Aalto University
School of Arts, Design
and Architecture

Urban Hydrology and Storm Water Management

iWater_3rd International Event

Juan Jose Galan Vivas (Aalto University)

OBJECTIVES of the LECTURE

- Provide the basics to understand the hydraulic factors and variables involved in Urban Storm water management
- Understand the main Design Issues and Goals on Urban Storm Water Management
- Get familiar with the runoff calculation systems and develop a very simple guided exercise

CONTENTS of the LECTURE

1. BASIC CONCEPTS
2. STORMWATER PLANNING AND DESIGN ISSUES (Ecosystem Services)
3. DESIGN PROCEDURES
4. RUNOFF CALCULATIONS and GUIDED EXERCISE
5. CONCLUSIONS

1. BASIC CONCEPTS
1.1.Precipitacion & Runoff

*“Precipitation occurs as rainfall, snowfall or mixtures of each…. For site planning and design, stormwater management focuses on the **estimation of runoff from rainfall”*** (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

1.2 Flood protection: Major & Minor systems

“Minor systems minimizes the inconveniences associated with frequently occurring storms. These systems (e.g. storm sewers and roadside and backyard swales) are usully designed to accommodate the 2, 5 or 10 year storm” (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

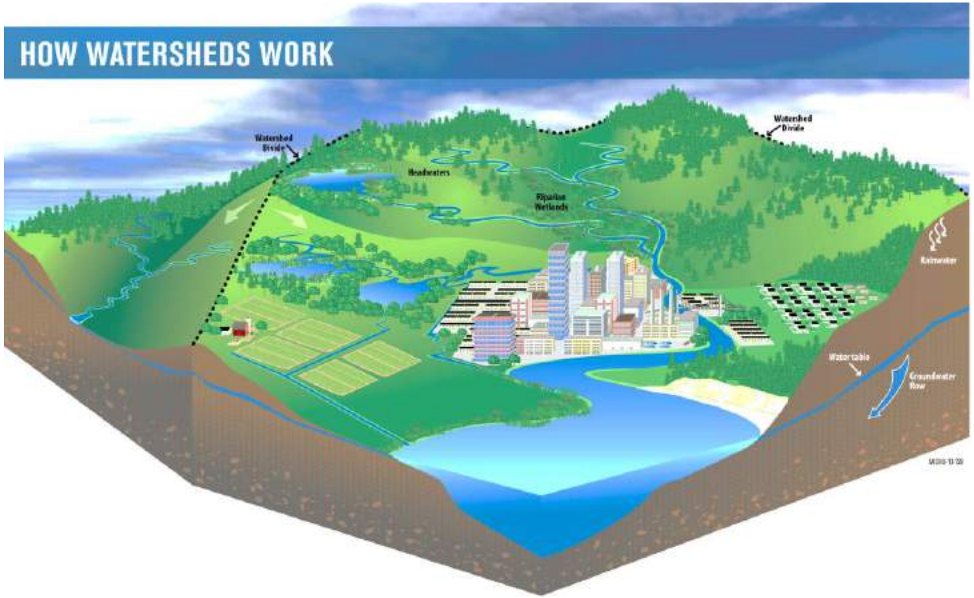
“Major system is used whenever the minor system is exceeded (25, 50, 100, 500 year storm)…. When . Runoff flows exceeds the minor system, it takes an alternative route through the landscape. Watersheds that have major structures and populations located in the flow path of the major system are subject to major flood damage… Flood studies produce maps produce maps designating official fllod hazard areas expected to be inundated by the 100 year and 5000 year event” (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

1. BASIC CONCEPTS

1.3 Watershed

Watershed is the portion of landscape that drains runoff to a particular point. Since water moves by gravity, the watershed has a topographically determined boundary, consisting of a line of ridges and saddle points"

(adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)



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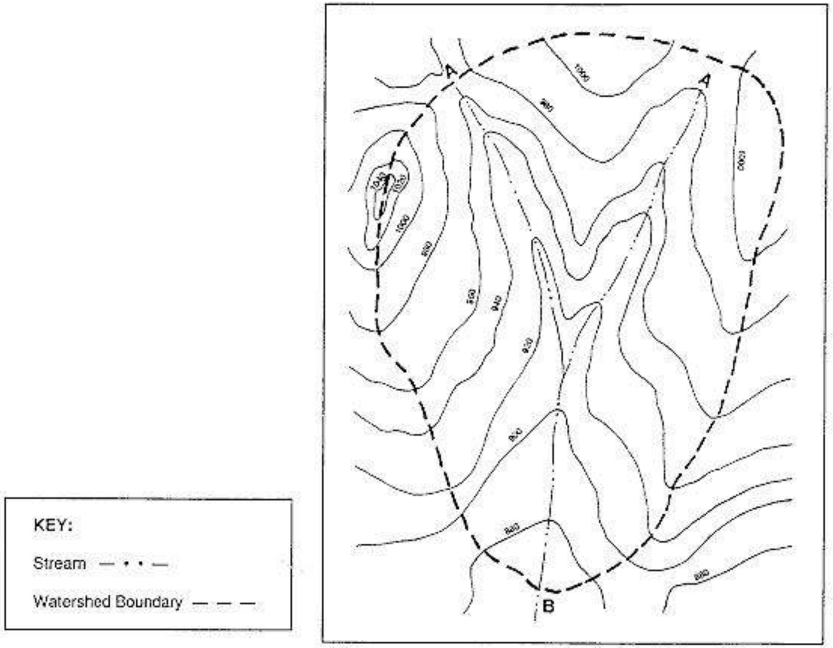

