CITY OF EAGLE DESIGN STANDARD FOR STORM DRAINAGE
GENERAL PROVISIONS

1. Drainage facility designs for proposed subdivisions shall be included as part of construction plan submittals to the Zoning Administrator. Drainage facility designs for construction projects on individual sites that are already platted shall be submitted to the Building Inspector as part of plans for review.

2. Drainage transmission facilities (pipes, orifices, intakes and the like) and drainage treatment facilities (sand and grease traps, filter swales, turf ramps and the like) shall be sized based on peak flow rate generated by the design storm. The design storm is defined as a precipitation event delivering 1.1 inch of water, with precipitation intensity as described by the SCS Triangular Hydrograph with a time-to-peak of one hour.

3. Retention facilities (seepage beds, basins, ponds, seepage swales, infiltration galleries and the like) shall be sized based on design storm volume.

4. In submittal documents, drainage transmission, treatment and retention facilities shall be shown to scale on a plan view of the development that also shows pre-development elevation contours and final elevation contours. Plan shall also show, by outlines or shading, the areas characterized by each of the runoff coefficients used in the runoff rate and volume calculations. Submittal documents shall include:
   a. Runoff volume and rate calculations,
   b. Size design calculations for runoff transmission, treatment and retention facilities,
   c. Structure detail drawings (showing dimensions, reinforcement, pipe sizes, inlet and outlet invert elevations and the like) for treatment and retention facility structures, and line location of any pipe, with notes giving pipe size, material, class, slope and inlet and outlet invert elevations. Structure detail drawing views shall include at least plan view and two cross sections in planes perpendicular to each other for each facility or structure built on site, or manufacturer's drawings in like detail for manufactured or pre-cast elements.
   d. Document of agreement with drainage receiver, if applicable.

5. Retention facilities:
   a. If a seepage bed is chosen as the retention device, City of Eagle standard design calculation form shall be completed and the dimensions so derived shall be minimum for the design.
   b. If a grassy basin is chosen as the retention device, City of Eagle standard design calculation form shall be completed and submitted as a part of design calculations, and basin size shall be not less than the dimensions so derived.
   c. If a wet pond is chosen as the retention facility, calculations shall be submitted to demonstrate storage of the total runoff volume, with no credit allowed for percolation during the event, plus not less than one foot freeboard, above design normal water level, along with construction plans of the basin.
   d. Storm runoff absorption time (time to virtually empty the bed or basin by percolation following the event) for seepage beds or grassy basins shall be estimated at one-third of site's percolation rate, or as 95% absorption by a falling-head analysis. If absorption time so estimated is more than 72 hours, required storage shall be increased 50 percent as a safeguard against subsequent storms.
   e. Grassy basin design shall incorporate an absorption bed, either open-trench type or covered, having a volume not less than one percent (1%) of the computed design runoff volume, situated so that its inlet is at the lowest point of the basin, to prevent the occurrence of

lingering puddling after storms. Base of any grassy retention basin shall be sloped not less than one percent (1%), also to minimize puddling.

6. Rational Method shall be used as calculation basis for catchment areas up to 10 acres. Designer may choose to use either Rational Method or NRCS TR-55 method for areas between 10 and 100 acres. NRCS TR-55 shall be used if area exceeds 100 acres.

7. Runoff coefficients for designs shall be based on the following component values:

Roofs	: 0.95
Pavement and concrete	: 0.90
Graveled surfaces	: 0.40
Landscaped areas	: 0.20
Parks and lawns (uninterrupted turf)	: 0.10
Typical undeveloped	: 0.15

<u>Undeveloped areas:</u>

Sandy and sandy loam	0 – 2% slope	: 0.05
Sandy and sandy loam	2 – 7% slope	: 0.10
Sandy and sandy loam	> 7% slope	: 0.15
Clay - loam and clay	0 – 2% slope	: 0.13
Clay - loam and clay	2 – 7% slope	: 0.18
Clay - loam and clay	> 7% slope	: 0.25

Composite runoff coefficients from tables shall not be used for design. Runoff quantity shall be based on actual components proposed or maximum sizes of buildings and impervious surfaces allowed by
zoning or by planned-unit development agreement. In cases where improvement design is not final, maximum development allowed by zoning or by planned-unit development agreement shall be assumed.

8. Calculation of concurrent infiltration during storms for design of all infiltrative systems, and of storage capacity of native base materials for seepage beds and open-trench beds, shall be subject to the following:

   A. Porosity of 1.5" to 2" washed drain gravel shall be taken as 0.38. Value used for bed sizing shall be reduced 15% from new-material value to account for silt accumulation as the bed ages.
   B. Porosity of washed sand meeting ASTM C – 33 or ITD 703.02 may be taken as 0.35.
   C. Porosity of fine-grained native strata shall be taken as 0.25 unless otherwise determined by laboratory.
   D. Appended tables of volume ratios and maximum depth during event are compiled by solving an equation derived as a classical solution of a differential equation of the form (generalized) dV = Qin – Qout. Copy of derivation may be viewed at the Planning and Zoning office. The values in these tables shall be the values used in design of seepage beds and grassy basins for retention.

9. Minimum vertical separation between bottom of trench or bed excavation and maximum ground water elevation shall be three (3) feet, subject to Health District requirements if more stringent.

10. Target recovery time after end of the design storm shall be seventy-two (72) hours to empty 95% of the medium in the seepage bed.

11. Design shall provide for protection of groundwater from major episodes of microbial contamination by including features to maintain unsaturated conditions in the native soils below the base elevation and above the seasonal high water table (called the "foundation soils" in the following), or by including special filtration provisions in lieu of assuring non-saturation.

   A. If the pore volume of the fine-grained strata of the foundation soils totals more than twice the during-storm seepage as calculated by 3.D foregoing, no special provisions are necessary. For this provision, "fine-grained" means strata having a 10% or more passing the No. 60 sieve (grain size less than 0.2 millimeter).

   B. If the criterion of (a) is not met, foundation soils shall be over-excavated to a depth three feet below design trench bottom and replaced with sand meeting ASTM C-33 or ITD 703.02. Such replacement fill material shall not be counted as part of storm water storage volume.

