discharge is generally taken as proportional to the product of its weight per unit of time and the velocity head of its mean velocity. For a constant discharge, kinetic energy may be represented by a line at a distance above a flowing water surface proportional to the velocity head of its mean velocity. The elevation of such a line above any datum represents the total energy (potential plus kinetic) of the given discharge above that datum. Strictly, the kinetic energy of a given discharge is the integral of the kinetic energies of its particles.

OPEN-CHANNEL FLOW - Flow in any open or closed conduit where the water surface is free; that is, where the water surface is at atmospheric pressure.

PRECIPITATION - The total measurable supply of water received directly from the clouds, as rain, snow, and hail; usually expressed as depth in a day, month, or year, and designated as daily, monthly, or annual precipitation.

REACH - A comparatively short length of a stream or channel.

RUN-OFF COEFFICIENT - The rate of run-off to precipitation.

SECOND-FOOT - A cubic foot per second; optional usage, cu. ft. per sec.; cfs.

SPECIFIC ENERGY - The energy of a stream referred to its bed; namely, depth plus velocity head of mean velocity.

STORM SEWER - A sewer that carries only storm water, drainage and other water from the surface of the street, but not domestic sewage or industrial wastes; is commonly known as a storm sewer. NOTE: A storm sewer system consists of underground conduits, inlets, manholes, open channels, swales, and special appurtenances.

TAIL-WATER - The water just downstream from a structure.

TIME OF CONCENTRATION- The estimated time required for run-off to flow from the most remote section of the drainage area to the point at which the discharge is to be determined.

VELOCITY HEAD - The distance a body must fall freely under the force of gravity to acquire the velocity it possesses; the kinetic energy, in feet of head, possessed by a given velocity.

503.00 CRITERIA FOR DESIGN OF STORM DRAINAGE SYSTEMS

503.01 Rational Formula: The rational method shall be used for all stormwater drainage design (for drainage areas less than 200 acres)

in which Q=ACI. In drainage areas larger than 200 acres another proven method shall be used, e.g., Anderson method.
Q = Quantity of stormwater runoff in cubic feet per second
A = Drainage area in acres, contributing to the point of concentration

C = Coefficient of runoff
I = Average rainfall intensity in inches per hour for the period of concentration to the point under consideration.

503.02 Schematic Drainage Plan: The on-site drainage area (A) shall be outlined on a schematic drawing which shall include contours at a two foot interval. Each differential area shall be shown with respect to the point of concentration and the acreage shown thereon. The minimum acceptable scale shall be 1" = 100' unless approved by the Director. Off-site drainage areas contributing water to the system being designed may be shown on USGS quad sheets or City topographic maps. A schematic drainage plan showing probable areas for detention, major drainage systems being proposed, and all existing drainage divides and any major changes in divides proposed must be submitted with the preliminary plan and all rezonings.

503.03 Runoff Coefficients: Coefficients of runoff shall be employed with respect to development as shown in Table 5-1.

503.04 Rainfall Intensity vs. Duration: Rainfall intensities for the following drainage designs can be derived by use of Plate V-A entitled "Rainfall Intensity vs. Duration".

A. For all storm sewer systems where the drainage area does not exceed 500 acres, the 10 year rainfall frequency curve shall be used.

B. For the design of all open, permanent channelization outfall systems where the quantity of water exceeds the equivalent capacity of a 72" concrete storm sewer, with 0.5% slope, the 25 year rainfall frequency curve shall be used.

C. For waterways under major bridges or through culverts in the secondary roads system where the contributing drainage area is 600 acres or less, the 10 year rainfall frequency curve shall be used but calculations for the 25 year storm must be included and the corresponding water elevation shown on the plan and contained in an easement. If the contributing area is greater than 600 acres, then the 50 year rainfall frequency curve shall be used for secondary road bridges, culverts, etc. except when conditions upstream warrant additional consideration as determined by the Director or Virginia Department of Transportation (VDOT).

D. Whenever a bridge or culvert is designed or considered for use on

the primary road system, then the 50 year rainfall frequency curve shall be used for all contributing drainage areas, and at least one foot (1') of freeboard shall be added to the waterway to avoid inundation of the roadway shoulder. See also 504.19.

E. For determining the width of the flood plain where the watershed is one square mile or less, the 100 year rainfall frequency curve shall be used and 2 feet of freeboard shall be added to the easement line. For watersheds greater than one square mile contributing to the flood plain, the 100 year rainfall frequency curve shall be used and no freeboard shall be required.

F. Standard curb inlets shall be designed in accordance with the latest edition of the VDOT Drainage Manual. Yard inlets and similar structures shall be designed using the 10-year storm event, unless otherwise specified by the Director.

503.05 Time of Concentration: The recommended time of concentration for various types of development are shown in Table 5-1. Plate V-B, entitled "Overland Flow Time", or any other acceptable engineering method may be used if the time of concentration is to be calculated.