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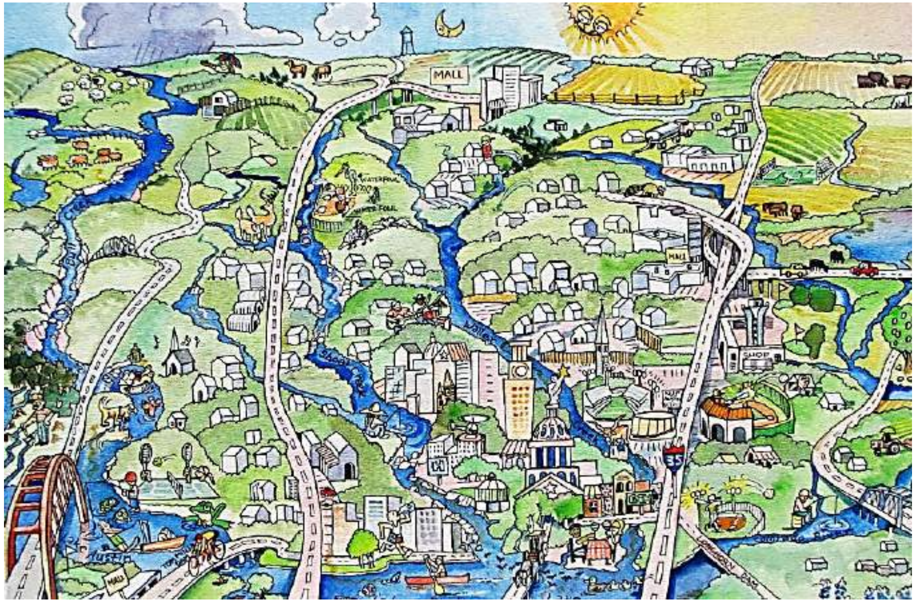


Austin watershed (source: http://www.bing.com/images/search?q=austin+watershed&view

1. BASIC CONCEPTS
1.3 Watershed Conditions

***Land Cover:** Generally, land cover with greater complexity will intercept more precipitation. The most complex natural land covers are highly layered plant communities with vast amounts leaf area. One of the effects of urbanization is the simplification of surfaces and the introduction of artificial surfaces that tend to be less complex and intercept less rainfall* (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)*….. TOWARDS MORE VARIED URBAN MOSAICS AND MORE COMPLEX ARTIFICIAL SURFACES?*

***Soils and Infiltration:** Soil type is the principal determinant of infiltration (gravel > sand > silt > clay…) Impervious paved surfaces block the infiltration capacity of the soils. Urban soils can lose their inflitartion capacity due to compaction* (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)*….. KEEPING OR IMPROVING THE INFILTRATION CAPACITY OF SOILS?*

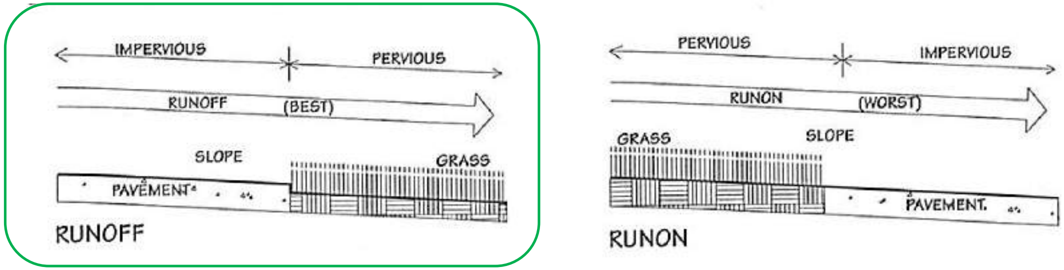
***Moisture conditions:** Wet surfaces produce more runoff than dry surfaces*(adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998), *Wet soils infiltrate less water than dry soils*

***Slope:** Rain falling on flatter slopes has more time to infiltrate than rainfall falling on steep slopes. Slope affects the volume of runoff and the risk of erosion… AVOID IMPERVIOUSNESS IN STEEP SLOPES*

1. BASIC CONCEPTS

1.3 Watershed Conditions

Imperviousness: *Urbanization tends to establish large areas of impervious surfaces. This increases runoff both in terms of volume and peak discharge. Disconnected imperviousness will result in less stormwater runoff and better water quality* (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)*….. INCREASE PERVIOUSNESS AND DISCONNECT IMPERVIOUS AREAS*



Runoff and Run-on + Disconnected Imperviousness (left); (Time-Saver Standards for Landscape Architecture", Harris, C. W; Dines, N. T.)

summary: *A watershed with steep slopes, tight soils, high imperviousness and moist, simple surfaces will produce far more runoff that the same size watershed with flat slopes, coarse soils, no imperviousness, dry, complex surfaces (e.g.: layered plant communities) and maximized disconnected imperviousness* (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

1. BASIC CONCEPTS

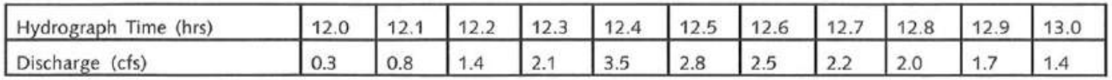
1.4 Runoff terms (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

Velocity (V): *Distance travelled by water over a given time. Runoff velocities are generally expressed in meters per second (m/s)*

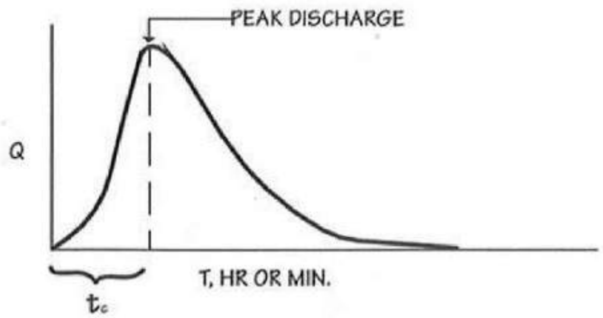
Discharge (Q)*: Volumetric flow rate of water. Discharge is expressed in cubic meters per second (m^3/s)*

Volume of flow (Qvol): *Total volume of flow for a period of time (m^3)*

Hydrograph*: It is a summary of storm water flows. It can be expressed in tabular form (discharges at specific times) or a graph plot (discharge versus time). In the case of a graph, the area under the curve plot is the total volume of plot for the plot period*



Hydrograph Time (hrs)	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0
Discharge (cfs)	0.3	0.8	1.4	2.1	3.5	2.8	2.5	2.2	2.0	1.7	1.4



Hydrograph (table and graph plot); (Time-Saver Standards for Landscape Architecture", Harris, C. W; Dines, N. T.)