12. For phased developments:
Each submittal for review shall be self-subsistent, containing all data, maps, and site-specific quantity derivations employed in the drainage design for the facilities currently under review. If calculations are presented in spreadsheet programming form, such spreadsheet programs shall be fully documented, including all formulas and nomenclature. In the event that quantity values employed in the design were developed at an earlier stage of a complex or phased development process, calculations and data demonstrating such values shall be included with documentation, as reference material in the submittal for staff review. Such previously reviewed materials shall be identified by the submitter as previously reviewed and included for reference.

In the event that a previously reviewed phase is significantly changed after drainage design review, and such change modifies the drainage volume received by the phase under consideration, such changes in volume shall be quantified by the applicant, documentation shall be supplied to verify the calculated volume change, and such changes in volume shall be accommodated by the facility being designed for the current phase.

13. Alternative retention designs:
Designs for retention systems of styles other than seepage beds and retention basins shall be subject to technical review by City staff. Performance criteria to be met by such alternative retention system designs shall be:

   A. Retention of 100-year storm runoff as herein defined, and reliable infiltration of the retained runoff into groundwater, or definite and workable provision for ultimate disposal of the retained runoff by other means equally protective of surface water, as by evaporation (for instance).
   B. Allowance for effects of degrading processes occurring over time upon the performance capability of the system, by (a) reduction of capacity rating, on a basis plainly stated, to accommodate deposition of particulates, growth of vegetation, accumulation of plant and other organic debris, or such other time-related process as degrades performance of the alternative under consideration; or by (b) a defined schedule of maintenance activities to be performed, with documentation clearly setting forth what persons or organization shall perform such maintenance and what institutional or organizational commitments there shall be to assure that such maintenance will be performed.

C. Protection of groundwater from pathogenic organism and particulate contamination, not less than the degree of protection afforded saturated infiltrative flow through a three-foot layer of sand conforming to ASTM C-33 or ITD 703.32.

D. Infiltration gallery systems: Design infiltration rate shall be not greater than 3.5 inches per hour. Provide storage volume as required by Table 3, plus a 15 percent allowance for deposited particulates. Pretreatment to reduce sand and grease is required as for other alternatives.

14. Conditions for exemption:
Residential subdivision development submittals conforming to either Criterion A or Criterion B, as follows, shall not be required to provide retention facilities for stormwater directed onto back yard turf areas, nor to submit stormwater retention design calculations to the City of Eagle, unless the streets are private streets. This does not relieve developer from any requirement of the highway authority that receives dedicated right of way as a part of the development process.

Criterion A: the subdivision is zoned A, A-R, or R-E.

Criterion B: impervious-surfaced area (roofs, concrete, pavement, decking, impermeable landscaping membrane and comparable surfaces) is restricted to not more than twenty-five pewrcent (25%) of lot area as defined I Eagle City Code 8-1-2 by a specific provision of a development agreement between the developer and the City of Eagle, and roof drainage is required to be directed onto back yard turf areas, rather than onto streets, by a specific provision of such development agreement.

