Wetlands
Modified from Massachusetts DEP, 1997; Schueler, 1992

Design Criteria	Shallow Wetland	ED Shallow Wetland	Pond/ Wetland	Pocket Wetland
Length to Width Ratio (minimum)	2:1	2:1	2:1	2:1
Extended Detention (ED)	No	Yes	Optional	Optional
Allocation of WQ_v Volume (pool/marsh/ED) in %	25/75/0	25/25/50	70/30/0 (includes pond volume)	25/75/0
Allocation of Surface Area (deepwater/low marsh/high marsh/semi-wet) in %	20/35/40/5	10/35/45/10	45/25/25/5 (includes pond surface area)	10/45/40/5
Forebay	Required	Required	Required	Required
Micropool	Required	Required	Required	Required
Outlet Configuration	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir	Hooded broad-crested weir

- The storm water wetland should be designed with the recommended proportion of "depth zones." Each of the four wetland design variants has depth zone allocations which are given as a percentage of the storm water wetland surface area. Target allocations are found in Table 5.2.27-1. The four basic depth zones are:

  Deepwater zone
  From 1.5 to 6 feet deep. Includes the outlet micropool and deepwater channels through the wetland facility. This zone supports little emergent wetland vegetation, but may support submerged or floating vegetation.

  Low marsh zone
  From 6 to 18 inches below the normal permanent pool or water surface elevation. This zone is suitable for the growth of several emergent wetland plant species.

  High marsh zone
  From 6 inches below the pool to the normal pool elevation. This zone will support a greater density and diversity of wetland species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.

  Semi-wet zone
  Those areas above the permanent pool that are inundated during larger storm events. This zone supports a number of species that can survive flooding.

- A minimum dry weather flow path of 2:1 (length to width) is required from inflow to outlet across the storm water wetland and should ideally be greater than 3:1. This path may be achieved by constructing internal dikes or berms, using marsh plantings, and by using multiple cells. Finger dikes are commonly used in surface flow systems to create serpentine configurations and prevent short-circuiting. Microtopography (contours along the bottom of a wetland or marsh that provide a variety of conditions for different species needs and increases the surface area to volume ratio) is encouraged to enhance wetland diversity.

- A 4- to 6-foot deep micropool must be included in the design at the outlet to prevent the outlet from clogging and resuspension of sediments, and to mitigate thermal effects.

- Maximum depth of any permanent pool areas should generally not exceed 6 feet.
- The volume of the extended detention must not comprise more than 50% of the total WQ_v, and its maximum water surface elevation must not extend more than 3 feet above the normal pool. Q_p and/or SP_v storage can be provided above the maximum WQ_v elevation within the wetland.
- The perimeter of all deep pool areas (4 feet or greater in depth) should be surrounded by safety and aquatic benches similar to those for storm water ponds (see subsection 5.2.21).
- The contours of the wetland should be irregular to provide a more natural landscaping effect.

D. SUBMERGED GRAVEL WETLANDS

- Submerged gravel wetlands should be designed as off-line systems designed to handle only water quality volume.
- Submerged gravel wetland systems need sufficient drainage area to maintain vegetation. See subsection 2.1.12 for guidance on performing a water balance calculation.
- The local slope should be relatively flat (<2%). While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 3 to 5 feet).
- A design maximum depth of 16 inches of water at the inlet is recommended, with a total gravel depth of 20 inches.
- Gravel should be 0.5-1.0 inch in size.
- Darcy's Law may be used to estimate flows in the gravel media, although the use of predesign tests with the actual gravel will refine the "effective" hydraulic conductivity.
- The initial design should not utilize more than 70 percent of the potential hydraulic gradient available in the proposed bed to allow a safety factor for clogging.
- Using a value of < 113 $m^3/m^2/d$ for the "effective" hydraulic conductivity (k_s) in the design will also help account for potential clogging.
- An adjustable outlet is recommended to ensure adequate hydraulic gradient and prevent surface flow from occurring and shortcircuiting treatment within the gravel media.
- Washed stone or gravel, should be specified to protect against an accumulation of fine material that could cause hydraulic blockages.
- All submerged gravel wetland designs should include a sediment forebay or other equivalent pretreatment measures to prevent sediment or debris from entering and clogging the gravel bed.
- Unless they receive hotspot runoff, submerged gravel wetland systems can be allowed to intersect the groundwater table.
- Guidance on establishing wetland vegetation can be found in Appendix F, *Landscaping and Aesthetics Guidance*.

E. PRETREATMENT / INLETS

- Sediment regulation is critical to sustain storm water wetlands. A wetland facility should have a sediment forebay or equivalent upstream pretreatment. A sediment forebay is designed to remove incoming sediment from the storm water flow prior to dispersal into the wetland. The forebay should consist of a separate cell, formed by an acceptable barrier. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the wetland facility.
- The forebay is sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The pretreatment storage volume is part of the total WQ_v requirement and may be subtracted from WQ_v for wetland storage sizing.

- A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.
- Inflow channels are to be stabilized with flared riprap aprons, or the equivalent. Inlet pipes to the pond can be partially submerged. Inflow pipe, channel velocities and exit velocities from the forebay must be nonerosive.

F. OUTLET STRUCTURES

- Flow control from a storm water wetland is typically accomplished with the use of a concrete or corrugated aluminum, aluminized steel, or HDPE riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the base of the micropool with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see Figure 5.2.27-2). The riser should be located within the embankment for maintenance access, safety, and aesthetics.
- A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality protection, streambank protection, and flood control runoff volumes. The number of orifices can vary and is usually a function of the pond design.

  For shallow and pocket wetlands, the riser configuration is typically comprised of a streambank protection outlet (usually an orifice) and flood control outlet (often a slot or weir). The streambank protection orifice is sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams). Since the water quality volume is fully contained in the permanent pool, no orifice sizing is necessary for this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the streambank protection orifice. Thus an off-line shallow or pocket wetland providing *only* water quality treatment can use a simple overflow weir as the outlet structure.

  In the case of a extended detention (ED) shallow wetland, there is generally a need for an additional outlet (usually an orifice) that is sized to pass the extended detention water quality volume that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to release the water quality extended detention volume in 24 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next outlet is sized for the release of the streambank protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention water quality volume and is sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams).

  Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch, proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the normal pool.

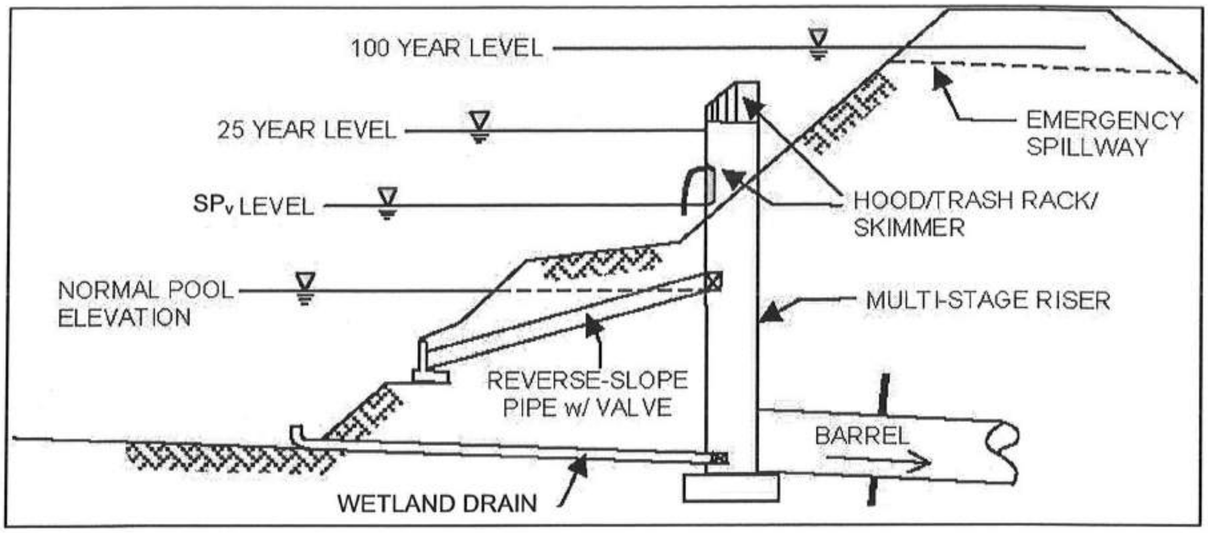


Figure 5.2.27-2 Typical Wetland Facility Outlet Structure

- The water quality outlet (if design is for an extended detention shallow wetland) and streambank protection outlet should be fitted with adjustable gate valves or other mechanism that can be used to adjust detention time.
- Higher flows pass through openings or slots protected by trash racks further up on the riser.
- After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the outlet of the barrel to prevent scouring and erosion. If a wetland facility daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. See Section 4.7 (*Energy Dissipation*) for more guidance.
- The wetland facility must have a bottom drain pipe located in the micropool with an adjustable valve that can completely or partially dewater the wetland within 24 hours.
- The wetland drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

See the design procedures in Section 4.5 (*Storage Design*) and Section 4.6 (*Outlet Structures*) for additional information and specifications on pond routing and outlet works.

G. EMERGENCY SPILLWAY

- An emergency spillway is to be included in the storm water wetland design to safely pass flows that exceed the design storm flows. The spillway prevents the wetland's water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the 100-year flood to the lowest point on top of the dam, not counting the emergency spillway.

H. MAINTENANCE ACCESS

- A maintenance right of way or easement must be provided to the wetland facility from a public road or easement. Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls.

I. SAFETY FEATURES

- All embankments and spillways must be designed to State of Texas Administrative Code for dams and reservoirs (see Appendix H).
- Fencing of wetlands is not generally desirable, but may be required by the local review authority. A preferred method is to manage the contours of deep pool areas through the inclusion of a safety bench (see above) to eliminate dropoffs and reduce the potential for accidental drowning.
- The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

J. LANDSCAPING

- A landscaping plan should be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of landscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed), and sources of plant material.
- Landscaping zones include low marsh, high marsh, and semi-wet zones. The low marsh zone ranges from 6 to 18 inches below the normal pool. This zone is suitable for the growth of several emergent plant species. The high marsh zone ranges from 6 inches below the pool up to the normal pool. This zone will support greater density and diversity of emergent wetland plant species. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone. The semi-wet zone refers to those areas above the permanent pool that are inundated on an irregular basis and can be expected to support wetland plants.
- The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.
- Woody vegetation may not be planted on a dam embankment or allowed to grow within 15 feet of the toe of the dam and 25 feet from the principal spillway structure.
- A wetland buffer shall extend 25 feet outward from the maximum water surface elevation, with an additional 15-foot setback to structures. The wetland buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall storm water management concept plan. No structures should be located within the buffer, and an additional setback to permanent structures may be provided.
- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To discourage resident water fowl populations, the buffer can be planted with trees, shrubs and native ground covers.
- The soils of a wetland buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration and therefore may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites and backfill these with uncompacted topsoil.

Guidance on establishing wetland vegetation can be found in Appendix F (*Landscaping and Aesthetics Guidance*).

K. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- Low Relief – Providing wetland drain can be problematic
- High Relief – Embankment heights restricted
- Karst – Requires poly or clay liner to sustain a permanent pool of water and protect aquifers; limits on ponding depth; geotechnical tests may be required

Soils

- Hydrologic group "A" soils and some group "B" soils may require liner (not relevant for pocket wetland)

Special Downstream Watershed Considerations

- Local Aquatic Habitat – Design wetland offline and provide shading to reduce thermal impact; limit WQ_v-ED to 12 hours
- Aquifer Protection – Prevent possible groundwater contamination by preventing infiltration of hotspot runoff. May require liner for type "A" soils; Pretreat hotspots; 2 to 4 foot separation distance from water table.

5.2.27.6 Design Procedures

Step 1. Compute runoff control volumes from the *integrated* Design Approach

Calculate the Water Quality Volume (WQ_v), Streambank protection Volume (SP_v), and the 100-year Flood Discharge, (for ED wetlands the design volume should be increased by 15%).

Details on the *integrated* Design Approach are found in Section 1.2.

Step 2. Determine if the development site and conditions are appropriate for the use of a storm water wetland

Consider the Application and Site Feasibility Criteria in subsections 5.2.27.4 and 5.2.27.5-A (Location and Siting).

Step 3. Confirm local design criteria and applicability

Consider any special site-specific design conditions/criteria from subsection 5.2.27.5-K (Additional Site-Specific Design Criteria and Issues).

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 4. Determine pretreatment volume

A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The forebay storage volume counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.

Step 5. Allocate the WQ_v volume among marsh, micropool, and extended detention volumes

Use recommended criteria from Table 5.2.27-1.

Step 6. Determine wetland location and preliminary geometry, including distribution of wetland depth zones

This step involves initially laying out the wetland design and determining the distribution of wetland surface area among the various depth zones (high marsh, low marsh, and deepwater). Set WQ_v permanent pool elevation (and WQ_v-ED elevation for extended detention shallow wetland) based on volumes calculated earlier.

See subsection 5.2.27.5-C (Physical Specification / Geometry) for more details.

Step 7. Compute extended detention orifice release rate(s) and size(s), and establish SP_v elevation

Shallow Wetland and Pocket Wetland: The SP_v elevation is determined from the stage-storage relationship and the orifice is then sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams). The streambank protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool is a recommended design. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an over-perforated vertical stand pipe with ½-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.

ED Shallow Wetland: Based on the elevations established in Step 6 for the extended detention portion of the water quality volume, the water quality orifice is sized to release this extended detention volume in 24 hours. The water quality orifice should have a minimum diameter of 3 inches, and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged one foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter. The SP_v elevation is then determined from the stage-storage relationship. The invert of the streambank protection orifice is located at the water quality extended detention elevation, and the orifice is sized to release the streambank protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams).

Step 8. Calculate the intermediate flood control release rate and water surface elevation

Set up a stage-storage-discharge relationship for the control structure for the extended detention orifice(s) and the flood control storm.

Step 9. Design embankment(s) and spillway(s)

Size emergency spillway, calculate 100-year water surface elevation, set top of embankment elevation, and analyze safe passage of the 100-year event (Q_f).

At final design, provide safe passage for the 100-year event. Attenuation may not be required.

Step 10. Investigate potential pond/wetland hazard classification

The design and construction of storm water management ponds and wetlands are required to follow the latest version of the State of Texas Administrative Code for dams and reservoirs (see Appendix H).

Step 11. Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features.

See subsection 5.2.27.5-E through I for more details.

Step 12. Prepare Vegetation and Landscaping Plan

A landscaping plan for the wetland facility and its buffer should be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation.

See subsection 5.2.27.5-J (Landscaping) and Appendix F for more details.