1. BASIC CONCEPTS

1.4 Runoff terms (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

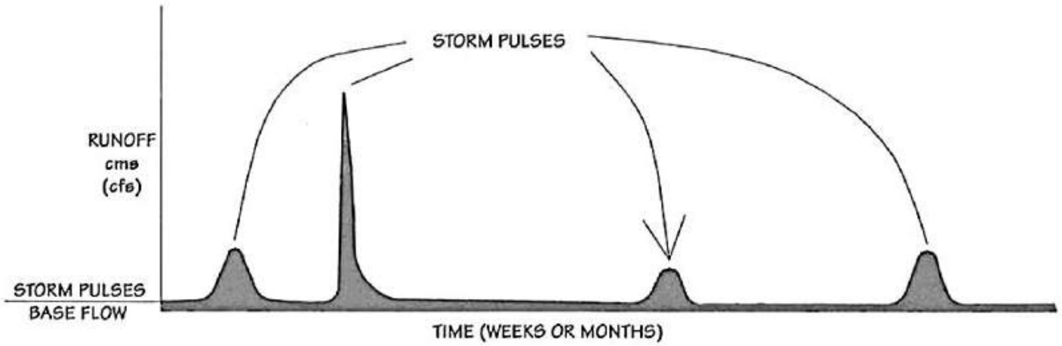
***Peak rate of flow**: The peak of the hydrograph is the maximum rate of flow. Predicting and accommodating the maximum or peak rate of flow is important*

***Time of Concentration (t_c)**: The time water takes to flow from the most distant point in the watershed to its outlet*

***Travel time (t_t):** Average time for water to flow through a particular segment or reach*

***Storm flows:** Large infrequent flows of runoff characterized by high peak discharges.*

***Base flows:** Steady flows that continue to occur after the pulse of flow from a a storm has subsided.*

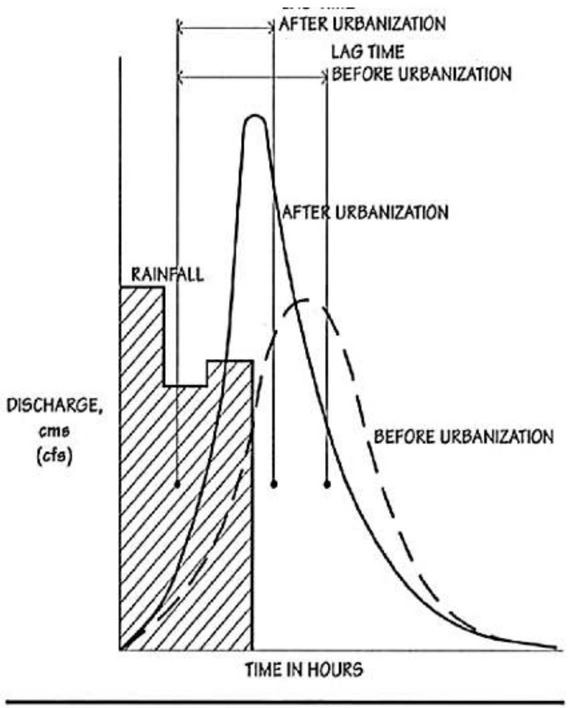


Base line hydrograph with Storm Pulses (Time-Saver Standards for Landscape Architecture", Harris, C. W; Dines, N. T.)

1. BASIC CONCEPTS

1.4 Runoff terms (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

***Key points**: Urbanization tends to drastically change the hydrographs. Peak discharges and volumes of runoff increase and time of concentration becomes shorter*



Effects of urbanization on hydrograph plots
(Time-Saver Standards for Landscape Architecture", Harris, C. W; Dines, N. T.)

1. BASIC CONCEPTS

1.4 Runoff terms (adapted by Pilar Meseguer from iSWM_North Central Texas Council of Governments)

Downstream Hydrologic Assessment: Reasons for it:

Common practice requires the designer to control peak flow at the outlet of a site such **that post-development peak discharge equals pre-development peak discharge**.

It has been shown that **in certain cases this does not always provide effective water quantity control downstream from the site** and may actually exacerbate flooding problems downstream.

The reasons for this have to do with: **The total increase of the volume of Runoff**

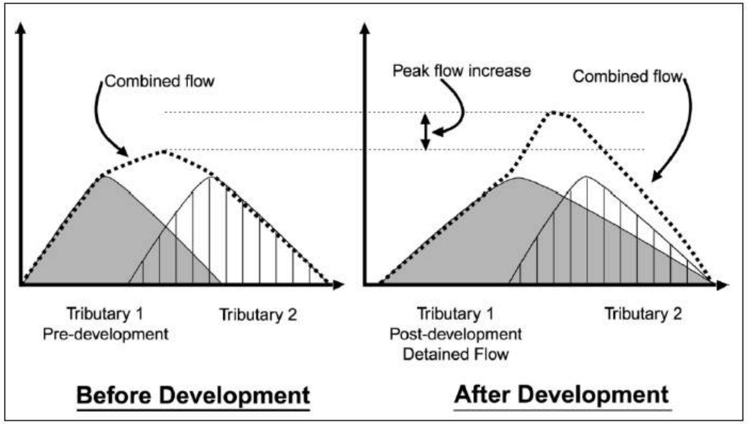


Figure 2.2 Effect of Increased Post-Development Runoff Volume with Detention on a Downstream Hydrograph

1. BASIC CONCEPTS

1.5 Design storm or Rainfall events (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

***Design Storms or Rainfall Events:** Statistical abstraction obtained from rainfall records. They give probability estimates of expected rainfall amounts in terms of INTENSITY, DURATION AND FREQUENCY*

***Duration**: Length of time over which historical rainfall depths are distributed for purpose of analysis (typically in hours)*

***Frequency (or Return Period):** Probability of recurrence of one event that produces a rainfall depth (typically in years)*

- *Rainfall for a 10 years period: 10% probability of exceeding that rainfall depth in any year*
- *Rainfall for a 100 years period: 1% probability of exceeding that rainfall depth in any year*
- *Rainfall for a 500 years period: 0,5% probability of exceeding that rainfall depth in any year*