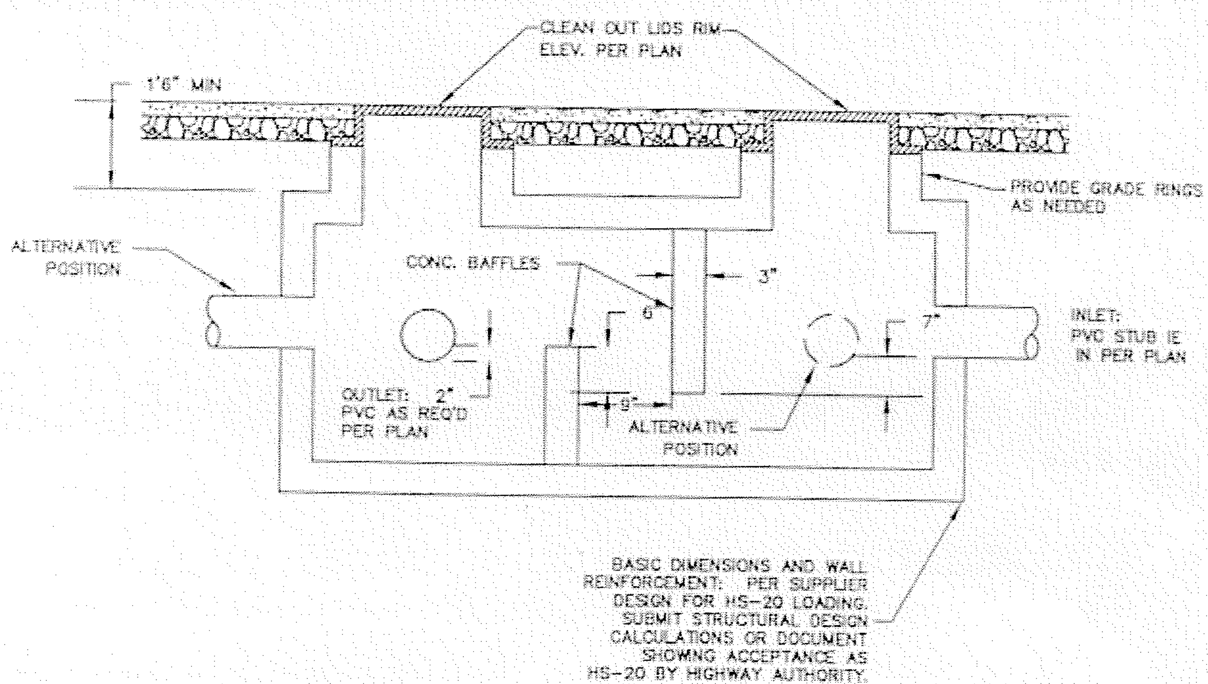
SEEPAGE BED DESIGN PROCEDURE

1. Determine total area that will drain to the seepage bed.
2. Determine areas of roof, pavement and concrete, landscaping, turf, gravelled and undeveloped. Check that the sum of partial areas is equal to the total.
3. Determine equivalent area A*, the sum of products of partial areas multiplied by the pertinent runoff coefficients.
4. For total areas 10 acres or less, calculate design peak flow as 1.1 inches per hour multiplied by equivalent area and design runoff volume as 1.1 inches multiplied by equivalent area. If total area exceeds 10 acres, and is 100 acres or less, design runoff volume shall be the equivalent area multiplied by 1.1 inches, but the design peak flow shall be as determined by the ITD small-basin analysis method for 100-year storm and the equivalent area. For total area greater than 100 acres, the NRCS TR-55 method shall be used for design peak flow, and design runoff volume shall be based on 1.1 inches multiplied by the equivalent area.
5. Percolation rate K of the receiving soil shall be determined at the base of the bed by percolation test or shall be based on the estimate stated in a written soils investigation report by a soils scientist or geologist. If based on a percolation test, the value of K shall be the equivalent rate in inches per hour; if reported in minutes per inch, the appropriate units transformation calculation shall be made. K shall be defined as the percolation rate at a head of one foot. If based upon a percolation test performed with two feet of standing water, K shall be prorated to one-half the test percolation value. If based on a percolation test performed at 6 inches standing water, K shall be prorated to double the reported value.
6. If K is less than 0.5 inch per hour, seepage beds may not be used. If K is greater than 8 inches per hour, the upper three feet of receiving soils shall be removed and replaced with washed sand conforming to ASTM C-33. Sand so placed for the purpose of modifying the hydraulic conductivity shall not be credited as a storage medium in storage pore volume calculations. Where sand is used to replace excessively pervious receiving soils, the original percolation rate of the sand shall be taken as 8 inches per hour. For <u>rock-filled</u> bed design, in-service percolation rate shall be taken as not greater than 2.0 inches per hour, based on anticipated silt accumulation on the absorption interface, and also as not greater than the value determined by soils investigation<u>. For open basin design, in-service percolation rate shall be taken as not less than 4.0 inches per hour, in recognition that the need for surface maintenance will be visible if silt accumulation slows percolation at the absorptive interface.</u>
7. Coefficients for design include:

a. porosity of 1" to 2" washed drain rock	: 0.38
b. runoff coefficient for roofs	: 0.95
c. runoff coefficient for concrete slabs and pavement	: 0.90
d. runoff coefficient for gravelled surfaces	: 0.40
e. runoff coefficient for landscaped areas	: 0.20
f. runoff coefficient for turf	: 0.10
g. runoff coefficient for undeveloped areas	: 0.15

8. Volume of storage gravel required shall be based on pore volume adequate for design storm volume, plus one foot freeboard to top of rock, at porosity of 85% of the porosity of new material, which equals 0.33 for washed drain gravel. Bed size shall be calculated as shown on the appended design calculation form.
9. If the facility is a covered seepage bed, then sides of trench and top of rock shall be covered with geotextile filter fabric not lighter than 6 ounce per square yard, and soil cover shall be not less than 1.5 foot.
10. If the facility is open-trench type, then sides of rock shall be separated from trench walls by geotextile filter fabric not lighter than six ounces per square yard.

11. If "pre-development drainage" is accepted by a drainage receiver (as duly documented by instrument bearing signature of receiver), it shall be conducted to the receiving facility through an overflow from the retention bed or basin, rather than through a by-pass.
12. Pre-treatment features (in most systems, sand and grease traps, but in some systems either flow-through grassy swales, overland-flow turf ramps, or other solids removal approaches) shall treat full storm runoff in all systems.

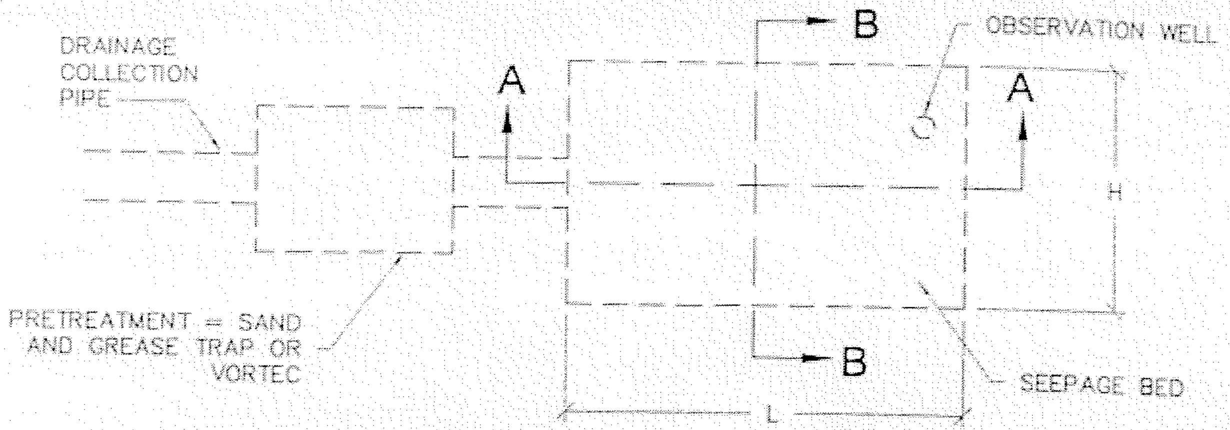


GENERAL SAND & GREASE TRAP DETAIL

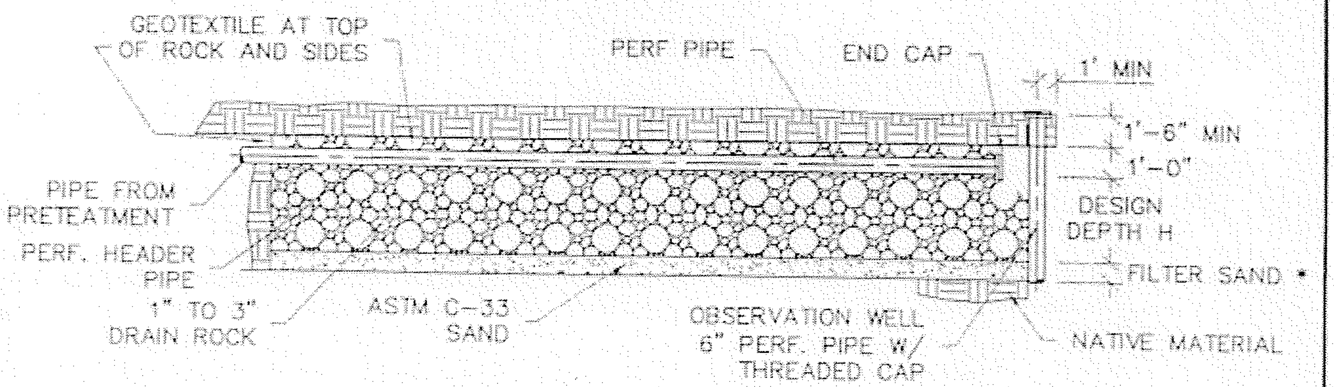
N.T.S.