5.2.27.7 Inspection and Maintenance Requirements

Table 5.2.27-2 Typical Maintenance Activities for Wetlands
(Adapted from WMI, 1997 and CWP, 1998)

Constructed Wetland Systems	
Activity	**Schedule**
• Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	One-Time Activity
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Frequently (3 to 4 times/year)
• Monitor wetland vegetation and perform replacement planting as necessary.	Semi-annual Inspection (first 3 years)
• Examine stability of the original depth zones and microtopographical features. • Inspect for invasive vegetation, and remove where possible. • Inspect for damage to the dam and inlet/outlet structures. Repair as necessary. • Note signs of hydrocarbon build-up, and remove appropriately • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual Inspection
• Repair undercut or eroded areas.	As Needed
• Harvest wetland plants that have been "choked out" by sediment build-up.	Annually
• Removal of sediment from the forebay	5 to 7 years or after 50% of the total forebay capacity has been lost
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	10 to 20 years or after 25% of the wetland volume has been lost
• Ensure that inlets and outlets to each submerged gravel wetland cell are free from debris and not clogged. • Check for sediment buildup in gravel bed.	Monthly Annual inspection
• If sediment buildup is preventing flow through the wetland, remove gravel and sediment from cell. Replace with clean gravel and replant vegetation.	As needed
• Although there is less evaporation with a submerged as opposed to a surface wetland, supplemental water may be required during long periods without storm water input.	As needed
• Routine maintenance of the vegetation (including harvesting) is not required, although weeds can be controlled by flooding the surface after planting and during early part of growing season.	As needed

Additional Maintenance Considerations and Requirements

- Maintenance requirements for constructed wetlands are particularly high while vegetation is being established. Monitoring during these first years is crucial to the future success of the wetland as a storm water structural control. Wetland facilities should be inspected after major storms (greater than 2 inches of rainfall) during the first year of establishment to assess bank stability, erosion damage, flow channelization, and sediment accumulation within the wetland. For the first 3 years, inspections should be conducted at least twice a year.
- A sediment marker should be located in the forebay to determine when sediment removal is required.
- Accumulated sediments will gradually decrease wetland storage and performance. The effects of sediment deposition can be mitigated by the removal of the sediments.
- Sediments excavated from storm water wetlands that do not receive runoff from designated hotspots are not considered toxic or hazardous material and can be safely disposed of by either land application or landfilling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present. Sediment removed from storm water wetlands should be disposed of according to an approved erosion and sediment control plan.
- Periodic mowing of the wetland buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.

> ⚠ Regular inspection and maintenance is critical to the effective operation of storm water wetlands as designed. Maintenance responsibility for a wetland facility and its buffer should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

5.2.27.8 Example Schematics

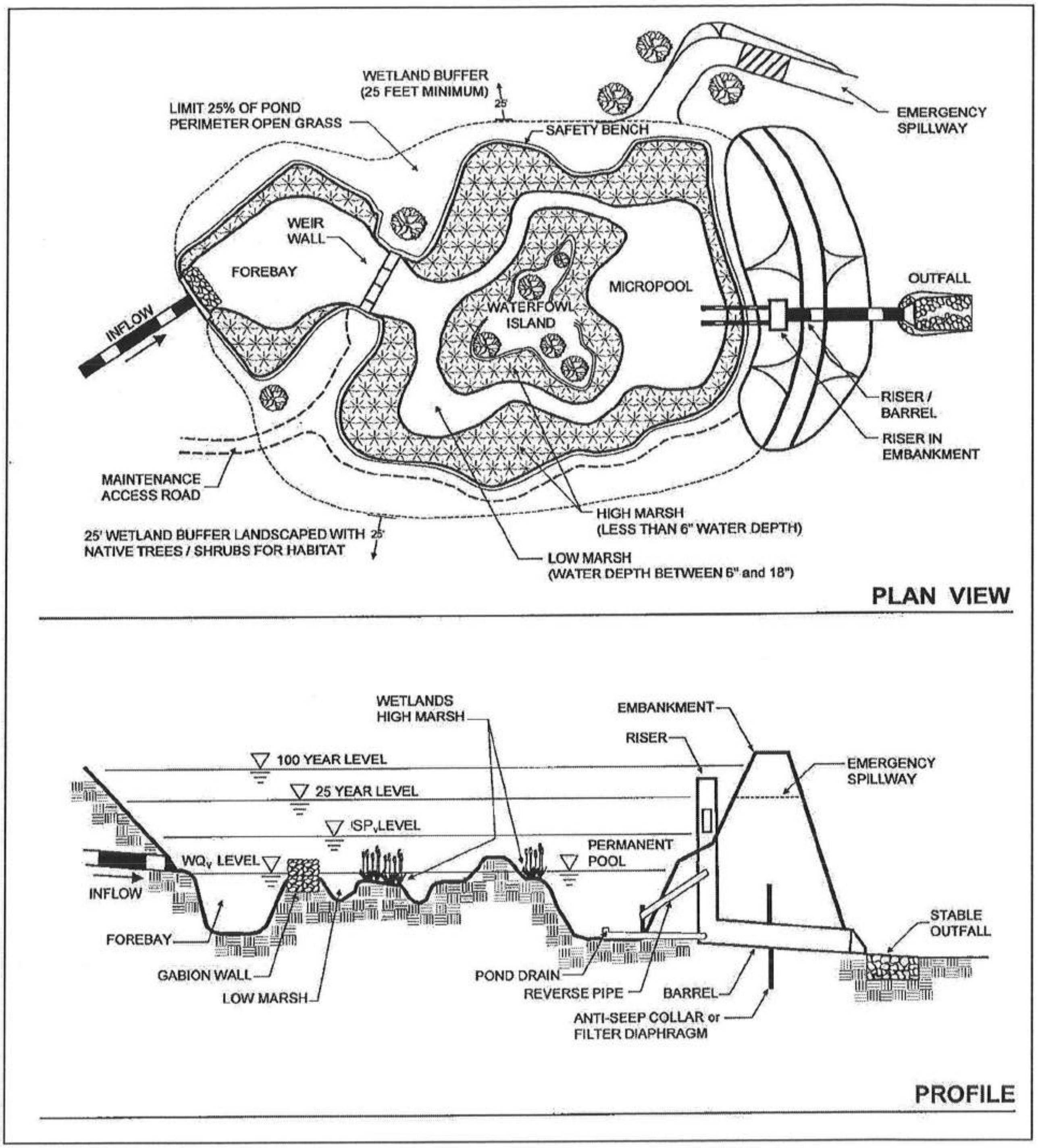


Figure 5.2.27-3 Schematic of Shallow Wetland
(Source: Center for Watershed Protection)

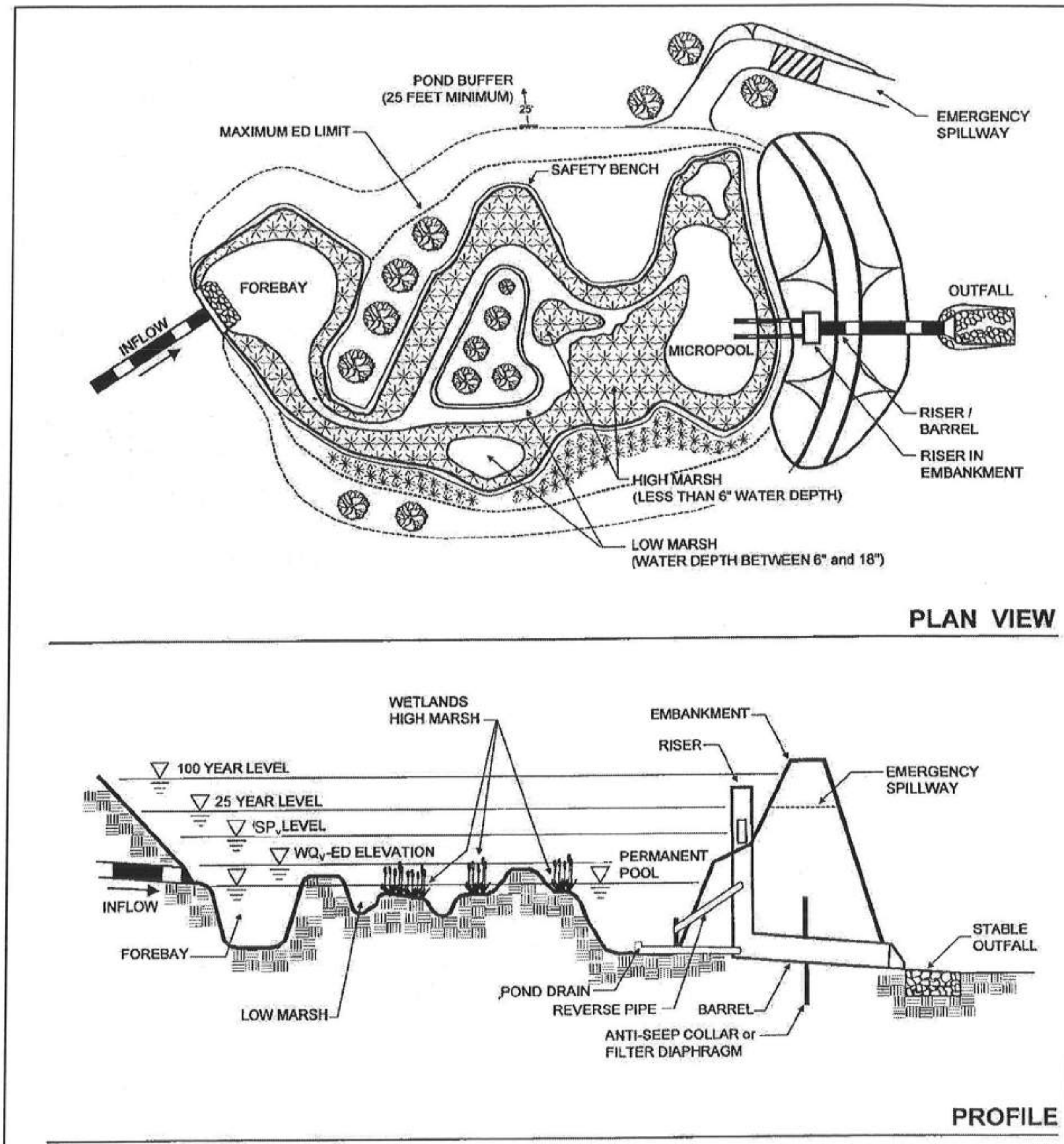


Figure 5.2.27-4 Schematic of Extended Detention Shallow Wetland
(Source: Center for Watershed Protection)

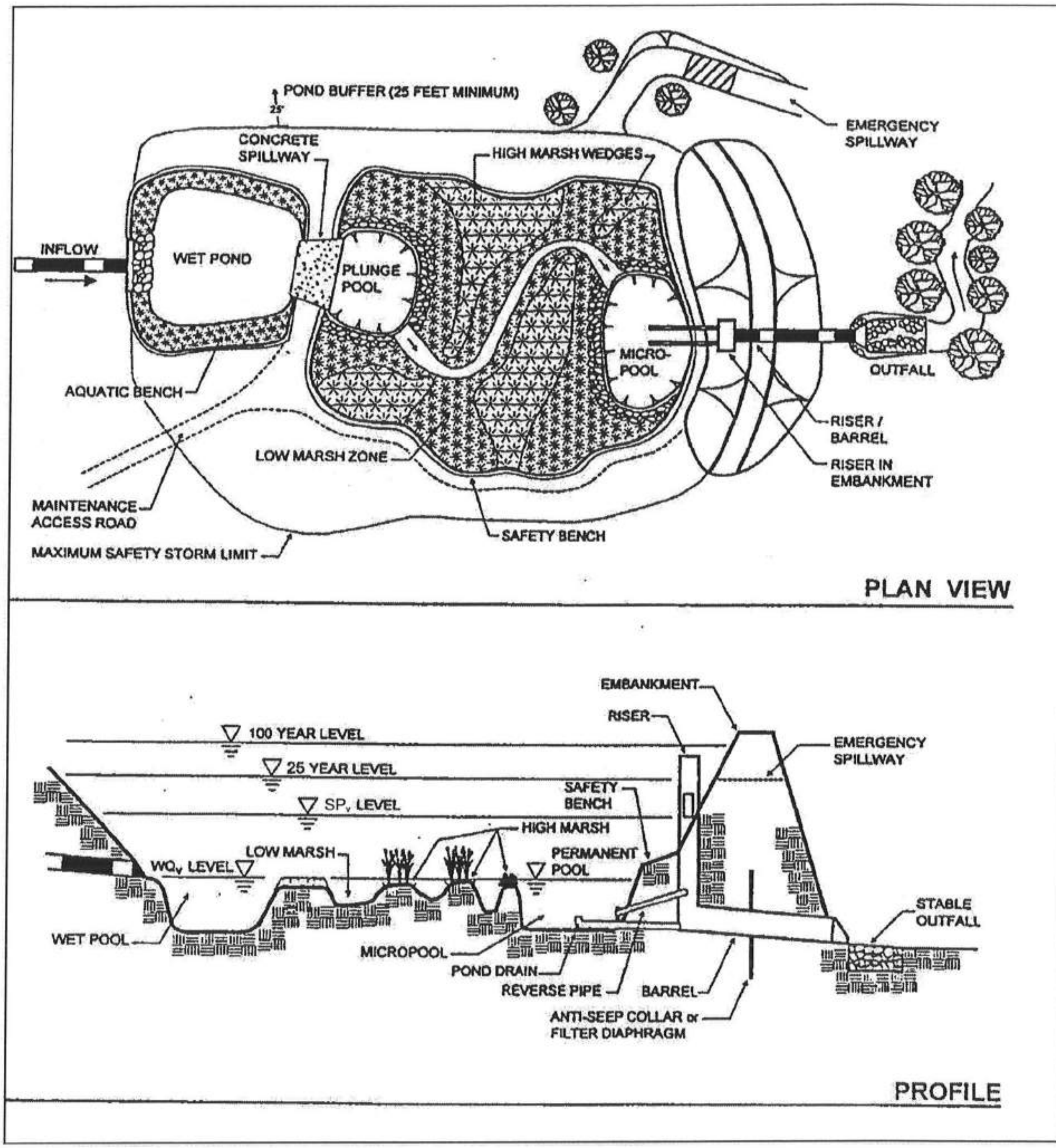


Figure 5.2.27-5 Schematic of Pond/Wetland System
(Source: Center for Watershed Protection)