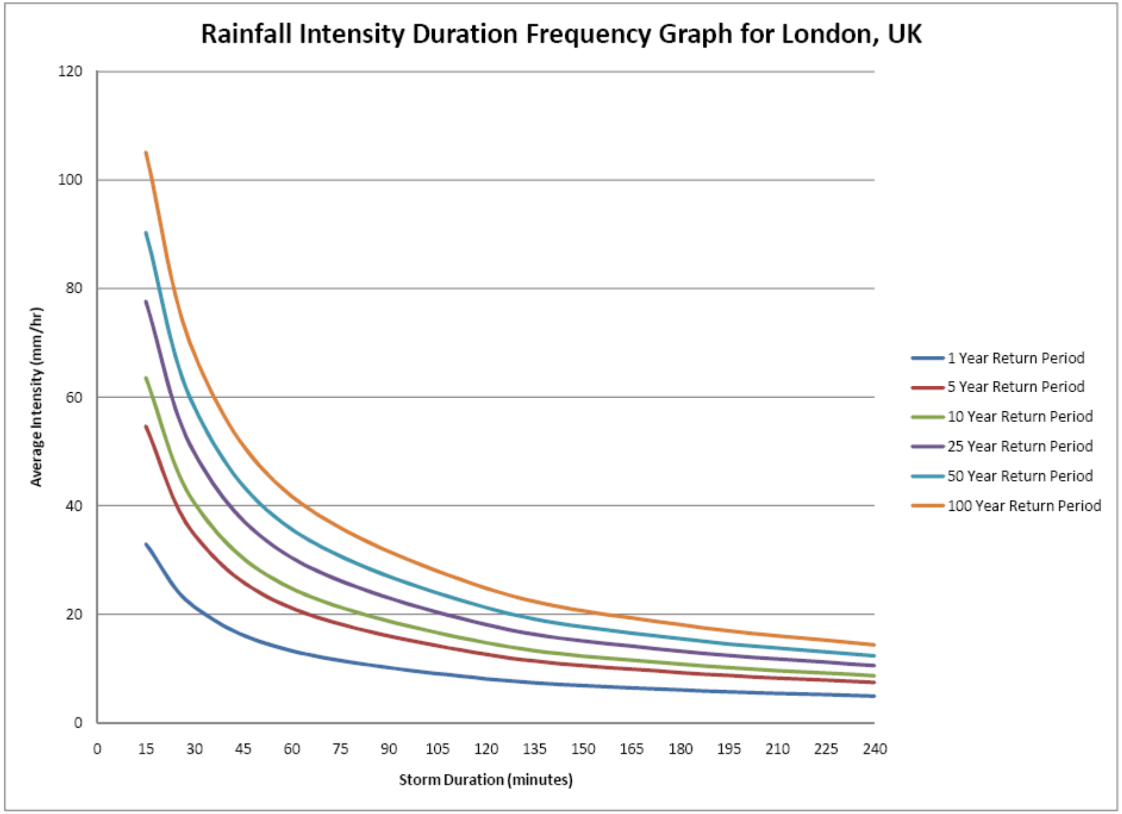
***Intensity:** rate at which the rain falls expressed in millimeters per hour (mm/hour). In design storms the Intensity is the average intensity for the duration*

1. BASIC CONCEPTS

1.5 Design storm or Rainfall events

Climate change has led to more frequent and intense storm and rainfall events along with increased flooding, storm water runoff, and soil erosion.

These are forcing planners and storm water specialists to develop strategies dealing with greater volume and velocity of storm water.



https://thecriticalflow.files.wordpress.com/2010/09/london-idf-mm.png

1. BASIC CONCEPTS

1.5 Design storm or Rainfall events

Climate change has led to more frequent and intense storm and rainfall events along with increased flooding, storm water runoff, and soil erosion.

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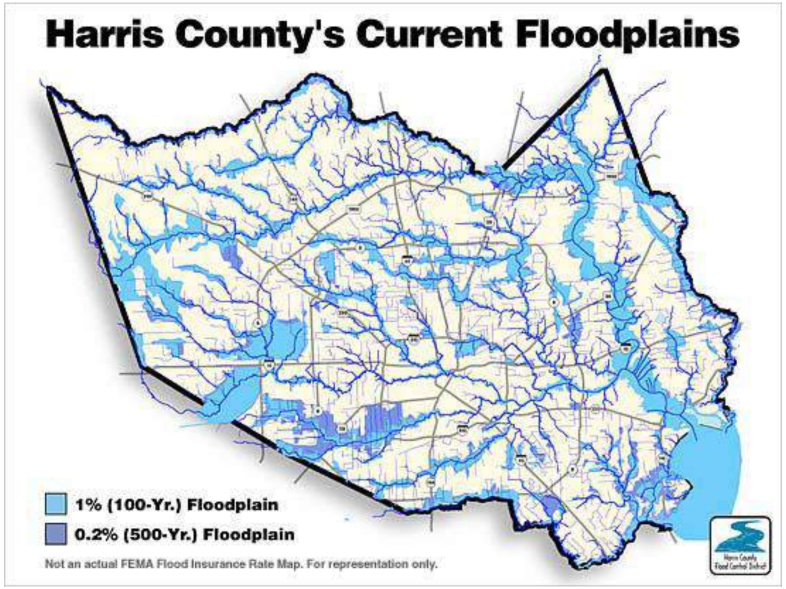
Flooding in 2015 with an expected frequency of 1:1,000 (source: Deltares)

Flooding in 2100 based on the W+ scenario and with an expected frequency of 1:1,000 (source: Deltares)