CAPACITY: NOT LESS THAN 1 / 12 HOUR DESIGN FLOW PER DRAINAGE CALCULATIONS, MEASURED TO INVERTS OF INLET & OUTLET PIPES.

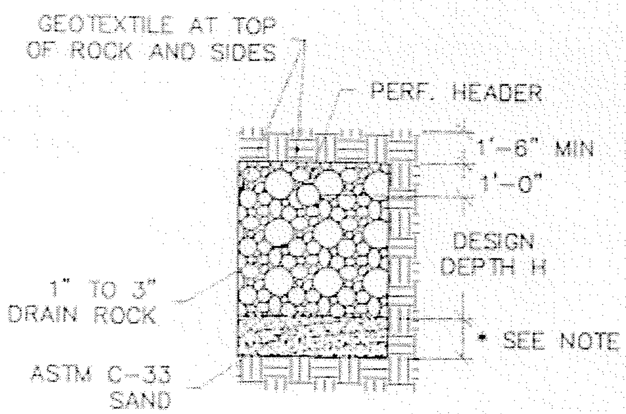
CITY OF EAGLE FOR PUBLIC WORKS CONSTRUCTION	STORM DRAINAGE STANDARD	STANDARDS DRAWING NO. SD-01



INSTALLATION: GENERAL PLAN
NOT TO SCALE



SECTION A – A
NOT TO SCALE



SECTION B – B
NOT TO SCALE

NOTE:

DEPTH OF FILTER SAND TO BE 6" UNLESS BASE REPLACEMENT IS REQUIRED DUE TO CLOSENESS OF WATER TABLE OR IMPERVIOUS LAYER. IF BASE REPLACEMENT IS REQUIRED, FILTER SAND SHALL BE 3.0 FT.

CITY OF EAGLE FOR PUBLIC WORKS CONSTRUCTION	TYPICAL SEEPAGE BED FOR STORMWATER	STANDARDS DRAWING NO. SD–02
FILE: # EG 042203		DATE: 08/26/03 REVISED: 0

Project: ______________________________ Site: ______________________________
Designer: ______________________________ Calculated by: ______________________________
Date: ______________________________

RE: Eagle Drainage Standards Seepage Bed Design Form

(See reverse for definitions of variables)

1. Percolation rate K, (attach soil column and investigation report):
   (See Note 1): K = ________ in/hr.

2. Equivalent watershed area:

Roof	________	sq. ft. x 0.95 =	________	sq. ft.
Concrete	________	sq. ft. x 0.95 =	________	sq. ft.
Pavement	________	sq. ft. x 0.90 =	________	sq. ft.
Gravel	________	sq. ft. x 0.40 =	________	sq. ft.
Landscaped	________	sq. ft. x 0.20 =	________	sq. ft.
Turf	________	sq. ft. x 0.10 =	________	sq. ft.
	________	A_{eq} = Total Equivalent =	________	sq. ft.

3. Design storm volume = A_{eq} x 0.0917 ft
   V_s = ________ x 0.0917 = ________ cu. ft.

4. If developer has a right to discharge a pre-development volume V_{pd}, then $V_d = V_s - V_{pd}$ = ________ - ________ = ________ cu. ft.
   If not, then $V_d = V_s$.
   Note: Right to discharge, if claimed, must be verified by a signed and dated document from drainage receiver granting permission, and by calculation or measurement of actual pre-development drainage quantity.

5. Interpolate value of retention ratio, V_r/V_d, corresponding to K, from table.
   V_r/V_d = ________. $V_r = V_r/V_d$/ x V_d = ________x________=________cu.ft.

6. Media bottom area A_b (chosen by designer) = ________ sq. ft. (________ ft. x ________ft.)
   V_d/A_b = ________ / ________ = ________/
   Max. height of stored water h_{max} = ________ ft. (from table)

7. Media depth (minimum) = h_{max} + 1.0 = D_m

8. A_b x D_m = ________ x ________ = V_m = ________ cu. ft.

   Note 1: Percolation rate may be based on soil scientist's reported probable value, or on a value determined by percolation test. If percolation test is used, value shall be expressed in inches per hour based on one foot depth of water. Values determined at depths other than one foot shall be pro-rated based on ratio of depths. Values reported in minutes per inch shall be converted to inches per hour.

RE: Eagle Drainage Standards Seepage Bed Design Form

Variables:

K	=	Percolation Rate, in/hr
A_e	=	Equivalent drainage area
V_s	=	Volume of storm runoff, cu. ft.
V_r	=	"Volume retained" (at peak) in bed, cu. ft.
V_{pd}	=	"Pre-development" runoff volume, cu. ft.
V_d	=	"Design volume," cu. ft.
A_b	=	Base area, sq. ft.
h_{max}	=	Maximum water depths in bed, ft.
D_m	=	Depth of media
V_m	=	Volume of media

Table 1.