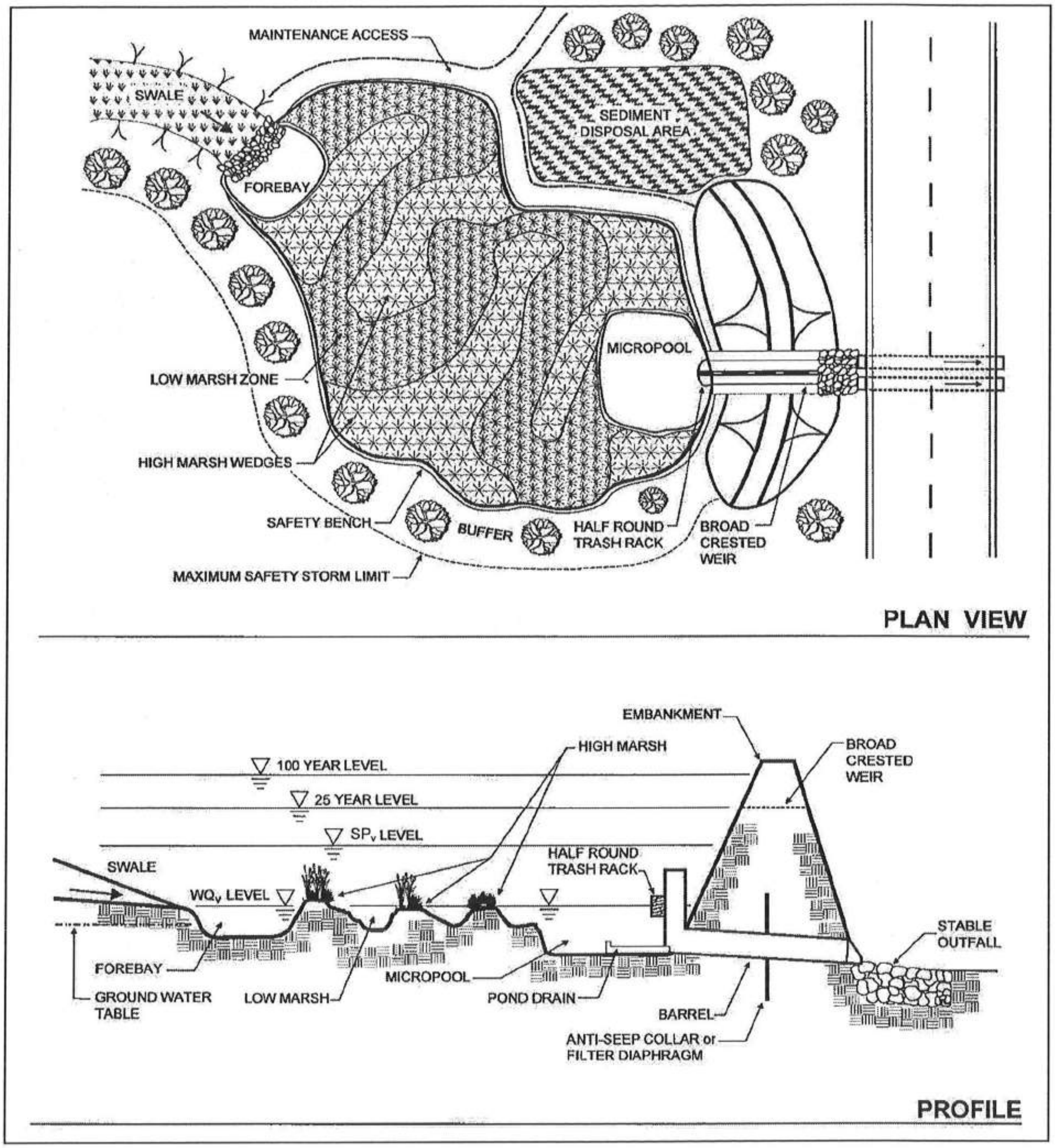


Figure 5.2.27-6 Schematic of Pocket Wetland
(Source: Center for Watershed Protection)

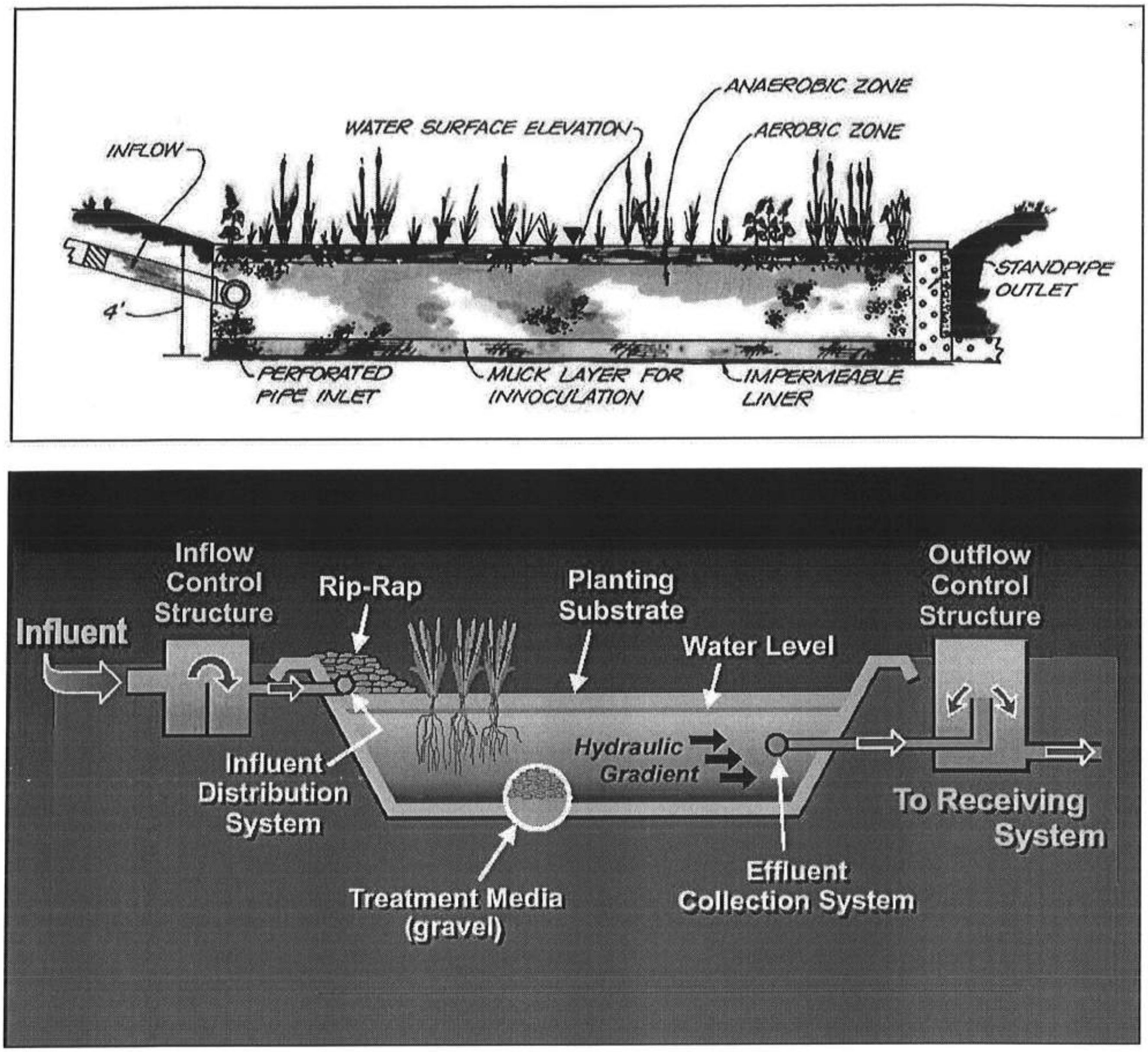


Figure 5.2.27-7 Schematics of Submerged Gravel Wetland System
(Sources: Center for Watershed Protection; Roux Associates Inc.)

5.2.27.9 Design Forms

Design Procedure Form: Storm Water Wetlands

PRELIMINARY HYDROLOGIC CALCULATIONS

1a. Compute WQ_v volume requirements
Compute Runoff Coefficient, R_v — R_v = ________
Compute WQ_v — WQ_v = ________ acre-ft

1b. Compute SP_v — SP_v = ________ acre-ft
Compute average release rate — release rate = ________ cfs
Compute Q_p (100-year detention volume required) — Q_p = ________ acre-ft
Add 15% to the required Q_p volume (if ED) — Q_p * 15% = ________ acre-ft
Compute (as necessary) Q_f — Q_f = ________ cfs

STORM WATER WETLAND DESIGN

2. Is the use of a storm water wetland appropriate? — ***See subsections 5.2.27.4 and 5.2.27.5-A***

3. Confirm local design criteria and applicability.

4. Pretreatment volume
Vol_{pre} = 1 (0.1")(1'/12") — Vol_{pre} = ________ acre-ft

5. Allocation of Pool, Marsh, and ED Volumes

Shallow Wetland: Vol_{pool} = 0.25 (WQ_v) — Vol_{pool} = ________ acre-ft
Vol_{marsh} = 0.75 (WQ_v) — Vol_{marsh} = ________ acre-ft

Shallow ED Wetland: Vol_{pool} = 0.25 (WQ_v) — Vol_{pool} = ________ acre-ft
Vol_{marsh} = 0.25 (WQ_v) — Vol_{marsh} = ________ acre-ft
Vol_{ED} = 0.5 (WQ_v) — Vol_{ED} = ________ acre-ft

Pocket Wetland: Vol_{pool} = 0.25 (WQ_v) — Vol_{pool} = ________ acre-ft
Vol_{marsh} = 0.75 (WQ_v) — Vol_{marsh} = ________ acre-ft

6. Allocation of Surface Area
(choose from Table 5.2.27-1 based on wetland variant)
Pool/Deepwater Wetland Zone (1.5-6 feet deep) — $Area_{water}$ = ________ acres, % = ________
Low Marsh Wetland Zone (6-18 inches deep) — $Area_{low}$ = ________ acres, % = ________
High Marsh Wetland Zone (0-6 inches deep) — $Area_{high}$ = ________ acres, % = ________
Semi-Wet Wetland Zone (above pool depth) — $Area_{semi}$ = ________ acres, % = ________

Conduct grading and determine storage available for marsh zones (and ED if applicable), and compute orifice size

Prepare an elevation-storage table and curve using the average area method for computing volumes.

Elevation MSL	Area ft^2	Average Area ft^2	Depth ft	Volume ft^3	Cummulative Volume ft^3	Cummulative Volume ac-ft	Volume above Permanent Pool ac-ft

Notes: ____
____

7. WQ_v Orifice Computations
Average ED release rate (if applicable) — release rate ____________ cfs
Average head, h = (ED elev. - Permanent pool elev.)/2 — h = ____________ ft
Area of orifice from orifice equation
$Q = CA(2gh)^{0.5}$ — A = ____________ ft^2
diameter = ____________ in
Discharge equation $Q = (h)^{0.5}$ — factor = ____________ $(h)^{0.5}$

Compute release rate for SP_v-ED control and establish SP_v elevation — WSEL = ____________ ft-NGVD
Release rate = — release rate = ____________ cfs
Average head, h = (SP_v elev. - Permanent pool elev.)/2 — h = ____________ ft
Area of orifice from orifice equation — A = ____________ ft^2
$Q = CA(2gh)^{0.5}$ — diameter = ____________ in
Discharge equation $Q = (h)^{0.5}$ — factor = ____________ $(h)^{0.5}$

8. Calculate Q_p release rate and WSEL — ***Set up a stage-storage-discharge relationship***

Elevation	Storage	Low Flow	Riser			Barrier		Emergency	Total
		WQ_v-ED	SPv-ED	High Storage		Inlet	Pipe	Spillway	Storage
MSL	ac-ft	Ft(ft) Q(cfs)	Ft(ft) Q(cfs)	Orif. Ft Q	Weir Ft Q	Ft(ft) Q(cfs)	Ft(ft) Q(cfs)	Ft(ft) Q(cfs)	Q(cfs)

Q_p = pre-dev. peak discharge - (WQ_v-ED release + SP_v-ED release) — Q_p = ____________ cfs

Maximum head = — H = ____________ ft
Use weir equation for slot length ($Q = CLH^{3/2}$) — L = ____________ ft

Check inlet condition
Check outlet condition — ***Use culvert charts (Section 4.2)***

9. Size emergency spillway, calculate 100-year WSEL and set top of embankment elevation
$WSEL_{25}$ = ____________ ft
$WSEL_{100}$ = ____________ ft
Q_{ES} = ____________ cfs
Q_{ps} = ____________ cfs

10. Investigate potential pond hazard classification — ***See Appendix H***

11. Design inlets, sediment forebays, outlet structures, maintenance access, and safety features. — ***See subsection 5.2.27.5-D through H***

12. Attach landscaping plan (including wetland vegetatoin) — ***See Appendix F***

Notes:
____
____

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Appendix H

Landscaping and Aesthetics Guidance

APPENDIX

H

Landscaping and Aesthetics Guidance

Introduction

Landscaping is a critical element in the design of storm water facilities for water quantity and quality management, serving both functional and aesthetic purposes. Plants and vegetation perform a number of functions in storm water controls and conveyance facilities, including:

- Slowing and retarding flow by increasing hydraulic roughness
- Preventing the erosion of bare soil
- Enhancing infiltration of runoff into the soil
- Providing pollutant removal through vegetative uptake
- Preventing access to deep open water areas
- Contributing to wildlife and fish habitat
- Improving the overall appearance of storm water facilities

The purpose of this Appendix is to provide guidance on landscaping and plant selection for storm water facilities and structural controls, as well as provide an overview on developing aesthetically-pleasing storm water facilities. This appendix is divided into the following sections:

- ❑ Subsection H.1 covers general landscaping guidance that should be considered when landscaping any storm water facility.

- ❑ Subsection H.2 discusses the physical site factors and considerations involved in selecting plant material for storm water facility landscaping.

- ❑ Subsection H.3 includes key factors to consider in selecting plant material for storm water landscaping are reviewed, including hardiness, physiographic regions, inundation tolerance, and other factors.

- ❑ Subsection H.4 outlines more specific guidance on landscaping criteria and plant selection for individual structural storm water control designs, including:
    - Storm Water Ponds and Wetlands
    - Bioretention Areas
    - Infiltration Trench and Surface Sand Filter Facilities
    - Enhanced Swales and Grass Channels
    - Filter Strips and Stream Buffers

- ❑ Subsection H.5 contains a detailed plant list of trees and shrubs that may be used when preparing a vegetation and landscaping planting plan for a storm water facility.

- ❑ Subsection H.6 provides examples of aesthetics and good landscaping in structural control design.

For information on native and adapted plants and trees to create landscapes that need less water, pesticides, and fertilizer to thrive in the North Central Texas climate, visit www.txsmartscape.com. Excessive fertilizer in runoff can lead to “overgrowth” of submerged plants.