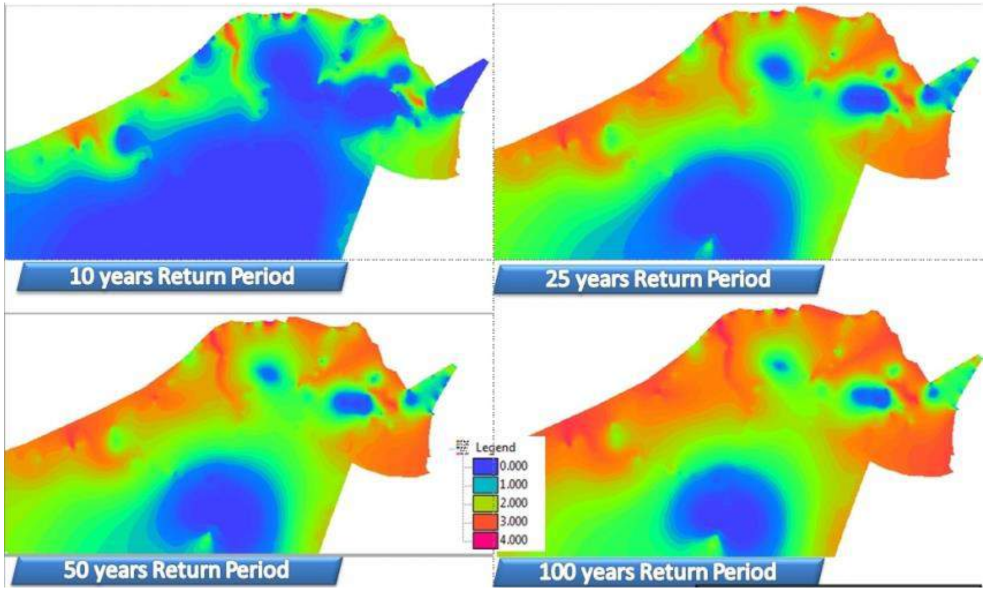
Inner dike water safety risk 2100 (Rotterdam Climate Change Adaptation Strategy)

1. BASIC CONCEPTS

1.5 Design storm or Rainfall events. Return periods in rivers and coastal areas



Harris County´s current floodplains
(Harris County Flood Control District, Texas, USA)



Water height maps for different return periods
Local scale risk assessment for coastal flooding in island countries (Leiska Powell and Cees van Westen, 2015)

2. STORM WATER MANAGEMENT ANF DESIGN ISSUES

2.1 Flood protection Hazard + Exposure + Vulnerability = Risk

The concept of risk combines an understanding of the likelihood of a hazardous event occurring with an assessment of its impact, for example:

Risk = Hazard x Elements at Risk x Vulnerability

The total risk may be decreased by reducing the size of any one or more of the three contributing variables, the hazard, the elements exposed and/or their vulnerability. The reduction of any one of the three factors to zero consequently would eliminate the risk. (source: Australian Government, Geoscience Australia)

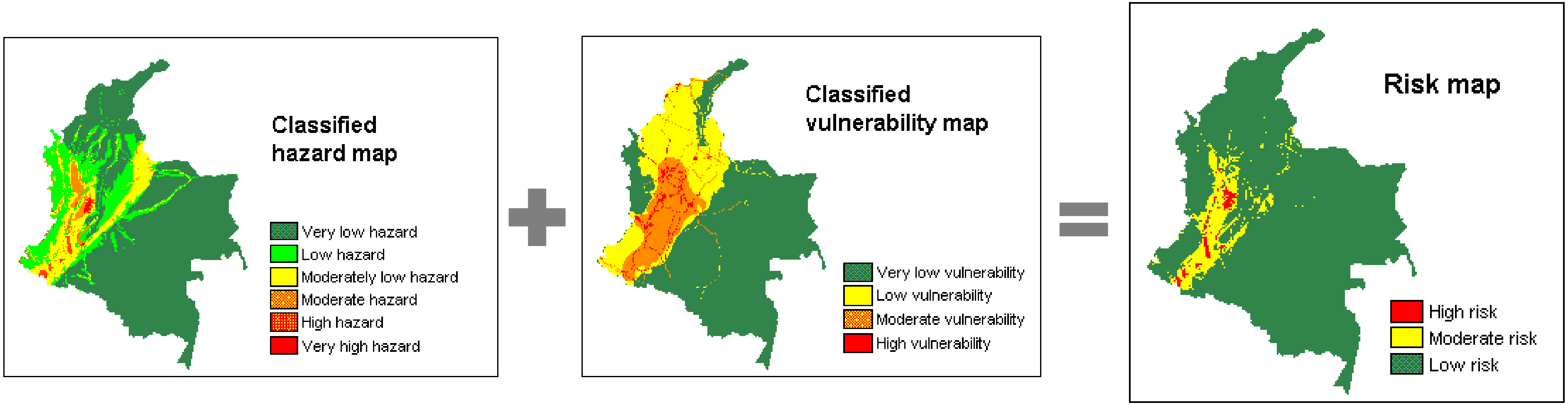
The risk, hazard, exposure, vulnerability relationship (Australian Government, Geoscience Australia)