Maximum Water Height in Rock-Filled Bed h_{max} (ft)

	K (in/hr)															
V_d/A_b	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
2	5.1	5.0	4.8	4.7	4.6	4.5	4.4	4.3	4.2	4.1	4.0	3.9	3.8	3.7	3.6	3.6
3	7.7	7.5	7.3	7.1	6.9	6.7	6.5	6.4	6.2	6.1	6.0	5.8	5.7	5.6	5.5	5.4
4	10.3	10.0	9.7	9.4	9.2	9.0	8.7	8.5	8.3	8.1	7.9	7.8	7.6	7.4	7.3	7.2
5	12.8	12.5	12.1	11.8	11.5	11.2	10.9	10.6	10.4	10.2	9.9	9.7	9.5	9.3	9.1	8.9
6	15.4	15.0	14.5	14.2	13.8	13.4	13.1	12.8	12.5	12.2	11.9	11.7	11.4	11.2	10.9	10.7
7	18.0	17.5	17.0	16.5	16.1	15.7	15.3	14.9	14.6	14.2	13.9	13.6	13.3	13.0	12.8	12.5
8	20.6	20.0	19.4	18.9	18.4	17.9	17.5	17.0	16.6	16.3	15.9	15.5	15.2	14.9	14.6	14.3
9	23.1	22.5	21.8	21.2	20.7	20.1	19.6	19.2	18.7	18.3	17.9	17.5	17.1	16.8	16.4	16.1
10	25.7	24.9	24.2	23.6	23.0	22.4	21.8	21.3	20.8	20.3	19.9	19.4	19.0	18.6	18.2	17.9

Time to Maximum Water Height in Rock-Filled Bed t_{max} (hr)

	K (in/hr)															
	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
	2.43	2.39	2.35	2.32	2.28	2.25	2.22	2.19	2.17	2.14	2.11	2.09	2.07	2.05	2.02	2.00

Fraction of Runoff Volume Stored in Rock-Filled Bed @ h_{max}, V_r/V_d

	K (in/hr)															
	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
	0.85	0.82	0.80	0.78	0.76	0.74	0.72	0.70	0.69	0.67	0.66	0.64	0.63	0.61	0.60	0.59

Input Values

Depth of Bottom Layer Material - L (ft)	1
Porosity of Rock Filled Basin - P ()	0.33

Notes:

P = 0.33 for design, to allow 15% silt accumulation as bed ages

K = 2.0 in/hr or less for design, due to anticipated interface silt accumulation as bed ages.

Derived Equations are solved based on field-measured percolation rate as K substituted for the hydraulic conductivity (k) and using unity for the "L" parameter.

Table 3.

Maximum Water Height in Infiltration Gallery h_{max} (ft)

	K (in/hr)												
V_d/A_b	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5
2	1.89	1.84	1.79	1.74	1.70	1.66	1.62	1.58	1.55	1.51	1.48	1.45	1.42
3	2.83	2.75	2.68	2.61	2.55	2.49	2.43	2.37	2.32	2.27	2.22	2.18	2.13
4	3.77	3.67	3.57	3.48	3.40	3.31	3.24	3.16	3.09	3.03	2.96	2.90	2.84
5	4.72	4.59	4.47	4.35	4.25	4.14	4.05	3.95	3.87	3.78	3.70	3.63	3.55
6	5.66	5.51	5.36	5.22	5.10	4.97	4.86	4.74	4.64	4.54	4.44	4.35	4.26
7	6.60	6.43	6.26	6.10	5.94	5.80	5.66	5.54	5.41	5.29	5.18	5.08	4.97
8	7.55	7.34	7.15	6.97	6.79	6.63	6.47	6.33	6.19	6.05	5.92	5.80	5.68
9	8.49	8.26	8.04	7.84	7.64	7.46	7.28	7.12	6.96	6.81	6.66	6.53	6.39
10	9.44	9.18	8.94	8.71	8.49	8.29	8.09	7.91	7.73	7.56	7.40	7.25	7.10

Time to Maximum Water Height in Infiltration Gallery t_{max} (hr)

	K (in/hr)												
	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5
	2.58	2.54	2.50	2.47	2.43	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.21

Fraction of Runoff Volume Stored in Infiltration Gallery @ h_{max}, V_r/V_d

	K (in/hr)												
	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5
	0.94	0.92	0.89	0.87	0.85	0.83	0.81	0.79	0.77	0.76	0.74	0.73	0.71

Input Values

Depth of Bottom Layer Material - L (ft)	1
Porosity of Infiltration Gallery - P ()	1

Notes:

K = 3.5.0 in/hr or less for design, due to anticipated interface silt accumulation as bed ages but higher than rock-filled bed due to ability to check pre-failure condition.

Derived Equations are solved based on field-measured percolation rate as K substituted for the hydraulic conductivity (k) and using unity for the "L" parameter.

Project: ______________________________ Site: ______________________________
Designer: ______________________________ Calculated by: ____________________
Date: ______________________________

RE: Eagle Drainage Standards Grassy Retention Basin Design Form:

(See reverse for definitions of variables.)

1. Percolation rate K, __________ in/hr
   Note 1: Percolation rate may be based on soil scientist's reported probable value, or on a value determined by percolation test. If percolation test is used, value shall be expressed in inches per hour based on one foot depth of water. Values determined at depths other than one foot shall be pro-rated based on ratio of depths. Values reported in minutes per inch shall be converted to inches per hour.

2. Equivalent watershed area:

Roofs	__________	sq. ft. x 0.95 = __________	sq. ft
Concrete	__________	sq. ft. x 0.95 = __________	sq. ft.
Pavement	__________	sq. ft. x 0.90 = __________	sq. ft.
Gravel	__________	sq. ft. x 0.40 = __________	sq. ft.
Landscaped	__________	sq. ft. x 0.20 = __________	sq. ft.
Turf	__________	sq. ft. x 0.10 = __________	sq. ft.

A_{eq} = Sum of C_pA_p = __________ sq. ft.

2. Design storm volume V_s = __________ x 0.0917 = __________ cu. ft.

3. "Pre-development" discharge volume V_{pd} = __________ cu. ft. (Must be verified by a signed and dated document from drainage receiver granting permission, and by calculation or measurement of actual pre-development drainage quantity, or V_{pd} = 0).