H.1 General Landscaping Guidance

Below are general guidelines that should be followed in the landscaping of any storm water control or conveyance facility.

DO NOT:

- Plant trees, scrubs or any type of woody vegetation on an embankment
- Plant trees and shrubs within 15 feet of the toe of slope of a dam.
- Plant trees or shrubs known to have long tap roots within the vicinity of the earthen dam or embankment, or subsurface drainage facilities.
- Plant trees and shrubs within 25 feet of a principal spillway structure (e.g., riser)
- Plant trees and shrubs within 25 feet of perforated pipes.
- Block maintenance access to structures with trees or shrubs.
- Plant trees and shrubs within 25 feet of a structural concrete dam.

DO:

- Take into account site characteristics and plant selection guidelines (see subsections H.2 and H.3, respectively) when selecting plants for storm water facilities.
- Consider how plant characteristics will affect the landscape and the performance of a structural storm water control or conveyance.
- Carefully consider the long-term vegetation management strategy for the structural control, keeping in mind the maintenance legacy for the future owners.
- Preserve existing natural vegetation when possible.
- Avoid the overuse of any plant materials.
- Have soils tested to determine if there is a need for amendments.
- Select plants that can thrive in on-site soils with no additional amendments or a minimum of amendments.
- Consider water availability, particularly for wetland and water-intensive plantings.
- Decrease the areas where turf is used. Use low maintenance ground cover to absorb run-off.
- Plant stream and edge of water buffers with trees, shrubs, ornamental grasses, and herbaceous materials where possible, to stabilize banks and provide shade.
- Provide slope stabilization methods for slopes steeper than 2:1, such as planted erosion control mats. Also, use seed mixes with quick germination rates in this area. Augment temporary seeding measures with container crowns or root mats of more permanent plant material.
- Utilize erosion control mats and fabrics to protect inverts of channels that are subject to frequent wash outs.
- Stabilize all water overflows with plant material that can withstand strong current flows. Root material should be fibrous and substantial but lacking a tap root.
- Sod area channels that are not stabilized using erosion control mats.
- Divert flows temporarily from seeded areas until stabilized.
- Check water tolerances of existing plant materials prior to inundation of area.
- Stabilize aquatic and safety benches with emergent wetland plants and wet seed mixes.
- Provide a 15-foot clearance from a non-clogging, low flow orifice.

- ❑ Limit herbaceous embankment plantings to 10 inches in height, to allow visibility for the inspector who is looking for burrowing rodents that may compromise the integrity of the embankment.
- ❑ Shade inflow and outflow channels, as well as the southern exposures of pond, to reduce thermal warming
- ❑ Avoid plantings that will require routine or intensive chemical applications (i.e. turf area).
- ❑ Maintain and frame desirable views. Be careful not to block views at entrances, exits, or difficult road curves. Screen or buffer unattractive views into the site.
- ❑ Use plants to prohibit pedestrian access to pools or slopes that may be unsafe.
- ❑ Keep maintenance area open to allow future access for pond maintenance.
- ❑ Provide a planting surface that can withstand the compaction of vehicles using maintenance access roads.
- ❑ Make sure the facility maintenance agreement includes a maintenance requirement of designated plant material.
- ❑ Provide signage for:
  - Storm water management facilities to help educate the public
  - Wildflower areas to designate limits of mowing
  - Preserving existing natural vegetation

H.2 Site Considerations

A development site's characteristics often will help to determine which plant materials and planting methods the site designer should select and will help improve plant establishment. Primary site considerations include:

(1) Soil Characteristics
(2) Drainage
(3) Slope
(4) Orientation

Soil Characteristics

Plant establishment and growth can be limited by a number of different soil characteristics including:

- Soil texture
- PH -- whether acid, neutral, or alkali
- Nutrient levels -- nitrogen, phosphorus, potassium
- Minerals -- such as chelated iron, lime
- Salinity
- Toxicity

Soils are made up of four basic ingredients: mineral elements, pore space, organic matter and other items consisting mainly of living organisms including fungi, bacteria, and nematodes. One classification of soils is based upon the mineral part of soil and consists of four sizes of particles. Clay particles are the smallest, followed by silt, sand, and gravel. The USDA has devised another system of classifying soil particles. In this system soil is divided into seven categories: clay, silt, and five sizes of sand.

Soil texture is determined by the percentage of sand, silt, and clay in the soil. The structure of a soil is influenced by soil texture and also by the aggregation of small soil particles into larger particles. The amount of aggregation in a soil is strongly influenced by the amount of organic matter present.

Soil samples should be analyzed by experienced and qualified individuals who can explain the results and provide information on any soil amendments that are required. Soil fertility can often be corrected by applying fertilizer or by increasing the level of organic matter in the soil. Soil pH can be corrected with applications of lime. Where poor soils can't be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

Areas that have recently been involved in construction can become compacted so that plant roots cannot penetrate the soil. Seeds lying on the surface of compacted soils can be washed away or be eaten by birds. Soils should be loosened to a minimum depth of two inches, preferably to a four-inch depth. Hard soils may require discing to a deeper depth. Loosening soils will improve seed contact with the soil, provide greater germination rates, and allow the roots to penetrate into the soil. If the area is to be sodded, discing will allow the roots to penetrate into the soil.

Whenever possible, topsoil should be spread to a depth of four inches (two inch minimum) over the entire area to be planted. This provides organic matter and important nutrients for the plant material. This also allows the stabilizing materials to become established faster, while the roots are able to penetrate deeper and stabilize the soil, making it less likely that the plants will wash out during a heavy storm. If topsoil has been stockpiled in deep mounds for a long period of time, it is desirable to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, it may be necessary to inoculate the soil after application.

Drainage

Soil moisture and drainage have a direct bearing on the plant species and communities that can be supported on a site. Factors such as soil texture, topography, groundwater levels and climatic patterns all influence soil drainage and the amount of water in the soil. Identifying the topography and drainage of the site will help determine potential moisture gradients. The following categories can be used to describe the drainage properties of soils on a site:

Flooded - Areas where standing water is present most of the growing season.

Wet - Areas where standing water is present most of the growing season, except during times of drought. Wet areas are found at the edges of ponds, rivers, streams, ditches, and low spots. Wet conditions exist on poorly drained soils, often with a high clay content.

Moist - Areas where the soil is damp. Occasionally, the soil is saturated and drains slowly. These areas usually are at slightly higher elevations than wet sites. Moist conditions may exist in sheltered areas protected from sun and wind.

Well-drained - Areas where rain water drains readily, and puddles do not last long. Moisture is available to plants most of the growing season. Soils usually are medium textures with enough sand and silt particles to allow water to drain through the soil.

Dry - Areas where water drains rapidly through the soil. Soils are usually coarse, sandy, rocky or shallow. Slopes are often steep and exposed to sun and wind. Water runs off quickly and does not remain in the soil.

Slope

The degree of slope can also limit its suitability for certain types of plants. Plant establishment and growth requires stable substrates for anchoring root systems and preserving propagules such as seeds and plant fragments, and slope is a primary factor in determining substrate stability. Establishing plants directly on or below eroding slopes is not possible for most species. In such instances, plant species capable of rapid spread and anchoring soils should be selected or bioengineering techniques should be used to aid the establishment of a plant cover.

In addition, soils on steep slopes generally drain more rapidly than those on gradual slopes. This means that the soils may remain saturated longer on gradual slopes. If soils on gradual slopes are classified as poorly drained, care should be taken that plant species are selected that are tolerant of saturation.

Site topography also affects maintenance of plant species diversity. Small irregularities in the ground surface (e.g., depressions, etc.) are common in natural systems. More species are found in areas with many micro-topographic features than in areas without such features. Raised sites are particularly important in wetlands because they allow plants that would otherwise die while flooded to escape inundation.

In wetland plant establishment, ground surface slope interacts with the site hydrology to determine water depths for specific areas within the site. Depth and duration of inundation are principal factors in the zonation of wetland plant species. A given change in water levels will expose a relatively small area on a steep slope in comparison with a much larger area exposed on a gradual or flat slope. Narrow planting zones will be delineated on steep slopes for species tolerant of specific hydrologic conditions, whereas gradual slopes enable the use of wider planting zones.

Orientation

Slope exposure should be considered for its effect on plants. A southern-facing slope receives more sun and is warmer and drier, while the opposite is true of a northern slope. Eastern- and western-facing slopes are intermediate, receiving morning and afternoon sun, respectively. Western-facing slopes tending to receive more wind.

H.3 Plant Selection for Storm Water Facilities

H.3.1 Hardiness Zones

Hardiness zones are based on historical annual minimum temperatures recorded in an area. A site’s location in relation to plant hardiness zones is important to consider first because plants differ in their ability to withstand very cold winters. This does not imply that plants are not affected by summer temperatures. Given that Texas summers can be very hot, heat tolerance is also a characteristic that should be considered in plant selection.

It is best to recommend plants known to thrive in specific hardiness zones. The plant list included at the end of this appendix identifies the hardiness zones for each species listed as a general planting guide. It should be noted, however, that certain site factors can create microclimates or environmental conditions which permit the growth of plants not listed as hardy for that zone. By investigating numerous references and based on personal experience, a designer should be able to confidently recommend plants that will survive in microclimates.

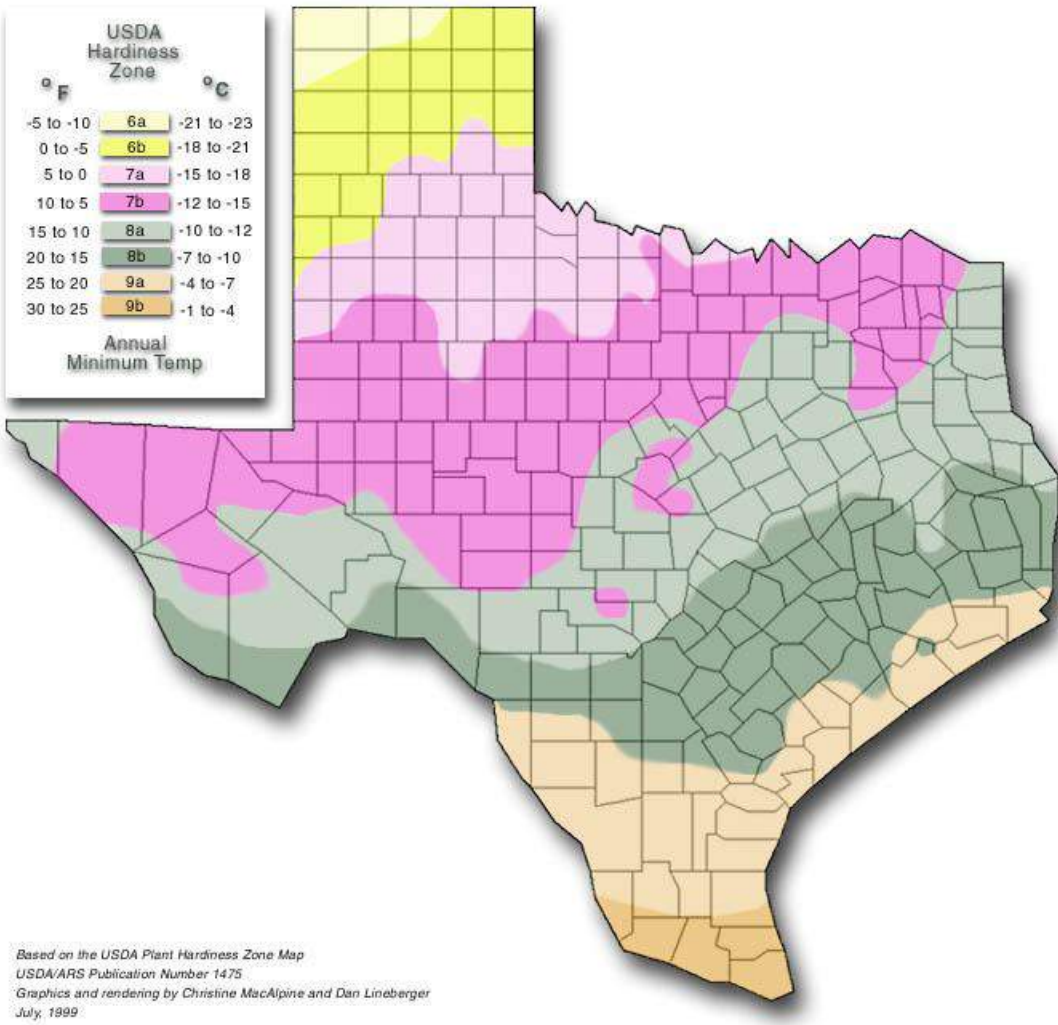
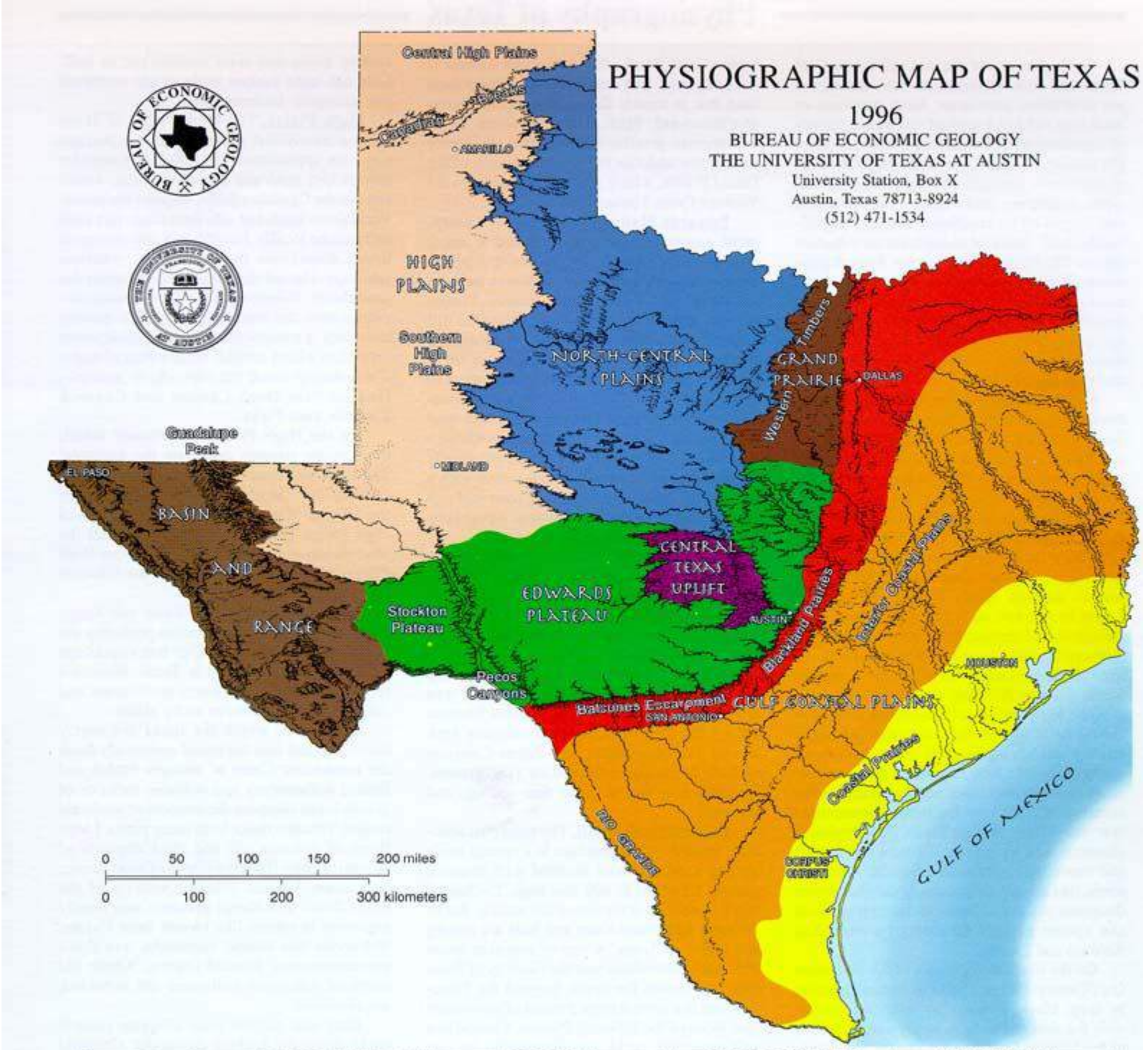