503.06 Pressure Flows at Junctions: Storm sewer systems shall not be designed based on head-water pressure in junctions such as curb inlets, manholes, etc. The location of the hydraulic grade line shall be calculated and submitted on all systems where it appears possible that the water surface elevation in junction structures may approach the elevation of inlet throats or manhole covers during passage of the design storm flow. Without limiting the generality of the foregoing, the following system characteristics act to increase the possibility that interior water surface elevations will approach the level of inlet throats or manhole covers. The following characteristics should either be avoided or their effects compensated for:

A. Numerous bends

B. Shallow systems

C. Junctions with directly opposed laterals

D. Systems which rely on pipes flowing full at high velocities

E. Systems with ineffective channelization

F. Systems with numerous junction structures - extensive systems.

503.07 Criteria for Acceptability of System: Systems shall be acceptable where the hydraulic grade line for the 10 year storm flow is below the elevation of inlet throats or manhole covers and where, as provided for in the body of this policy, the capacity of pipes flowing full by Manning's Formula equals or exceeds the 10 year storm flow. Systems not meeting these criteria are unacceptable.

503.08 Hydraulic Grade Line: Calculation of the hydraulic grade line shall include adequate consideration of head losses at all junction structures (see Plate V-H). The hydraulic grade line shall be completed as recommended by the latest edition of the VDOT Drainage Manual. Other methods of computation must be approved by the Director.

503.09 Measures for Lowering the Hydraulic Grade Line: Measures for lowering the hydraulic grade line include the following:

A. Increase pipe sizes thus reducing necessary velocities.

B. Eliminate bends (but do not, for instance, replace one 90° bend with two 45° bends).

C. Lower the system to provide deeper structures.

D. Eliminate opposing laterals by off setting their centerlines a distance equal to the sum of the diameters.

E. Limit the extent of individual systems.

F. Provide effective channelization.

G. Provide inlet shaping per VDOT IS-1 standard.

TABLE 5-1
COEFFICIENTS OF RUNOFF (C) TO BE
USED WITH THE RATIONAL FORMULA

	C	Tc (MIN)
Residential (Average lot size)		
a. 10,000 sq. ft. to 20,000 sq. ft.	0.35 - 0.45	10 - 15
b. 20,000 sq. ft. to 5 Ac	0.30 - 0.40	10 - 15
Parks and Agriculture (over 5 acres)	0.25 - 0.35	to be computed
Cemeteries	0.25 - 0.35	to be computed
Townhouses	0.65 - 0.75	5 - 10
Schools	0.50 - 0.60	10 - 15
Apartments	0.65 - 0.75	5 - 10
Industrial	0.80 - 0.90	5
Business, Commercial or Office	0.80 - 0.90	5
Residential Planned Community		
a. High Density	0.80 - 0.90	5
b. Medium Density	0.65 - 0.75	5 - 10
c. Low Density	0.35 - 0.45	10 - 15
d. Commercial and Industrial	0.80 - 0.90	5
e. Schools	0.50 - 0.60	5 - 10
f. Open Space	0.25 - 0.35	10 - 15
g. Gravel Lots	0.65 - 0.75	5 - 10
h. Asphalt Parking Lots Roofs	0.90 - 0.95	5
i. Grass Areas	0.50 - 0.60	10 - 15

NOTES:

1. When calculating flow to a structure if all run-off to the structure is from impervious areas (i.e. pavement & roofs) the C to be used is 0.90.

2. The lowest range of run-off coefficients may be used for flat areas (areas where the majority of the grades and slopes are 2% and less).

3. The average range of run-off coefficients should be used for Intermediate areas (areas where the majority of the grades and slopes are from 2% to 5%).

4. The highest range of run-off coefficients shall be used for steep areas (areas where the majority of the grades are greater than 5%), for cluster areas, and for development in clay soil areas.

504.00 GENERAL REQUIREMENTS FOR STORM SEWERS AND CULVERTS

504.01 Deviation from Standards: This Manual shall be followed unless specific deviation therefrom is authorized, in writing, by the Director.

504.02 Plan and Profile Sheets: The storm sewer and culvert systems are to be shown in plan and profile on 24" x 36" sheets.

A. All construction information, including invert elevations (in and out), size, type of pipe, gauge, length and percent of slope shall be shown on plan and/or profile.

B. All storm sewer appurtenances shall be identified by type and number (i.e., DI-3B, Y1-1), including number of throats and locations on both plan and profile.

504.03 Pipe Materials: All pipe used for the construction of storm drainage systems shall be concrete. Corrugated metal pipe can be used for culverts where permitted.

A. Concrete pipe whether designated for use within the right of way of a public street or thoroughfare or beyond the limits of a street right-of-way shall meet the three-edge-bearing strength test requirements for ASTM C76 Class III reinforced concrete pipe; latest revision. Culvert pipe classed as "seconds" by the manufacturer of pipe which has been rejected from another project shall not be permitted for use. Class will be increased above these requirements based on height of cover.