4. Design basin volume
   $V_d = V_s - V_{pd}$
   V_d = ________ - ________ = __________ cu. ft.

5. Base area (mid depth)____________ Sq. ft.; Ratio V_d/A_d = ______________ ft.

6. "Fraction of Runoff Stored" from table V_r/Vd = ______________

7. Required retained volume $V_r = (V_r/V_d) \times (V_d)$ = ______________ cu. ft.

8. Select design water depth D_w and freeboard of basin. Design water depth D_w shall be not less than h_{max} as shown in table for design K and Vd/A_b and not greater than 24K inches. Freeboard shall be not less than one foot and not less than one-third of D_w.
   D_w = __________ inches = __________ ft.
   Freeboard F = __________ ft.
   Total depth $D_b = D_w + F$ = __________ ft.

9. Basin dimensions:
   Show check calculations to demonstrate that basin volume up to depth D_w is greater than or equal to V_d.
   Notes:
   a) Steepest slope of any part 4 horizontal to 1 vertical (includes freeboard).
   b) Minimum width at top of any dike 8 feet.
   c) Outer slope of any dike, unless supported by special structural provision, shall be not steeper than 4 horizontal to 1 vertical.

RE: Eagle Drainage Standards Grassy Retention Basin Design Form

Variables:

K	=	Percolation rates, in/hr
A_{eq}	=	Equivalent drainage area
V_s	=	Storm runoff volume, cu. ft. (for the design storm)
V_r	=	"Retained volume," cu. ft.
A_b	=	Equivalent base area, (at one-half design depth) sq. ft.
V_{pd}	=	"Pre-development" runoff volume, cu.ft.
V_d	=	"Design volume," cu. ft.
D_w	=	Required water depth, ft; at peak
D_b	=	Total base depth, including freeboard, ft.
F	=	Freeboard, ft.

Table 2.
Maximum Water Height in Basin h_{max} (ft)

	K (in/hr)														
V_d/A_b	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
2	1.89	1.84	1.79	1.74	1.70	1.66	1.62	1.58	1.55	1.51	1.48	1.45	1.42	1.39	1.37
3	2.83	2.75	2.68	2.61	2.55	2.49	2.43	2.37	2.32	2.27	2.22	2.18	2.13	2.09	2.05
4	3.77	3.67	3.57	3.48	3.40	3.31	3.24	3.16	3.09	3.03	2.96	2.90	2.84	2.79	2.73
5	4.72	4.59	4.47	4.35	4.25	4.14	4.05	3.95	3.87	3.78	3.70	3.63	3.55	3.48	3.41
6	5.66	5.51	5.36	5.22	5.10	4.97	4.86	4.74	4.64	4.54	4.44	4.35	4.26	4.18	4.10
7	6.60	6.43	6.26	6.10	5.94	5.80	5.66	5.54	5.41	5.29	5.18	5.08	4.97	4.87	4.78
8	7.55	7.34	7.15	6.97	6.79	6.63	6.47	6.33	6.19	6.05	5.92	5.80	5.68	5.57	5.46
9	8.49	8.26	8.04	7.84	7.64	7.46	7.28	7.12	6.96	6.81	6.66	6.53	6.39	6.27	6.15
10	9.44	9.18	8.94	8.71	8.49	8.29	8.09	7.91	7.73	7.56	7.40	7.25	7.10	6.96	6.83

Time to Maximum Water Height in Basin t_{max} (hr)

	K (in/hr)														
	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
	2.58	2.54	2.50	2.47	2.43	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.21	2.18	2.16

Fraction of Runoff Volume Stored in Basin @ h_{max}, V_r/V_d

	K (in/hr)														
	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
	0.94	0.92	0.89	0.87	0.85	0.83	0.81	0.79	0.77	0.76	0.74	0.73	0.71	0.70	0.68

Input Values

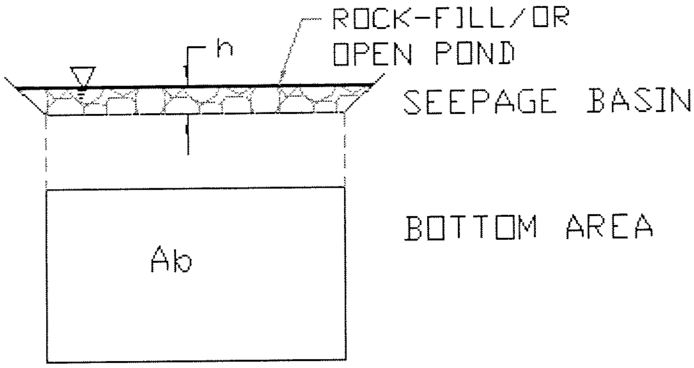
Depth of Bottom Layer Material - L (ft)	1
Porosity of Basin - P ()	1

Notes:
K = 4.0 in/hr or less for design, due to anticipated interface silt accumulation as bed ages but higher than rock-filled bed due to ability to observe pre-failure condition.
Derived Equations are solved based on field-measured percolation rate as K substituted for the hydraulic conductivity (k) and using unity for the "L" parameter.

EAGLE DRAINAGE DESIGN STANDARD: APPENDIX A
City of Eagle
Storm Drainage Basin/Rock-Bed Design Derivation
9/18/03, SK

Define the Situation

This derivation is used to set the City of Eagle design standard for rock basins and open ponds for storm drainage infiltration. The derivation is a classical solution based on mathematical principles and the governing differential equation.



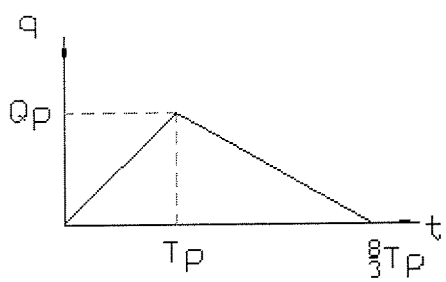
A visualization of the physical basis for the derivation is shown in the illustration below.

Goals

- Develop the differential equation that governs the situation illustrated above.
- Derive the formula for water depth in the basin as a function of time.
- Derive the formula for maximum water depth in the basin.

Assumptions

- Percolation through trench walls is disregarded, based on anticipated bacterial blinding of the interstices of the geotextile wrap.
- The influent flow rate to a storm water basin is governed by the SCS Triangular Hydrograph shown in the illustration below.
- The governing law for percolation out of the pond/rock-bed bottom in this case is Darcy's Law for saturated flow through a porous media.