Figure H-1 USDA Plant Hardiness Zones in Texas

H.3.2 Physiographic Provinces

There are three physiographic provinces in Texas that describe distinct geographic regions in the state with similar physical and environmental conditions (Figure H-2). These physiographic provinces include, from northwest to southeast, High Plains, Edwards Plateau, and Gulf Coastal Plains (subdivided into multiple subregions). Each physiographic region is defined by unique geological strata, soil type, drainage patterns, moisture content, temperature and degree of slope which often dictate the predominant vegetation. Because the predominant vegetation has evolved to live in these specific conditions, a successful storm water management facility planting design can be achieved through mimicking these natural associations. The three physiographic regions are described below with associated vegetation listed as general planting guidance.



PROVINCE	MAX. ELEV. (ft)	MIN. ELEV. (ft)	TOPOGRAPHY	GEOLOGIC STRUCTURE	BEDROCK TYPES
Gulf Coastal Plains					
Coastal Prairies	300	0	Nearly flat prairie, <1 ft/mi to Gulf	Nearly flat strata	Deltaic sands and muds
Interior Coastal Plains	800	300	Parallel ridges (questas) and valleys	Beds tilted toward Gulf	Unconsolidated sands and muds
Blackland Prairies	1000	450	Low rolling terrain	Beds tilted south and east	Chalks and marls
Grand Prairie	1250	450	Low stairstep hills west; plains east	Strata dip east	Calcareous east; sandy west
Edwards Plateau					
Principal	3000	450	Flat upper surface with box canyons	Beds dip south; normal faulted	Limestones and dolomites
Pecos Canyons	2000	1200	Steep-walled canyons		Limestones and dolomites
Stockton Plateau	4200	1700	Mesa-formed terrain; highs to west	Unfaulted, near-horizontal beds	Carbonates and alluvial sediments
Central Texas Uplift	2000	800	Knobby plain; surrounded by questas	Centripetal dips, strongly faulted	Granites; metamorphics; sediments
North-Central Plains	3000	900	Low north-south ridges (questas)	West dip; minor faults	Limestones; sandstones; shales
High Plains					
Central	4750	2900	Flat prairies slope east and south	Slight dips east and south	Eolian silts and fine sands
Canadian Breaks	3800	2350	Highly dissected; local solution valleys		
Southern	3800	2200	Flat; many playas; local dune fields		
Basin and Range	8750	1700	North-south mountains and basins	Some complex folding and faulting	Igneous; metamorphics; sediments

Figure H-2 Physiographic map of Texas

Gulf Coastal Plains. The Gulf Coastal Plains include three subprovinces named the Coastal Prairies, the Interior Coastal Plains, and the Blackland Prairies. The Coastal Prairies begin at the Gulf of Mexico shoreline. Young deltaic sands, silts, and clays erode to nearly flat grasslands that form almost imperceptible slopes to the southeast. Trees are uncommon except locally along streams and in Oak mottes, growing on coarser underlying sediments of ancient streams. Minor steeper slopes, from 1 foot to as much as 9 feet high, result from subsidence of deltaic sediments along faults. Between Corpus Christi and Brownsville, broad sand sheets pocked by low dunes and blowouts forming ponds dominate the landscape.

The Interior Coastal Plains comprise alternating belts of resistant uncemented sands among weaker shales that erode into long, sandy ridges. At least two major down-to-the coast fault systems trend nearly parallel to the coastline. Clusters of faults also concentrate over salt domes in East Texas. That region is characterized by pine and hardwood forests and numerous permanent streams. West and south, tree density continuously declines, pines disappear in Central Texas, and chaparral brush and sparse grasses dominate between San Antonio and Laredo.

On the Blackland Prairies of the innermost Gulf Coastal Plains, chalks and marls weather to deep, black, fertile clay soils, in contrast with the thin red and tan sandy and clay soils of the Interior Gulf Coastal Plains. The blacklands have a gentle undulating surface, cleared of most natural vegetation and cultivated for crops.

From sea level at the Gulf of Mexico, the elevation of the Gulf Coastal Plains increases northward and westward. In the Austin San Antonio area, the average elevation is about 800 feet. South of Del Rio, the western end of the Gulf Coastal Plains has an elevation of about 1,000 feet.

Grand Prairie. The eastern Grand Prairie developed on limestones; weathering and erosion have left thin rocky soils. North and west of Fort Worth, the plateau like surface is well exposed, and numerous streams dissect land that is mostly flat or that gently slopes southeastward. There, silver bluestem-Texas wintergrass grassland is the flora. Primarily sandstones underlie the western margin of the Grand Prairie, where post oak woods form the Western Cross Timbers.

Edwards Plateau. The Balcones Escarpment, superposed on a curved band of major normal faults, bounds the eastern and southern Edwards Plateau. Its principal area includes the Hill Country and a broad plateau. Stream erosion of the fault escarpment sculpts the Hill Country from Waco to Del Rio. The Edwards Plateau is capped by hard Cretaceous limestones. Local streams entrench the plateau as much as 1,800 feet in 15 miles. The upper drainages of streams are waterless draws that open into box canyons where springs provide permanently flowing water. Sinkholes commonly dot the limestone terrain and connect with a network of caverns. Alternating hard and soft marly limestones form a stair step topography in the central interior of the province.

The Edwards Plateau includes the Stockton Plateau, mesa like land that is the highest part of this subdivision. With westward decreasing rainfall, the vegetation grades from mesquite juniper brush westward into creosote bush tarbush shrubs.

The Pecos River erodes a canyon as deep as 1,000 feet between the Edwards and Stockton Plateaus. Its side streams become draws forming narrow blind canyons with nearly vertical walls. The Pecos Canyons include the major river and its side streams. Vegetation is sparse, even near springs and streams.

Central Texas Uplift. The most characteristic feature of this province is a central basin having a rolling floor studded with rounded granite hills 400 to 600 feet high. Enchanted Rock State Park is typical of this terrain. Rocks forming both basin floor and hills are among the oldest in Texas. A rim of resistant lower Paleozoic formations surrounds the basin. Beyond the Paleozoic rim is a second ridge formed of limestones like those of the Edwards Plateau. Central live oak mesquite parks are surrounded by live oak ash juniper parks.

North-Central Plains. An erosional surface that developed on upper Paleozoic formations forms the North-Central Plains. Where shale bedrock prevails, meandering rivers traverse stretches of local prairie. In areas of harder bedrock, hills and rolling plains dominate. Local areas of hard sandstones and limestones cap steep slopes severely dissected near rivers. Lengthy dip slopes of strongly fractured limestones display extensive rectangular patterns. Western rocks and soils are oxidized red or gray where gypsum dominates, whereas eastern rocks and soils weather tan to buff. Live oak ash juniper parks grade westward into mesquite lotebush brush.

High Plains. The High Plains of Texas form a nearly flat plateau with an average elevation approximating 3,000 feet. Extensive stream-laid sand and gravel deposits, which contain the Ogallala aquifer, underlie the plains. Windblown sands and silts form thick, rich soils and caliche locally. Havard shin oak mesquite brush dominates the silty soils, whereas sandsage Havard shin oak brush occupies the sand sheets. Numerous playa lakes scatter randomly over the treeless plains. The eastern boundary is a westward-retreating escarpment capped by a hard caliche. Headwaters of major rivers deeply notch the caprock, as exemplified by Palo Duro Canyon and Caprock Canyons State Parks.

On the High Plains, widespread small, intermittent streams dominate the drainage. The Canadian River cuts across the province, creating the Canadian Breaks and separating the Central High Plains from the Southern High Plains. Pecos River drainage erodes the west-facing escarpment of the Southern High Plains, which terminates against the Edwards Plateau on the south.

Basin and Range. The Basin and Range province contains eight mountain peaks that are higher than 8,000 feet. At 8,749 feet, Guadalupe Peak is the highest point in Texas. Mountain ranges generally trend nearly north-south and rise abruptly from barren rocky plains.

Plateaus in which the rocks are nearly horizontal and less deformed commonly flank the mountains. Cores of strongly folded and faulted sedimentary and volcanic rocks or of granite rocks compose the interiors of mountain ranges. Volcanic rocks form many peaks. Large flows of volcanic ash and thick deposits of volcanic debris flank the slopes of most former volcanoes. Ancient volcanic activity of the Texas Basin and Range province was mostly explosive in nature, like Mount Saint Helens. Volcanoes that poured successive lava flows are uncommon. Eroded craters, where the cores of volcanoes collapsed and subsided, are abundant.

Gray oak, pinyon pine, and alligator juniper parks drape the highest elevations. Creosote bush and lechuguilla shrubs sparsely populate plateaus and intermediate elevations. Tobosa black grama grassland occupies the low basins.

Floodplain Plant Communities – Floodplain areas are a microclimatic area that results in a characteristic plant community that is similar in all three physiographic provinces. Floodplain plant communities are an important reference community since many storm water practices are located with this area. Floodplains occur along streams in both steep and level areas. The most noteworthy plants found along floodplains are River Birch, Willows, Poplars, Maple, Sweet Gum, Sycamore, Box Elder, Green Ash, American Elm, Swamp White Oak, Bur Oak, Honeylocust and Hackberry. Shrubs commonly found in floodplains include Shrub Willows, Yaupon, Buttonbush, Blackberry, and Elderberry.

H.3.3 Other Considerations in Plant Selection

Use or Function

In selecting plants, consideration must be given to their desired function in the storm water management facility. Is the plant needed as ground cover, soil stabilizer, biofilter or source of shade? Will the plant be placed for functional or aesthetic purposes? Does the adjacent use provide conflicts or potential problems and require a barrier, screen, or buffer? Nearly every plant and plant location should be provided to serve some function in addition to any aesthetic appeal.

Plant Characteristics

Certain plant characteristics are so obvious, they may actually be overlooked in the plant selection. These are:

- Size
- Shape

For example, tree limbs, after several years, can grow into power lines. A wide growing shrub may block maintenance access to a storm water facility. Consider how these characteristics can work for you or against you, today and in the future.

Other plant characteristics must be considered to determine how the plant grows and functions seasonally, and whether the plant will meet the needs of the facility today and in the future. Some of these characteristics are:

- Growth Rate
- Regeneration Capacity
- Maintenance Requirements (e.g. mowing, harvesting, leaf collection, etc.)
- Aesthetics

In urban or suburban settings, a plant's aesthetic interest may be of greater importance. Residents living next to a storm water system may desire that the facility be appealing or interesting to look at throughout the year. Aesthetics is an important factor to consider in the design of these systems. Failure to consider the aesthetic appeal of a facility to the surrounding residents may result in reduced value to nearby lots. Careful attention to the design and planting of a facility can result in maintained or increased values of a property.

Availability and Cost

Often overlooked in plant selection is the availability from wholesalers and the cost of the plant material. There are many plants listed in landscape books that are not readily available from the nurseries. Without knowledge of what is available, time spent researching and finding the one plant that meets all the needs will be wasted, if it is not available from the growers. It may require shipping, therefore, making it more costly than the budget may allow. Some planting requirements, however, may require a special effort to find the specific plant that fulfills the needs of the site and the function of the plant in the landscape.

Native versus Nonnative Species

This Manual encourages the use of native plants in storm water management facilities, since they are best suited to thrive under the physiographic and hardiness conditions encountered at a site. Unfortunately, not all native plants provide the desired landscape or appearance, and may not always be available in quantity from local nurseries. Therefore, naturalized plants that are not native species, but can thrive and reproduce in the new area may be a useful alternative.

Because all landscaping needs may not be met by native or naturalized plants, some ornamental and exotic species are provided in this guide that can survive under difficult conditions encountered in a storm water management facility. Since many storm water facilities are adjacent to residential areas, the objectives of the storm water planting plan may shift to resemble the more controlled appearance of nearby yards, or to provide a pleasing view. Great care should be taken; however, when introducing plant species so as not to create a situation where they may become invasive and take over adjacent natural plant communities.

Moisture Status

In landscaping storm water management facilities, hydrology plays a large role in determining which species will survive in a given location.

For areas that are to be planted within a storm water management facility it is necessary to determine what type of hydrologic zones will be created within the facility.

The six zones shown in Table F-1 in the next section describe the different conditions encountered in storm water management facilities. Every facility does not necessarily reflect all of these zones. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation by water. Each zone has its own set of plant selection criteria based on the hydrology of the zone, the storm water functions required of the plant and the desired landscape effect.

H.4 Specific Landscaping Criteria for Structural Storm Water Controls

H.4.1 Storm Water Ponds and Wetlands

Storm water ponds and wetlands are engineered basins and wetland areas designed to control and treat storm water runoff. Aquatic vegetation plays an important role in pollutant removal in both storm water ponds and wetlands. In addition, vegetation can enhance the appearance of a pond or wetland, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris.

Within a storm water pond or wetland, there are various hydrologic zones as shown in Table H-1 that must be considered in plant selection. These hydrologic zones designate the degree of tolerance a plant must have to differing degrees of inundation by water. Hydrologic conditions in an area may fluctuate in unpredictable ways; thus the use of plants capable of tolerating wide varieties of hydrologic conditions greatly increases the successful establishment of a planting. Plants suited for specific hydrologic conditions may perish when those conditions change, exposing the soil, and therefore, increasing the chance for erosion. Each of the hydrologic zones is described in more detail below along with examples of appropriate plant species.