2. STORM WATER MANAGEMENT ANF DESIGN ISSUES

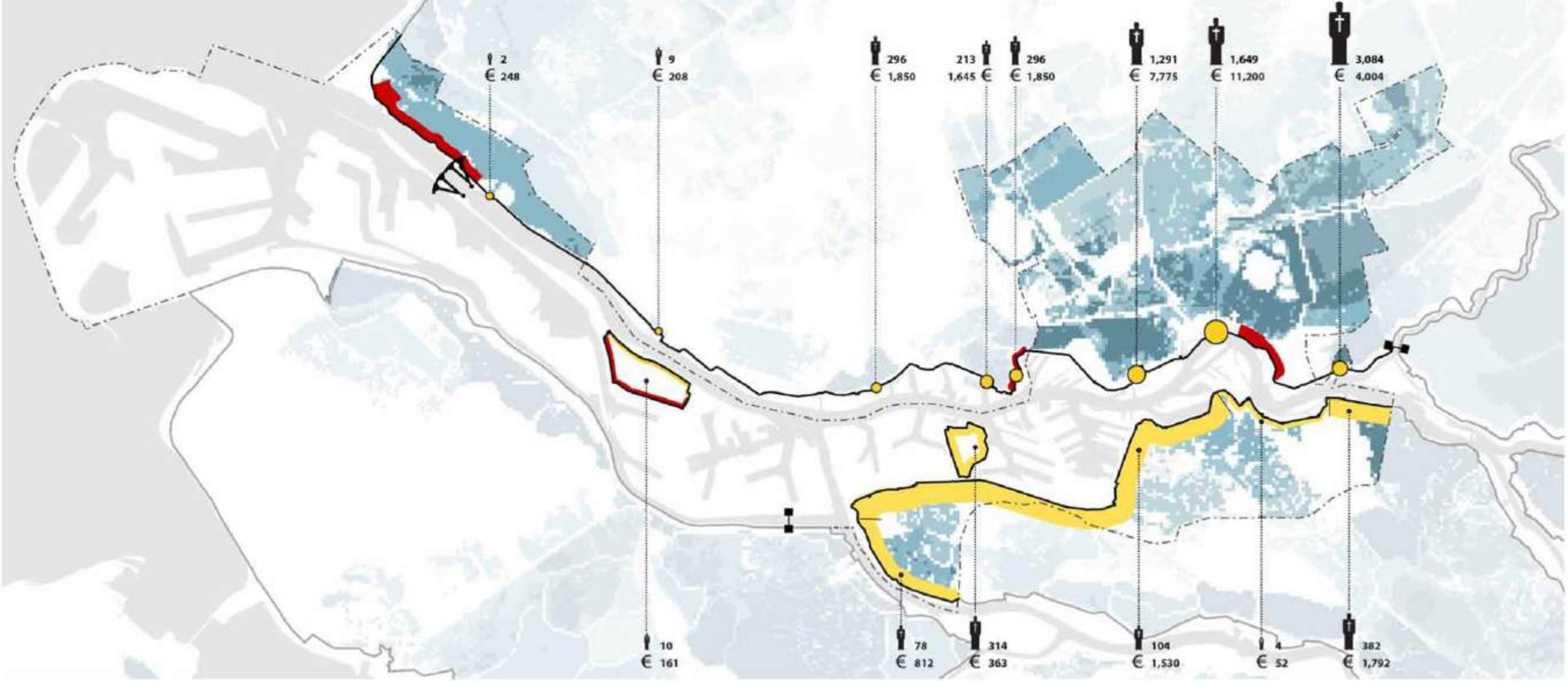
2.1 Flood protection Risk = Hazard + Vulnerability

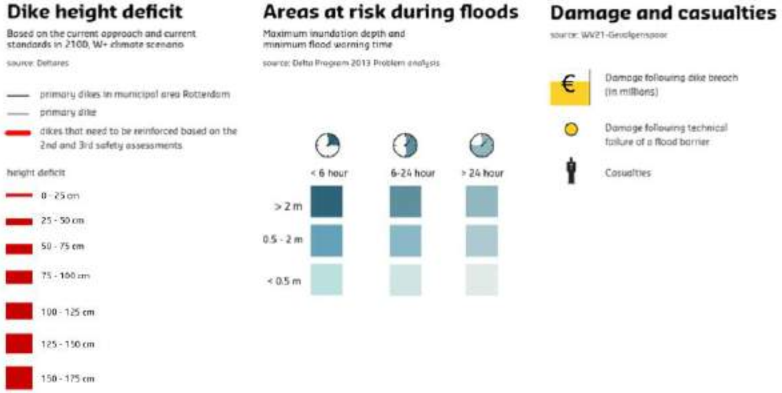
hazard: the probability of occurrence of a potentially damaging phenomenon,

vulnerability: the degree of loss resulting from the occurrence of the phenomenon



Hazard, vulnerability and risks to natural disasters in Colombia (C.J. van Westen, University of Twente, Netherlands)





Inner-dike water safety risk map - 2100

The risk map shows the areas that are at risk of flooding together with the potential economic damage and the number of casualties resulting from a dike breach (south side) or the failure of a technical engineering works (north side). In many places, such a situation would result in water rapidly surging deep into the city.

Inner dike water safety risk 2100 (Rotterdam Climate Change Adaptation Strategy)

2. STORM WATER MANAGEMENT AND DESIGN ISSUES

2.2 Design Issues & Ecosystem Services (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

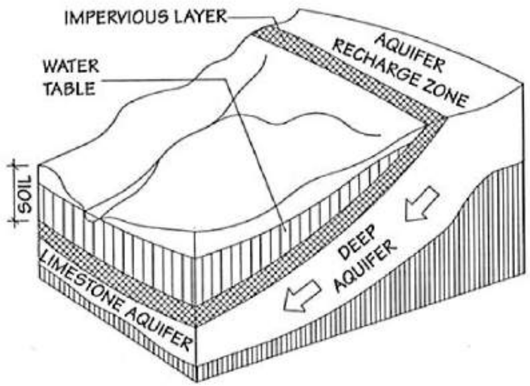
a) ***Water Quality Protection:*** *In 1989 US Environmental Protection Agency found that non-point source pollution contributed over 65 per cent of the total pollution load to inland surface waters. In USA water quality protection systems are designed to treat runoff from a 30 mm rainfall.*

- ***Sediments and erosion****: delivers the largest load of pollutants into water bodies that receive runoff*
- ***Oxygen demand:*** *Dissolved oxygen (DO) is essential to maintain life in water bodies. The most common cause of depletion of DO is excessive nutrients loads delivered to the water body.*
- ***Nutrients:*** *Major contributor to surface water quality degradation (Carbon, Nitrogen and Phosphorus from fertilizers)*
- ***Heavy metals*** *e.g. Copper (Cu), Lead (Pb), Zinc (Zn)*
- ***Chemical contaminants:*** *e.g. Chlorine from potable water*
- ***Pathogens****: e.g. fecal coliform bacteria*
- ***Thermal pollution:*** *e.g. In summer, unshaded impervious surfaces can have air and ground temperatures 5-7 degrees higher that vegetated areas*