Variable Definitions

Refer to the sketches outlined above for dimensioned variable definitions.

h	=	depth of water in the storm water seepage basin/or rock-bed (ft)
h_{max}	=	maximum depth of water in the storm water seepage basin/rock-bed (ft)

A_b = area of the base of the basin/rock-bed (ft^2)
k = coefficient of permeability as defined by Darcy's law (ft/hr)
P = porosity of rock-fill in rock-filled bed (P = 1 for a basin)
t = time (hrs)
T_p = time of concentration as defined by the SCS Triangular Hydrograph (hrs)
Q_p = peak flow rate as defined by the SCS Triangular Hydrograph (ft^3/hr)
q = influent flow rate to a basin/rock-bed (ft^3/hr)
Vs = total volume of surface runoff to the seepage basin/rock-bed (ft^3)
L = depth of limiting soil layer at bottom of seepage basin/rock-bed (ft)

Solution

The governing differential equation:

$$\frac{dh}{dt} := \frac{q_{in}}{A_b \cdot P} - \frac{h \cdot k}{L \cdot P}$$

The equations for influent flow rate are defined by the SCS Triangular Hydrograph:
Equation describing Interval 1 of the SCS Triangular Hydrograph:

$$q_1 := \frac{Q_p}{T_p} \cdot t$$

$$0 < t < T_p$$

Equation describing Interval 2 of the SCS Triangular Hydrograph:

$$q_2 := \frac{1}{5} \cdot Q_p \cdot \left(8 - 3 \cdot \frac{t}{T_p}\right)$$

$$T_p < t < \frac{8}{3} \cdot T_p$$

Darcy's Law:
Darcy's Law for saturated flow through a porous media is

$$v := \frac{h \cdot k}{L}$$

Adjustment of the general equation for porosity of a rock filled bed is included by dividing the influent flow and seepage terms by P.
The total volume of stormwater from the design event:

$$V_s := \frac{4}{3} \cdot Q_p \cdot T_P$$

Solve for Q_p:

$$Q_p := \frac{3}{4} \cdot \frac{V_s}{T_p}$$

Substitute Q_p in the 1st and 2nd interval equations for the influent flow rate:
Interval 1:

$$q_1 := 0.75 \frac{V_s \cdot t}{T_p^{\,2}}$$

Interval 2:

$$q_2 := \frac{1.2 \cdot V_s}{T_p} - \frac{0.45 \cdot t \cdot V_s}{T_p^{\,2}}$$

Solve The Differential Equation for Interval 1 ($0<t<T_p$):

$$\frac{dh}{dt} := \frac{q_{in}}{A_b \cdot P} - \frac{h \cdot k}{L \cdot P}$$

Substitute the equation for q_1 into the governing differential equation for q_{in}.

$$\frac{dh}{dt} := \frac{0.75 \cdot V_s}{T_p^{\,2} \cdot A_b \cdot P} \cdot t - \frac{h \cdot k}{L \cdot P}$$

Define constants in the equation for simplification:

$$a_1 := \frac{k}{L \cdot P}$$

$$a_2 := \frac{0.75 \cdot V_s}{T_p^{\,2} \cdot A_b \cdot P}$$

Substitute the constant definitions into the diffential equation:

$$\frac{dh}{dt} := a_2 \cdot t - a_1 \cdot h$$

Rearange the equation in the general form of a 1^{st}-order, linear differential equation:

$$\frac{dh}{dt} + a_1 \cdot h := a_2 \cdot t$$

Solve the differential equation:

Calculate the integrating factor

$$p := e^{\int a_1 \, dt}$$

$$p := e^{a_1 \cdot t}$$

Multiply the general form of the differential equation by the integrating factor and rearange the expression. The reader is referred to a standard textbook on differential equations to show the intermediate steps for this manipulation. (Reference: R.K. Nagle and E.B. Saff. Fundamentals of Differential Equations, 4th Ed. pp. 46-52.)

$$e^{a_1 \cdot t} \cdot h := \int e^{a_1 \cdot t} \cdot a_2 \cdot t \, dt + C$$

Solve the integral in the above expression (Reference: CRC Standard Math Tables, 14th Ed. pp. 335, Equation 397.)

$$\int e^{a_1 \cdot t} \cdot a_2 \cdot t \, dt := a_2 \cdot \left[\frac{e^{a_1 \cdot t}}{a_1^{\,2}} \cdot \left(a_1 \cdot t - 1\right)\right]$$

Substitue the solution to the integral into the expression

$$e^{a_1 \cdot t} \cdot h := a_2 \cdot \left[\frac{e^{a_1 \cdot t}}{a_1^{\,2}} \cdot \left(a_1 \cdot t - 1\right)\right] + C$$

Rearrange the Equation

$$h := \frac{a_2 \cdot \left[\frac{e^{a_1 \cdot t}}{a_1^{\,2}} \cdot \left(a_1 \cdot t - 1\right)\right] + C}{e^{a_1 \cdot t}}$$

Rearrange the Equation Again

$$h := \left(\frac{a_2}{a_1}\right)\cdot t - \frac{a_2}{a_1^2} + \frac{C}{e^{a_1 \cdot t}}$$

Apply a boundary condition to determine C

h = 0 @ t = 0

$$C := \frac{a_2}{a_1^2}$$

Solution to the 1st interval ($0<t<T_p$)

$$h := \left(\frac{a_2}{a_1}\right)\cdot t - \frac{a_2}{a_1^2} + \frac{a_2}{a_1^2 \cdot e^{a_1 \cdot t}}$$

Substitute the values for a_1 and a_2 into the expression, rearrange, and write the final form of the equation:

$$h := \left[\frac{(0.75)\cdot V_s \cdot L^2 \cdot P}{T_p^2 \cdot A_b \cdot k^2}\right]\cdot\left[\left(\frac{k}{L\cdot P}\right)\cdot t - 1 + \frac{1}{e^{\left(\frac{k}{L\cdot P}\right)\cdot t}}\right]$$

for $0 < t < T_p$

Solve The Differential Equation for Interval 2 ($T_p < t < 8/3T_p$):

$$\frac{dh}{dt} := \frac{q_{in}}{A_b \cdot P} - \frac{h\cdot k}{L\cdot P}$$

Substitute the equation for q_2 into the governing differential equation for q_{in}.