Table H-1 Hydrologic Zones

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep Water Pool	1-6 feet depth (permanent pool)
Zone 2	Shallow Water Bench	Normal pool elevation to 1 foot depth
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Zone 1: Deep Water Area *(1- 6 Feet)*

Ponds and wetlands both have deep pool areas that comprise Zone 1. These pools range from one to six feet in depth, and are best colonized by submergent plants, if at all.

This pondscaping zone is *not* routinely planted for several reasons. First, the availability of plant materials that can survive and grow in this zone is limited, and it is also feared that plants could clog the storm water facility outlet structure. In many cases, these plants will gradually become established through natural recolonization (e.g., transport of plant fragments from other ponds via the feet and legs of waterfowl). If submerged plant material is commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

- Plant material must be able to withstand constant inundation of water of one foot or greater in depth.
- Plants may be submerged partially or entirely.

- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects, and other aquatic life.

Some suggested emergent or submergent species include, but are not limited to: Water Lily, Deepwater Duck Potato, Spatterdock, Wild Celery and Redhead Grass.

Zone 2: Shallow Water Bench *(Normal Pool To 1 Foot)*

Zone 2 includes all areas that are inundated below the normal pool to a depth of one foot, and is the primary area where emergent plants will grow in storm water wetlands. Zone 2 also coincides with the aquatic bench found in storm water ponds. This zone offers ideal conditions for the growth of many emergent wetland species. These areas may be located at the edge of the pond or on low mounds of earth located below the surface of the water within the pond. When planted, Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. This food chain includes predators, allowing a natural regulation of mosquito populations, thereby reducing the need for insecticidal applications.

- Plant material must be able to withstand constant inundation of water to depths between six inches and one foot deep.
- Plants will be partially submerged.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects and other aquatic life.

Common emergent wetland plant species used for storm water wetlands and on the aquatic benches of storm water ponds include, but are not limited to: Arrowhead/Duck Potato, Soft Rush, various Sedges, Softstem Bulrush, Cattail, Switchgrass, Southern Blue-Flag Iris, Swamp Hibiscus, Swamp Lily, Pickerelweed, Pond Cypress and various Asters.

Zone 3: Shoreline Fringe *(Regularly Inundated)*

Zone 3 encompasses the shoreline of a pond or wetland, and extends vertically about one foot in elevation from the normal pool. This zone includes the safety bench of a pond, and may also be periodically inundated if storm events are subject to extended detention. This zone occurs in a wet pond or shallow marsh and can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. In order to stabilize the soil in this zone, Zone 3 must have a vigorous cover.

- Plants should stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- Plant material must be able to withstand occasional inundation of water. Plants will be partially submerged partially at this time.
- Plant material should, whenever possible, shade the shoreline, especially the southern exposure. This will help to reduce the water temperature.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife. Plants could also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- Plants should have very low maintenance requirements, since they may be difficult or impossible to reach.
- Plants should be resistant to disease and other problems which require chemical applications (since

chemical application is not advised in storm water ponds).

Many of the emergent wetland plants that perform well in Zone 2 also thrive in Zone 3. Some other species that do well include Broom Grass, Upland Sea-Oats, Dwarf Tickseed, various Ferns, Hawthorns. If shading is needed along the shoreline, the following tree species are suggested: Boxelder, Ash, Willow, Red Maples and Willow Oak.

Zone 4: Riparian Fringe *(Periodically Inundated)*

Zone 4 extends from one to four feet in elevation above the normal pool. Plants in this zone are subject to periodic inundation after storms, and may experience saturated or partly saturated soil inundation. Nearly all of the temporary extended detention (ED) storage area is included within this zone.

- Plants must be able to withstand periodic inundation of water after storms, as well as occasional drought during the warm summer months.
- Plants should stabilize the ground from erosion caused by run-off.
- Plants should shade the low flow channel to reduce the pool warming whenever possible.
- Plants should be able to enhance pollutant uptake.
- Plant material should have very low maintenance, since they may be difficult or impossible to access.
- Plants may provide food and cover for waterfowl, songbirds and wildlife. Plants may also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce pedestrian access to the deeper pools.

Some frequently used plant species in Zone 4 include Broom Grass, Yellow Indian Grass, Ironweed, Joe Pye Weed, Lilies, Flatsedge, Hollies, Forsythia, Lovegrass, Hawthorn and Sugar Maples.

Zone 5: Floodplain Terrace *(Infrequently Inundated)*

Zone 5 is periodically inundated by flood waters that quickly recede in a day or less. Operationally, Zone 5 extends from the maximum two year or Cp_v water surface elevation up to the 25 or 100 year maximum water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone, and establish a low maintenance, natural vegetation.

- Plant material should be able to withstand occasional but brief inundation during storms, although typical moisture conditions may be moist, slightly wet, or even swing entirely to drought conditions during the dry weather periods.
- Plants should stabilize the basin slopes from erosion.
- Ground cover should be very low maintenance, since they may be difficult to access on steep slopes or if the frequency of mowing is limited. A dense tree cover may help reduce maintenance and discourage resident geese.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife.
- Placement of plant material in Zone 5 is often critical, as it often creates a visual focal point and provides structure and shade for a greater variety of plants.

Some commonly planted species in Zone 5 include many wildflowers or native grasses, many Fescues, many Viburnums, Witch Hazel, Blueberry, American Holly, American Elderberry and Red Oak.

Zone 6: Upland Slopes *(Seldom or Never Inundated)*

The last zone extends above the maximum 100 year water surface elevation, and often includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe.

- Plant material is capable of surviving the particular conditions of the site. Thus, it is not necessary to select plant material that will tolerate any inundation. Rather, plant selections should be made based on soil condition, light, and function within the landscape.
- Ground covers should emphasize infrequent mowing to reduce the cost of maintaining this landscape.

Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, or serve as a buffer.

Some frequently used plant species in Zone 6 include most ornamentals (as long as soils drain well, many wildflowers or native grasses, Linden, False Cypress, Magnolia, most Spruce, Mountain Ash and most Pine.

- Table H-2 provides a list of selected wetland plants for storm water ponds and wetlands. For hydrologic zones 1-4, provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

Table H-2 Wetland Plants (Herbaceous Species) for Storm Water Facilities

Scientific Name	Common Name	Hydrologic Zone
Acorus calumus	Sweetflag	2
Andropogon glomeratus	Bushy Broom Grass	3
Andropogon virginicus	Broom Grass	4
Canna flaccida	Golden Canna	2
Carex spp.	Caric Sedges	2
Chasmanthium latifolium	Upland Sea-Oats	3
Coreopsis leavenworthii	Tickseed	2
Coreopsis tinctoria	Dwarf Tickseed	3
Crinum americanum	Swamp Lily	2
Cyperus odoratus	Flat Sedge	2
Eleocharis cellulose	Coastal Spikerush	2
Eleocharis interstincta	Jonited Spikerush	2
Eupatorium fistolosum	Joe Pye Weed	4
Helianthus angustifolius	Swamp Sunflower	2
Hibiscus coccinieus	Swamp Hibiscus	2
Iris Louisiana	Louisiana Iris	2
Iris virginica	Southern Blue-Flag	2

Scientific Name	Common Name	Hydrologic Zone
Juncus effuses	Soft Rush	2
Leersia oryzoides	Rice Cut Grass	2
Liatris spicata	Spiked Gayfeather	3
Lobelia cardinalis	Cardinal Flower	3
Nuphar luteum	Spatterdock	1
Nymphaea mexicana	Yellow Water Lily	1
Nymphaea odorata	Fragrant Water Lily	1
Osmunda cinnamomea	Cinnamon Fern	3
Osmunda regalis	Royal Fern	3
Panicum virgatum	Switchgrass	2
Peltandra virginica	Green Arum	2
Polygonum hydropiperoides	Smartweed	2
Pontederia cordata	Pickerelweed	2
Pontederia lanceolata	Pickerelweed	2
Rudbeckia hirta	Black-eyed Susan	4
Sagittaria lancifolia	Lance-leaf Arrowhead	2
Sagittaria latifolia	Duck Potato	2
Saururus cernuus	Lizard’s Tail	2
Scirpus americanus	Three-square	2
Scirpus californicus	Giant Bulrush	2
Scirpus validus	Softstem Bulrush	2
Sorgham nutans	Yellow Indian Grass	4
Thalia geniculata	Alligator Flag	2
Vernonia gigantea	Ironweed	4
Woodwardia virginica	Virginia Chain Fern	2

Source: Aquascape, Inc.

12 to 36 inch depth below normal pool elevation
Water Lily, Deep Water Duck Potato, Spatterdock, Wild Celery, Redhead Grass

0 to 12 inch depth below normal pool elevation
Arrowhead/Duck Potato, Soft Rush, various Sedges, Softstem Bulrush, Switchgrass, Southern Blue Flag Iris, Swamp Hibiscus, Swamp Lily, Pickerelweed, Pond Cypress, various Asters

0 to 12 inch elevation above normal pool elevation
Various species from above, Broom Grass, Upland Sea-Oats, Dwarf Tickseed, various Ferns, Hawthorns, Boxelder, Ash, Willow, Red Maple, Willow Oak

1 to 4 foot elevation above normal pool elevation
Broom Grass, Yellow Indian Grass, Ironweed, Joe Pye Weed, various Lilies, Flatsedge, Hollies, Lovegrass, Hawthorn, Sugar Maple

Cp_v to Q_p or Q_f water surface elevation
Many wildflowers or native grasses, many Fescues, many Viburnums, Witch Hazel, Blueberry, American Holly, American Elderberry, Red Oak

Q_f water surface elevation and above
Many ornamentals as long as soils drain well, many wildflowers or native grasses, Linden, False Cypress, Magnolia, most Spruce, Mountain Ash, most Pine