2. STORM WATER MANAGEMENT AND DESIGN ISSUES

2.2 Design Issues & Ecosystem Services (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

b) Ground Water Recharge: *The replenishment of groundwater by rainwater infiltration is known as recharge. The layers of water bearing soil and rock are aquifers. Impervious surfaces eliminate aquifers recharge when places in recharge areas*



c) Water Supply

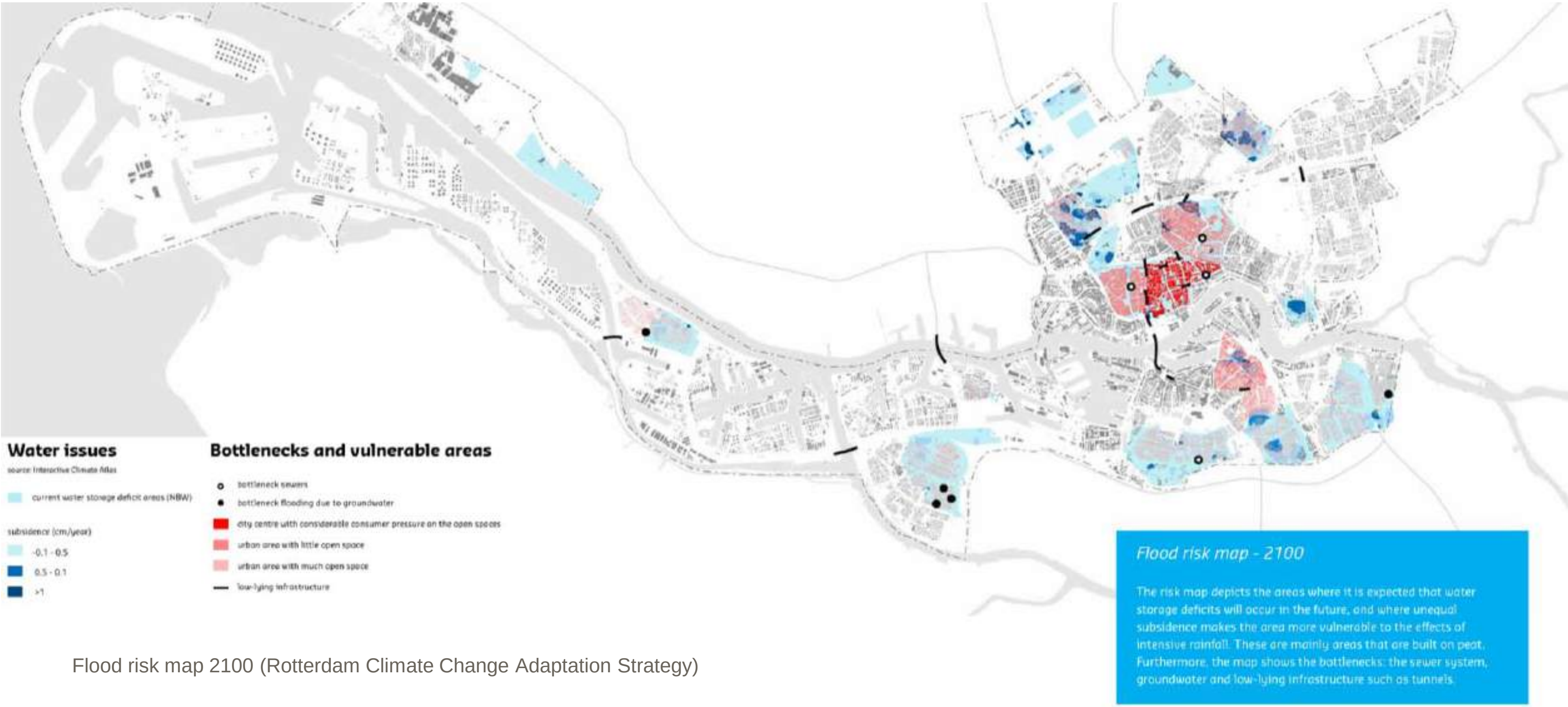
d) Wildlife Habitat: *Urbanization can change the availability and quality of water needed to sustain habitat. It tends to reduce or eliminate base flow. In such cases the original species are replaced by others more adapted to the new regime*

e) Quality of Life: *Water bodies and are regarded as positive attributes of places to live and work. They provide open view and vistas, cultural values and increase real estate market values*

2. STORM WATER MANAGEMENT AND DESIGN ISSUES

2.2 Design Issues & Ecosystem Services

f) Soil Stability: *Clays, silt and organic soils become unstable when wet*



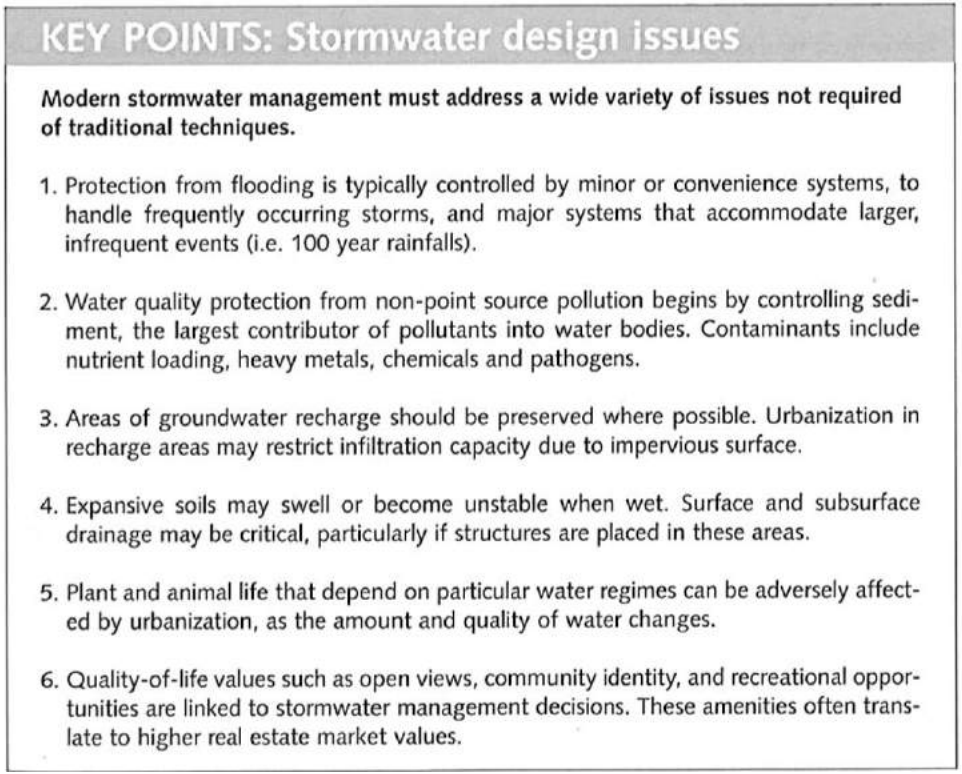
Flood risk map - 2100

The risk map depicts the areas where it is expected that water storage deficits will occur in the future, and where unequal subsidence makes the area more vulnerable to the effects of intensive rainfall. These are mainly areas that are built on peat. Furthermore, the map shows the bottlenecks: the sewer system, groundwater and low-lying infrastructure such as tunnels.