$$\frac{dh}{dt} := \frac{\left(1.2\cdot\frac{V_s}{T_p} - 0.45\cdot\frac{V_s}{T_p^2}\cdot t\right)}{A_b \cdot P} - \frac{h\cdot k}{L\cdot P}$$

Rearrange the equation.

$$\frac{dh}{dt} := \frac{1.2\cdot V_s}{T_p \cdot A_b \cdot P} - \frac{0.45\cdot V_s}{T_p^2 \cdot A_b \cdot P}\cdot t - \frac{h\cdot k}{L\cdot P}$$

Define constants in the equation for simplification:

$$a_3 := \frac{1.2\cdot V_s}{T_p \cdot A_b \cdot P}$$

$$a_4 := \frac{0.45\cdot V_s}{T_p^2 \cdot A_b \cdot P}$$

$$a_5 := \frac{k}{L\cdot P}$$

Substitute the constant definitions into the diffential equation:

$$\frac{dh}{dt} := a_3 - a_4\cdot t - a_5\cdot h$$

Rearange the equation in the general form of a 1^{st}-order, linear differential equation:

$$\frac{dh}{dt} + a_5\cdot h := a_3 - a_4\cdot t$$

Solve the differential equation:

Calculate the integrating factor

$$p := e^{\int a_5\, dt}$$

$$p := e^{a_5 \cdot t}$$

Multiply the general form of the differential equation by the integrating factor and rearange the expression. The reader is referred to a standard textbook on differential equations to show the intermediate steps for this manipulation. (Reference: R.K. Nagle and E.B. Saff. Fundamentals of Differential Equations, 4th Ed. pp. 46-52.)

$$e^{a_5 \cdot t} \cdot h := \int e^{a_5 \cdot t} \cdot (a_3 - a_4 \cdot t)\, dt + C$$

Rearrange the above expression

$$e^{a_5 \cdot t} \cdot h := a_3 \cdot \int e^{a_5 \cdot t}\, dt + a_4 \cdot \int t \cdot e^{a_5 \cdot t}\, dt$$

Solve the expression (Reference: CRC Standard Math Tables, 14th Ed. pp. 308 & 335, Equations 12 & 397.)

$$e^{a_5 \cdot t} \cdot h := \frac{a_3 \cdot e^{a_5 \cdot t}}{a_5} - \frac{a_4 \cdot e^{a_5 \cdot t}}{a_5^{\,2}} \cdot (a_5 \cdot t - 1) + C$$

Rearrange the Equation

$$h := \frac{a_3}{a_5} - \frac{a_4}{a_5^{\,2}} \cdot (a_5 \cdot t - 1) + \frac{C}{e^{a_5 \cdot t}}$$

Rearrange the Equation Again

$$h := \frac{a_3}{a_5} - \frac{a_4}{a_5} \cdot t + \frac{a_4}{a_5^{\,2}} + \frac{C}{e^{a_5 \cdot t}}$$

Apply a boundary condition to determine C. h for the first interval is equal to h for the second interval at $t = T_p$

$$h := \left[\frac{(0.75) \cdot V_s \cdot L^2 \cdot P}{T_p^{\,2} \cdot A_b \cdot k^2}\right] \cdot \left[\left(\frac{k}{L \cdot P}\right) \cdot T_p - 1 + \frac{1}{e^{\left(\frac{k}{L \cdot P}\right) \cdot T_p}}\right]$$

@

$t = T_p$

define the right-hand side of the equation as a constant to simplify the expression ...

$= z$

Set h for the second interval equation equal to h from the first interval equation @ t = Tp and solve for the constant of integration.

$$z := \frac{a_3}{a_5} - \frac{a_4}{a_5} \cdot T_p + \frac{a_4}{a_5^{\,2}} + \frac{C}{e^{a_5 \cdot T_p}}$$

$$C := \left(z - \frac{a_3}{a_5} + \frac{a_4}{a_5} \cdot T_p - \frac{a_4}{a_5^{\,2}}\right) \cdot e^{a_5 \cdot T_p}$$

Substitute the constant of integration into the equation for h for the 2nd interval and solve

$$h := \frac{a_3}{a_5} - \frac{a_4}{a_5}\cdot t + \frac{a_4}{a_5^{\,2}} + \frac{e^{a_5\cdot T_p}\cdot\left(z - \frac{a_3}{a_5} + \frac{a_4}{a_5}\cdot T_p - \frac{a_4}{a_5^{\,2}}\right)}{e^{a_5\cdot t}}$$

for $T_p < t < 8/3{*}T_p$

Substitution of the values of a_3, a_4, a_5, and z and expansion of the equation is shown on the next page

Determine the equation for t where h is a maximum. This is the time at which the maximum water depth in the basin occurs.

$$\frac{dh}{dt} := 0$$

This function determines the time value at maximum water depth.

Take the derivative of the function for h using the second interval equation (Reference: CRC Standard Math Tables, 14th Ed. pp. 303 & 304, Equations 1, 2, & 18)

$$\frac{dh}{dt} := \frac{-a_4}{a_5} + e^{a_5\cdot T_p}\cdot\left[z - \frac{a_3}{a_5} + \left(\frac{a_4}{a_5}\right)\cdot T_p - \frac{a_4}{a_5^{\,2}}\right]\cdot(-a_5)\cdot e^{-a_5\cdot t}$$

Set

$$\frac{dh}{dt} := 0$$

and solve for t

$$t_{max} := \frac{\ln\left[\frac{-a_4}{a_5}\cdot\left[\frac{1}{e^{a_5\cdot T_p}\cdot\left[(z) - \frac{a_3}{a_5} + \left(\frac{a_4}{a_5}\right)\cdot T_p - \frac{a_4}{a_5^{\,2}}\right]\cdot a_5}\right]\right]}{-a_5}$$

To determine the value of h_{max}, substitute this equation for t into the equation for h in the 2nd interval. The expanded equation for t is show on the last page.