Figure H-3 Legend of Hydrologic Zones Around Storm Water Facilities

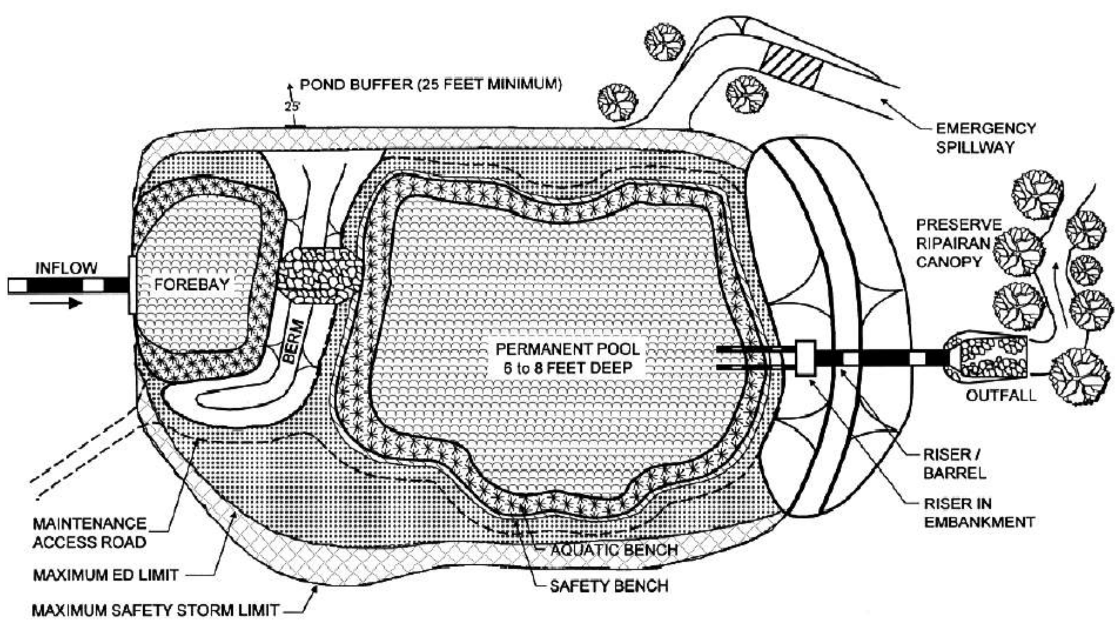


Figure H-4 Plan View of Hydrologic Zones around Storm Water Wet ED Pond

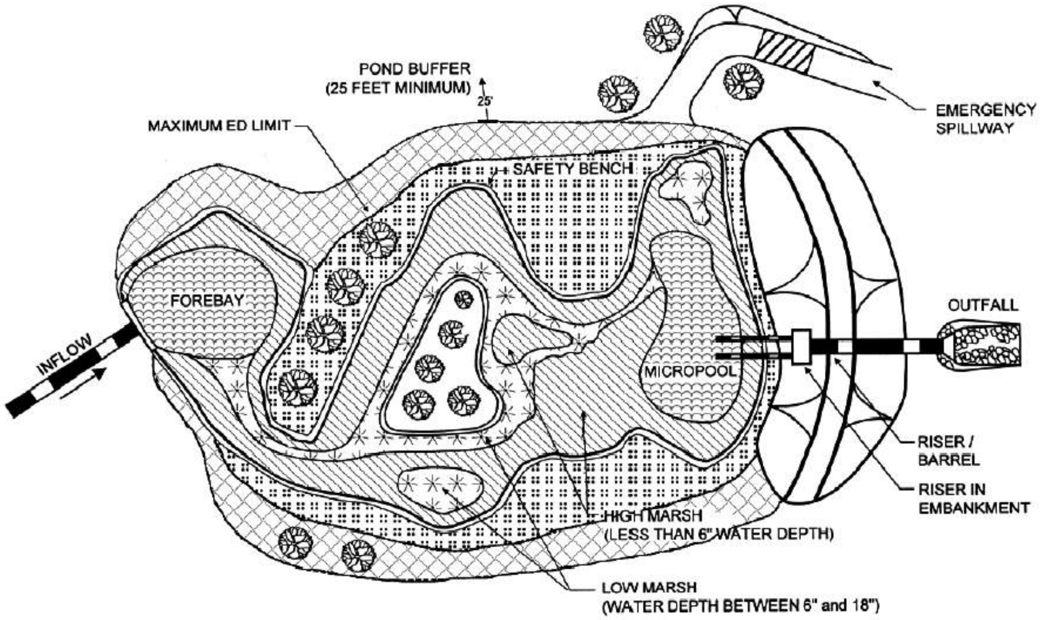


Figure H-5 Plan View of Hydrologic Zones around Storm Water ED Shallow Wetland

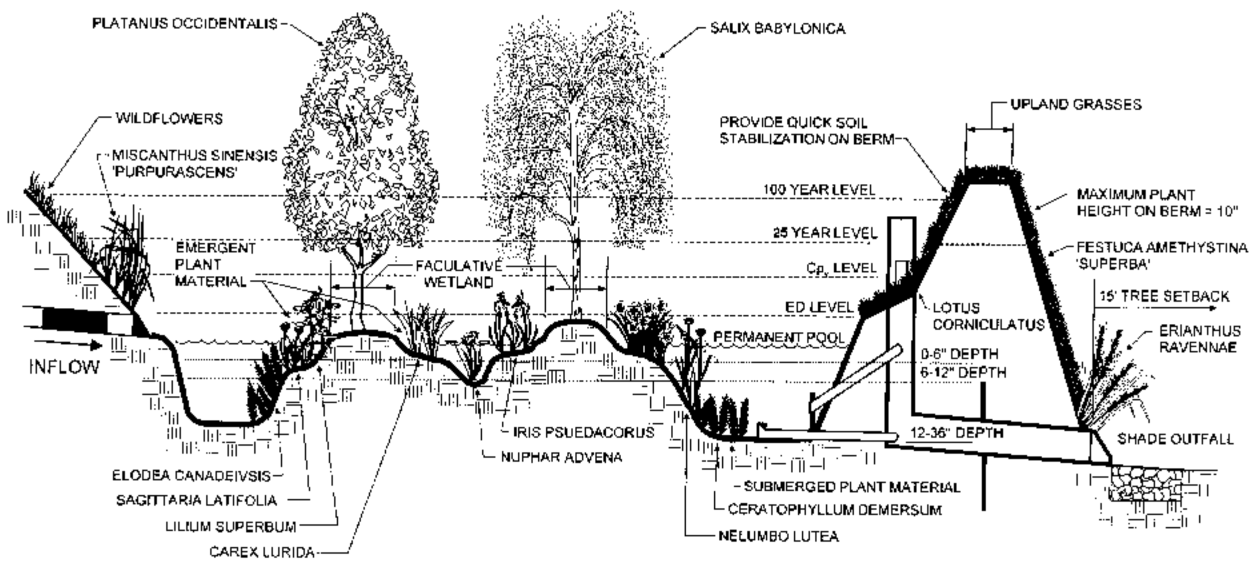


Figure H-6 Section Typical Shallow ED Wetland

H.4.2 Bioretention Areas

Bioretention areas are structural storm water controls that capture and treat runoff using soils and vegetation in shallow basins or landscaped areas. Landscaping is therefore critical to the performance and function of these facilities. Below are guidelines for soil characteristics, mulching, and plant selection for bioretention areas.

Planting Soil Bed Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location and size. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

The planting soil should be a sandy loam, loamy sand, loam, or a loam/sand mix (should contain a minimum of 35 to 60% sand, by volume). The clay content for these soils should by less than 25% by volume. Soils should fall within the SM, ML, SC classifications of the Unified Soil Classification System (USCS). A permeability of at least 1.0 feet per day (0.5"/hr) is required (a conservative value of 0.5 feet per day should be used for design). The soil should be free of stones, stumps, roots, or other woody material over 1" in diameter. Brush or seeds from noxious weeds, such as Johnson Grass, Mugwort, Nutsedge, and Canadian Thistle should not be present in the soils. Placement of the planting soil should be in lifts of 12 to 18", loosely compacted (tamped lightly with a dozer or backhoe bucket). The specific characteristics are presented in Table H-3.

Table H-3 Planting Soil Characteristics

Parameter	Value
pH range	5.2 to 7.00
Organic matter	1.5 to 4.0%
Magnesium	35 lbs. per acre, minimum (0.0072 lbs/Sq yd)
Phosphorus (P_2O_5)	75 lbs. per acre, minimum (0.0154 lbs/Sq yd)
Potassium (K_2O)	85lbs. per acre, minimum (0.0175 lbs/Sq yd)
Soluble salts	500 ppm
Clay	10 to 25%
Silt	30 to 55%
Sand	35 to 60%

(Adapted from EQR, 1996; ETAB, 1993)

Mulch Layer

The mulch layer plays an important role in the performance of the bioretention system. The mulch layer helps maintain soil moisture and avoids surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. It also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment. The mulch layer should be standard landscape style, single or double, shredded hardwood mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least 12 months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Planting Plan Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat storm water runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (Figure H-7). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. A sample of appropriate plant materials for bioretention facilities are included in Table H-4. More potential bioretention species can be found in the wetland plant list in subsection H.5.

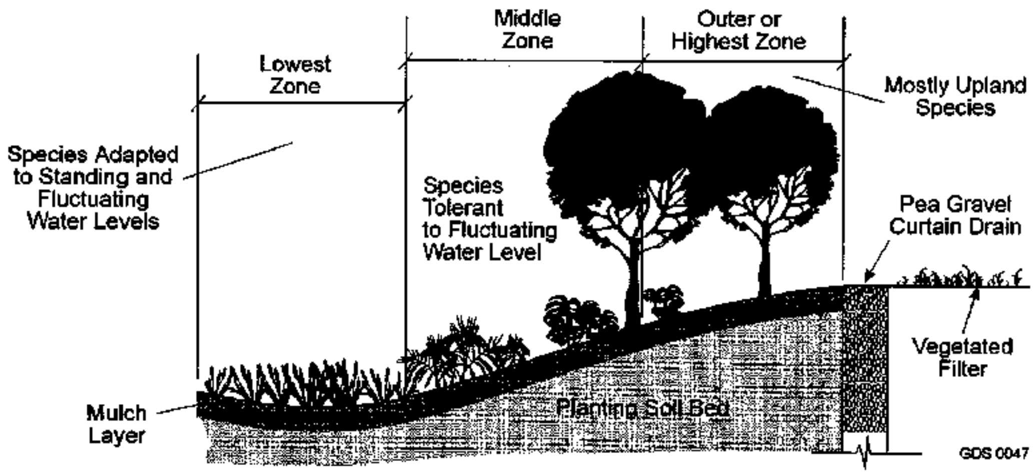


Figure H-7 Planting Zones for Bioretention Facilities

The layout of plant material should be flexible, but should follow the general principals described below. The objective is to have a system that resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth.

- Native plant species should be specified over exotic or foreign species.
- Appropriate vegetation should be selected based on the zone of hydric tolerance
- Species layout should generally be random and natural.

The tree-to-shrub ratio should be 2:1 to 3:1. On average, the trees should be spaced 8 feet apart.
Plants should be placed at regular intervals to replicate a natural forest.
Woody vegetation should not be specified at inflow locations.

A canopy should be established with an understory of shrubs and herbaceous materials.

- Woody vegetation should not be specified in the vicinity of inflow locations.
- Trees should be planted primarily along the perimeter of the bioretention area.
- Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be

considered when laying out the planting plan.

- Noxious weeds should not be specified.
- Aesthetics and visual characteristics should be a prime consideration.
- Traffic and safety issues must be considered.
- Existing and proposed utilities must be identified and considered.

Plant materials should conform to the American Standard Nursery Stock, published by the American Association of Nurserymen, and should be selected from certified, reputable nurseries. Planting specifications should be prepared by the designer and should include a sequence of construction, a description of the contractor's responsibilities, a planting schedule and installation specifications, initial maintenance, and a warranty period and expectations of plant survival. Table H-5 presents some typical issues for planting specifications. Figure H-8 shows an example of a sample planting plan for a bioretention area.

Table H-4 Commonly Used Species for Bioretention Areas

Trees	Shrubs	Herbaceous Species
Acer rubrum Red Maple	*Aesculus pariviflora* Bottlebrush Buckeye	*Andropogon virginicus* Broomsedge
Betula nigra River Birch	*Aronia arbutifolia* Red Chokeberry	*Eupatorium perpurea* Joe Pye Weed
Juniperus virginiana Eastern Red Cedar	*Fothergilla gardenii* Fothergilla	*Hemerocalis spp.* Day Lily
Koelreuteria paniculata Golden Rain Tree	*Hamemelis virginiana* Witch Hazel	*Iris pseudacorus* Yellow Iris
Nyssa sylvatica Black Gum	*Hypericum densiflorum* Common St. Johns Wort	*Lobelia cardinalis* Cardinal Flower
Platanus acerifolia London Plane-Tree	*Ilex glabra* Inkberry	*Panicum virgatum* Switchgrass
Platanus occidentalis Sycamore	*Ilex verticillata* Winterberry	*Pennisetum alopecuroides* Fountaingrass
Quercus palustris Pin Oak	*Juniperus horizontalis* Creeping Juniper	*Rudbeckia laciniata* Greenhead Coneflower
Quercus phellos Willow Oak	*Lindera benzoin* Spicebush	*Scirpus cyperinus* Woolgrass
Salix nigra Black willow	*Myrica pennsylvanica* Bayberry	*Vernonia gigantea* Ironweed

Table H-5 Planting Plan Specification Issues for Bioretention Areas

Specification Element	Elements
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation.
Contractor's Responsibilities	Specify the contractors responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency; removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair and replacement of staking and wires.
Warranty	Specify warranty period, the required survival rate, and expected condition of plant species at the end of the warranty.

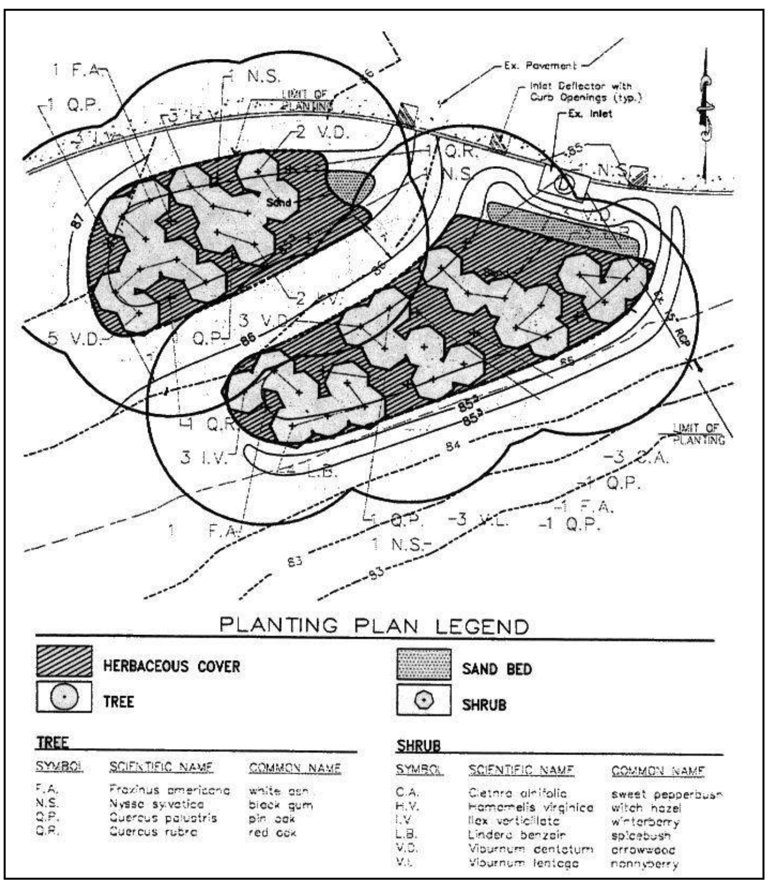


Figure H-8 Sample Bioretention Area Planting Plan
(Source: VDCR, 1999)

H.4.3 Surface Sand Filters and Infiltration Trenches

Both surface sand filters and infiltration trenches can be designed with a grass cover to aid in pollutant removal and prevent clogging. The sand filter or trench is covered with permeable topsoil and planted with grass in a landscaped area. Properly planted, these facilities can be designed to blend into natural surroundings.

Grass should be capable of withstanding frequent periods of inundation and drought. Vegetated filter strips and buffers should fit into and blend with surrounding area. Native grasses are preferable, if compatible.

Design Constraints:

- Check with your local review authority to see if the planning of a grass cover or turf over a sand filter or infiltration trench is allowed.
- Do not plant trees or provide shade within 15 feet of infiltration or filtering area or where leaf litter will collect and clog infiltration area.
- Do not locate plants to block maintenance access to the facility.
- Sod areas with heavy flows that are not stabilized with erosion control mats.
- Divert flows temporarily from seeded areas until stabilized.
- Planting on any area requiring a filter fabric should include material selected with care to insure that no tap roots will penetrate the filter fabric.

H.4.4 Enhanced Swales, Grass Channels and Filter Strips

Table F-6 provides a number of grass species that perform well in the stressful environment of an open channel structural control such as an enhanced swale or grass channel, or for grass filter strips. In addition, wet swales may include other wetland species (see H.4.1). Select plant material capable of salt tolerance in areas that may include high salt levels.

Table H.6 Common Grass Species for Dry and Wet Swales and Grass Channels

Common Name	Scientific Name	Notes
Bermuda grass	*Cynodon dactylon*	1,2
Big Bluestem	*Andropogon gerardii*	2, 3, Not for wet swales
Creeping Bentgrass	*Agrostis palustris*	1,2
Red Fescue	*Festuca rubra*	Not for wet swales
Reed Canary grass	*Phalaris arundinacea*	Wet swales
Witchgrass	*Panicum capillare*	2,3, Not for wet swales
Rescuegrass	*Bromus unioloides*	2, Not for wet swales
Switchgrass	*Panicum virgatum*	3
Buffalograss	*Buchloe dactyloides*	1, 2, 3
Bushy Bluestem	*Andropogon glomeratus*	2,3
Virginia Wildrye	*Elymus virginicus*	2,3,4 Not for wet swales

Common Name	Scientific Name	Notes
Texas Bluegrass	*Poa arachnifera*	2,3, Not for wet swales
Common Sixweeksgrass	*Vulpia octoflora*	2,3
Green Sprangletop	*Leptochloa dubia*	2,3
Canada Wildrye	*Elymus canadensis*	2,3,4, Wet swales
Longleaf Chasmanthium	*Chasmanthium latifolium*	2,3,4
Eastern Gamagrass	*Tripsacum dactyloides*	2,3

Note 1: These grasses are sod-forming and can withstand frequent inundation, and are thus ideal for the swale or grass channel environment. Most are salt-tolerant, as well.
Note 2: Where possible, one or more of these grasses should be in the seed mixes
Note 3: Native Texas grasses
Note 4: Shade tolerant

H.5 Trees and Shrubs for Storm Water Facilities

The following pages present a detailed list of wetland trees and shrubs that may be used for storm water management facilities such as storm water ponds, storm water wetlands and bioretention areas. (Source: Garber and Moorhead, 1999)

Table H-7 Wetland indicator status, growth form, flood tolerance and seed dispersal and treatment for selected native wetland trees and shrubs'

Species	Indicator*	Form	Flood Tolerance**	Seed Dispersal***	Seed Treatments****	Comments
Boxelder *Acer negundo*	FACW-	Tree	T	Sept.-Mar.	Cold Strat. 30-40 Days (Mech. Rup. Pericarp)	Can propagate by softwood cuttings
Red Maple *Acer rubrum*	FAC	Tree	T	Apr.-July	Strat. not required	Can propagate by softwood cuttings, tissue culture
Silver Maple *Acer saccharinum*	FAC	Tree	T	Apr.-June	Strat. not req.	
Red Buckeye *Aesculus pavia*	FAC-	Shrub	NE	Sept.-Nov.	Strat. not req.	Plant seed as soon as collected. Do not let dry out.
Painted Buckeye *Aesculus sylvatica*	NI	Shrub	NE	July-Aug.	Cold Strat. 90 Days	
Hazel Alder *Alnus serrulata*	OBL	Tree	NE	Sept.-Oct.	Cold Strat. 30-60 Days	Can propagate by cuttings, tissue culture
Common Pawpaw *Asimina triloba*	FAC-	Tree	I	Sept.-Oct.	Scarification Required Cold Strat. 60-90 Days	

			Flood	Seed	Seed	
Species	**Indicator***	**Form**	**Tolerance****	**Dispersal*****	**Treatments******	**Comments**
River Birch *Betula nigra*	FACW	Tree	IT	May-June	Cold Strat. 60-90 Days	Can propagate by softwood cuttings
American Hornbeam *Carpinus caroliniana*	FAC	Tree	WT	Oct.-Spring	Cold Strat. 60 Days	
Water Hickory C *Carya aquatica*	OBL	Tree	IT	Oct.-Dec.	Cold Strat. 30-90 Days Warm Strat. 60 Days	
Bitternut Hickory *I Carya cordiformus*	FAC	Tree	NE	Sept.-Dec.	Cold Strat. 90 Days	
Pecan *Carya illinoensis*	FAC +	Tree	IT	Sept.-Dec.	Cold Strat. 30-90 Days	
Shellbark Hickory *Carya laciniosa*	FAC	Tree	NE	Sept.-Oct.	Cold Strat. 90-120 Days	
Sugarberry *Celtis laevigata*	FAC	Tree	IT	Oct.-Dec.	Cold Strat. 60-90 Days	
Common Buttonbush *Cephalanthus occidentalis*	OBL	Shrub	VT	Sept.-Oct.	Strat. not req.	
Atlantic White Cedar *Chemaecyparis thyoides*	OBL	Tree	T	Oct.-March	Warm Strat. 30 Days Cold Strat. 30 Days	
Slash Pine *Pinus elliottii*	NI	Tree	IT	Oct.	Cold Strat. 30 Days	
Spruce Pine *Pinus glabra*	FACW	Tree	IT	Oct.-Nov.	Cold Strat. *28* Days	
Pond Pine *Pinus serotina*	FACW +	Tree	T	Spring	Cold Strat. 30 Days	Cones often remain closed after ripening
Loblolly Pine *Pinus taeda*	FAC-	Tree	IT	Oct.-Dec.	Cold Strat. 30-60 Days	
American Sycamore *Platanus occidentalis*	FAC +	Tree	T	Feb.-Apr.	Cold Strat. *60-90* Days	
Eastern Cottonwood *Populus deltoides*	FAC	Tree	VT	May-Aug.	Strat. not req.	Can propagate by cuttings
Swamp Cottonwood *Populus heterophylla*	OBL	Tree	VT	Apr.-July	Strat. not req.	Can propagate by cuttings
Wafer Ash *Ptelea trifoliata*	FAC	Shrub	NE	Sept.	Cold Strat. *90-120* Days	
Swamp White Oak *Quercus bicolor*	FACW +	Tree	T	Aug.-Dec.	Strat. not req.	White oak group, check native range
Cherrybark Oak *Quercus pagoda*	FAC +	Tree	I	Aug.-Dec.Cold Strat.	*30-90* Days	Red Oak group
Laurel Oak *Quercus laurifolia*	FACW	Tree	IT	Aug.-Dec.	Cold Strat. *30-90* Days	Red Oak group
Overcup Oak *Quercus lyrata*	OBL	Tree	T	Aug.-Dec.	Strat. not req.	White Oak group
Swamp Chestnut Oak *Quercus michiauxii*	FACW	Tree	I	Aug.-Dec.	Strat. not req.	White Oak group

Species	Indicator*	Form	Flood Tolerance**	Seed Dispersal***	Seed Treatments****	Comments
Water Oak *Quercus nigra*	FAC+	Tree	T	Aug.-Dec.	Cold Strat. *30-90* Days	Red Oak group
Willow Oak *Quercus phellos*	FACW	Tree	T	Aug.-Dec.	Cold Strat. *30-90* Days	Red Oak group
Shumard Oak *Quercus shumardii*	FAC	Tree	IT	Aug.-Dec.	Cold Strat. *30-90* Days	Red Oak group
Coastal Plain Willow *Salix caroliniana*	FACW+	Tree	VT	Mar.-Apr.	Strat. not req.	Seed will not remain viable in storage; plant within 10 days after collection.Can propagate by cuttings
Black Willow *Salix nigra*	FACW+	Tree	VT	June-July	Not required.	Seed will not remain viable in storage. Plant within 10 days after collection.Can propagate by cuttings
Baldcypress *Taxodium distichum* var. *distichum*	OBL	Tree	VT	Oct.-Nov.	Cold Strat. *90* Days.	Soak seed for S min. in ethyl alcohol be-fore placing in cold stratification.
Pondcypress *Taxodium distichum* var. *nutans*	OBL	Tree	VT	Oct.-Nov.	Cold Strat. *60-90* Days.	Soak seed for *24* to *48* hrs. in 0.0196 cit-ric acid before plac-ing in cold stratification.
American Elm *Ulmus Americana*	FAC	Tree	T	Mar.-June	Cold Strat. 60-90 Days	Can propagate by cuttings
Slippery elm *Ulmus rubra*	FAC	Tree	I	Apr.-June	Cold Strat. 60-90 Days	Can propagate by cuttings
Rough-Leaf Dogwood	FAC	Tree	T	Aug.-Jan.	Warm Strat. 70°-	
Cornus drummondii					80°	
					1 Day	
					Cold Strat. 30 Days	
Hawthornes	FAC	Shrub	IT	Fall-Winter	May Req. Scari-	
Crataegus spp.					fication	
					Warm Strat. 70°-	
					80°	
					30-90 Days	
					Cold Strat. 90-180 Days	
Common Persimmon *Diospyros virginiana*	FAC	Tree	T	Oct.-Nov.	Cold Strat. 60-90 Days	
Eastern Burning Bush	FAC+	Shrub	NE	Sept.-Oct.	Warm Strat. 68°-	
Euonymus atropurpuresu					86°	
					60 Days	
					Cold Strat. 60 Days	
Carolina Ash *Fraxinus caroliniana*	OBL	Shrub	VT	Sept.- Dec.	Cold Strat. 60 Days	
Green Ash *Fraxinus pennsylvanica*	FACW-	Tree	VT	Oct.-Feb.	Cold Strat. 60-90 Days	
Pumpkin Ash *Fraxinus profonda*	OBL	Tree	VT	Oct.-Dec.	Cold Strat. 60 Days	
Waterlocust *Gleditsia aquatica*	OBL	Tree	T	Sept.-Dec.	Req. Scarifica-tion	
Loblolly Bay *Gordonia laisianthus*	FACW-	Tree	T	Fall	Not Established	
Decidious Holly *Illex deciduas*	FACW	Shrub	VT	Sept.-Mar.	Warm Strat. 68°-Day, 86°-Night 60 Days Cold Strat.-60 Days	

Species	**Indicator***	**Form**	**Flood Tolerance****	**Seed Dispersal*****	**Seed Treatments******	**Comments**
Spicebush *Lindera benzoin*	FACW	Shrub	NE	Sept.-Oct.	Cold Strat. 120 Days	
Sweetgum *Liquidamber styraciflua*	FAC	Tree	T	Sept.-Nov.	Cold Strat. *30* Days	
Yellow Poplar *Liriodendron tulipifera*	FACU	Tree	I	Oct.-Nov.	Cold Strat. 60-90 Days	
Sweetbay *Magnolia virginiana*	OBL	Tree	IT	Sept.-Nov.	Cold Strat. 90-180 Days	Can propagate by cuttings
Red Mulberry *Morus rubra*	FACU	Tree	IT	June-Aug.	Cold Strat. 30-90 Days	
Southern Bayberry *Myrica cerifera*	FAC	Shrub	NE	Aug.-Oct.	Cold Strat. 60-90 Days	
Water Tupelo *Nyssa aquatica*	OBL	Tree	VT	Oct.-Nov.	Cold Strat. 30-120 Days	
Ogeechee Tupelo *Nyssa ogeche*	OBL	Tree	VT	Aug.-Sept.	Cold Strat. 30-120 Days	
Swamp Tupelo *Nyssa sylvatica* var. *biflora*	OBL	Tree	VT	Sept.-Dec.	Cold Strat. 30-120 Days	
Redbay *Persea borbonia*	FACW	Tree	MT	Fall	Not established	

* *Indicator*: **OBL-obligate**; **FACW-facultative wetland**; **FAC-facultative**; **FACU-facultative upland**.
Indicators may be modified by (+) or (-) suffix; (+)indicates a species more frequently found in wetlands; (-) indicates species less frequently found in wetlands.

** *Flood Tolerance Mature Plants*:

VT-Very Tolerant: Survives flooding for periods of two or more growing seasons.
T-Tolerant: Survives flooding for one growing season.
I-Intermediately Tolerant: Survives one to three months of flooding during growing season
WT-Weakly Tolerant: Survives several days to several weeks of growing-season flooding.
IT-Intolerant: Cannot survive even short periods of a few days or weeks of growing-season flooding.
NE-Not established.

*** *Seed Dispersal*: Approximate dates across natural range of a given species.

**** *Seed Treatments*:
Cold stratification: Place moist seeds in polyethylene plastic bags and place in refrigerated storage at 33°-41° F for specified time.
Warm stratification: Place moist seeds in polyethylene plastic bags at 68°-86° F for specified time. Scarification-mechanical or chemical treatment to increase permeability of seed coat.

Table H-8 Seedling response of selected species to flooding conditions

Species	Water Level	Seedling Survival*	Comments
Boxelder *Acer negundo*	Total submersion Growing Season	100% at 2 weeks 70% at 3 weeks 36% at 4 weeks 0% at 32 days	Chlorotic leaves after 4 days. Slow recovery.
Red Maple *Acer rubrum*	Partial submersion Growing season	100% at 5 days 90% at 10 days 0% at 20 days	Adventitious roots developed after 15 days Height growth decreased in saturated soil Soil saturation
	Soil saturation Growing season	Growing season 100% at 32 days	
Silver Maple *Acer saccharinum*	Total submersion Growing season	100% at 3 weeks	Lower leaves wilt after 2 days. Slow recovery Height growth better at saturated conditions than field capacity
	Soil saturation Growing season	100% at 60 days	
River Birch *Betula nigra*	Soil saturation Growing season	100% at 32 days	Growth severely stunted
Pecan *Carya illinoensis*	Total submersion Growing season	75% at 4 weeks	
Sugarberry *Celtis laevigata*	Soil saturation Growing season	100% at 60 days	
Common Buttonbush *Cephalanthus occidentalis*	Total submersion Growing season	100% at 30 days	
Green Ash *Fraxinus pennsylvanica*	Total submersion Growing season	100% at 5 days 90% at 10 days 73% at 20 days 20% at 30 days	Lower leaves chlorotic after 8 days Better growth in saturated soil than soil at field capacity
	Partial submersion Growing season	100% at 14 days	
	Soil saturation Growing season	100% at 60 days	
Sweetgum *Liquidambar styraciflua*	Total submersion Growing season	0% at 32 days	
	Partial submersion Growing season	0% at 3 months	

Adapted from Teskey & Hinkley, 1977

* Seeding survival in relation to length of flooding

Table H-8 continued

Species	Water Level	Seedling Survival*	Comments
Yellow Poplar *Liriodendron tulipifera*	Partial submersion Growing Season	0% at 2 months No adverse effects	
Water Tupelo *Nyssa aquatica*	Partial submersion Growing season	90-100% over growing season 32% when seedlings near- ly overtopped	Best growth when water ta- ble fluctuates
Swamp Tupelo *Nyssa sylvatica* var. *bif ora*	Partial submersion Growing season	90 - 100% over growing season	Poor root growth in stag- nant water
	Soil saturation Growing season	90 - 100% over growing season	Best growth in saturated soil
Slash Pine *Pinus elliottii*	Partial submersion Growing season	68% at 2 months 12% at 7 months	Root and shoot growth de- creased
Loblolly Pine *Pinus taeda*			Root & shoot growth re- duced during flooding Dormant season flooding increased height and diam- eter growth
American Sycamore *Platanus occidentalis*	Total submersion Growing season	100% at 10 days 0% at 30 days	Growth decreased by satu- rated soil
	Soil saturation Grnwina season	95% at 32 days	
Eastern Cottonwood *Populus deltoids*	Total submersion Growing season	0% at 16 days	Best growth when water ta- ble is 2 feet below surface
	Partial submersion Growing season	90% at 10 days 70% at 20 days 47% at 30 days	High mortality when deep- ly flooded
Cherrybark Oak *Quercus pagoda*	Total submersion Growing season	87% at 5 days 6% at 10 days 0% at 20 days	Height growth decreased by soil saturation
	Soil saturation Growing season	89% at 15 days 47% at 30 days 13% at 60 days	
Water Oak *Quercus nigra*	Partial submersion Growing season	Survived 2 months	
Willow Oak *Quercus phellos*	Soil saturation Growing season	100% at 50 days	Poorer growth in saturated soil than soil at field capac- ity
Shumard Oak *Quercus shumardii*	Total submersion Growing season	100% at 5 days 90% at 10 days 6% at 20 days	Height growth poorer in saturated soil than soil at field capacity
	Soil saturation Growing season	100% at 30 days 66% at 60 days	
Black Willow *Salix nigra*	Total submersion Growing season	100% at 30 days	Better height growth in sat- urated soil than soil at field capacity
	Soil saturation Growing season	100% at 60 days	
Baldcypress *Taxodium distichum* var. *disti- Chum*	Total submersion Growing season	100% at 4 weeks	
American Elm *Ulmus Americana*	Total submersion Growing season	100% at 10 days 27% at 20 days 0% at 30 days	Height growth decreased in saturated soil
	Soil saturation Growing season	100% at 15 days 94% at 60 days	

* Seeding survival in relation to length of flooding

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