Flood risk map 2100 (Rotterdam Climate Change Adaptation Strategy)

2. STORM WATER MANAGEMENT AND DESIGN ISSUES

2.2 Design Issues & Ecosystem Services (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)



KEY POINTS: Stormwater design issues

Modern stormwater management must address a wide variety of issues not required of traditional techniques.

1. Protection from flooding is typically controlled by minor or convenience systems, to handle frequently occurring storms, and major systems that accommodate larger, infrequent events (i.e. 100 year rainfalls).
2. Water quality protection from non-point source pollution begins by controlling sediment, the largest contributor of pollutants into water bodies. Contaminants include nutrient loading, heavy metals, chemicals and pathogens.
3. Areas of groundwater recharge should be preserved where possible. Urbanization in recharge areas may restrict infiltration capacity due to impervious surface.
4. Expansive soils may swell or become unstable when wet. Surface and subsurface drainage may be critical, particularly if structures are placed in these areas.
5. Plant and animal life that depend on particular water regimes can be adversely affected by urbanization, as the amount and quality of water changes.
6. Quality-of-life values such as open views, community identity, and recreational opportunities are linked to stormwater management decisions. These amenities often translate to higher real estate market values.

Time Savers for Landscape Architecture (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

3. DESIGN PROCEDURES

3.1 Data gathering and Mapping (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

- ***Rainfall data***
- ***Storm works and Flow Data/carrying capacity*** *(streams, channels and storm sewers, water bodies, etc.)*
- ***Topography***
- ***Soils:*** *Consult soils surveys. Estimates of soil texture and infiltration performance can be based on direct observation of vegetation and soils*
- ***Land Cover:*** *maps + aerial photographs (key Data for storm water runoff estimation)*
- ***Bedrock and Water Table Depths****: shallow impervious bedrocks and high water tables can limit infiltration of rainfall and storm sewer techniques*

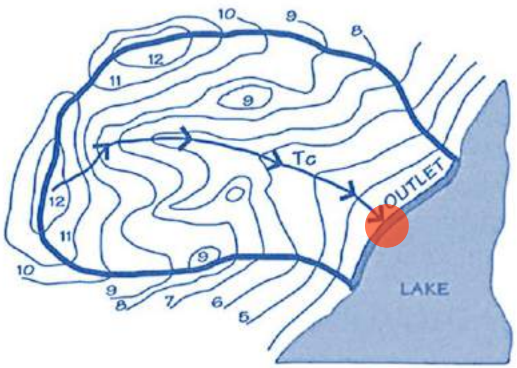
3. DESIGN PROCEDURES

3.2 Base line Runoff Analysis (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

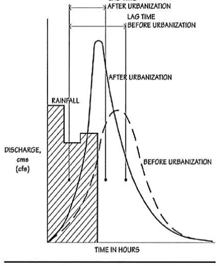
A base line runoff analysis should be developed against which design proposals can be compared for performance (existing situation or existing masterplan).

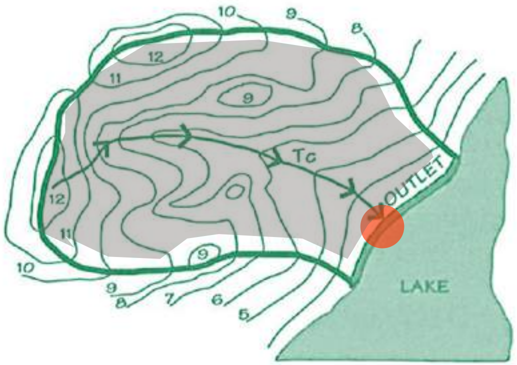
Analysis is typically made in terms of ***peak discharge and volume*** *from a specified design storm at each dispersal point (outlets) or edge*

Post development runoff analysis must be made at the same points or edges



EXISTING Peak discharge and Volume on outlet (for a specified Design Storm)





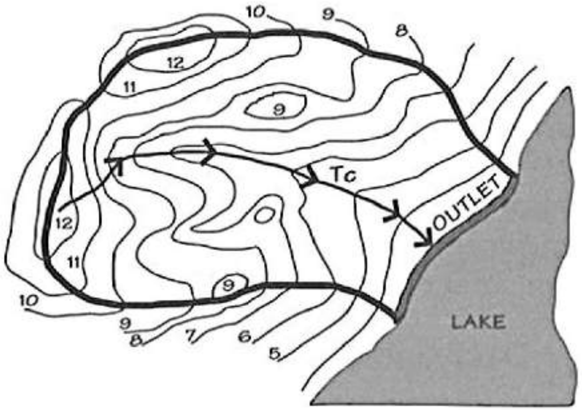
FUTURE Peak discharge and Volume on outlet (for the same specified Design Storm)

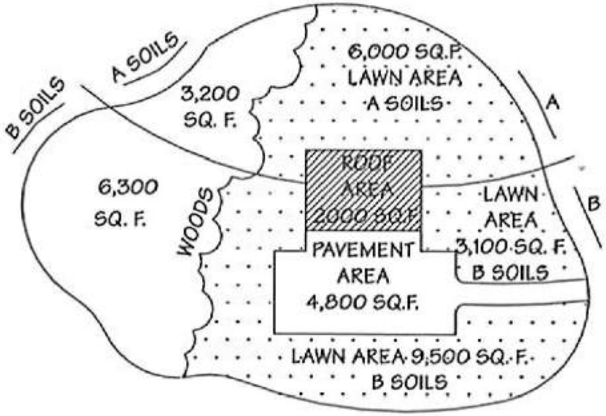
3. DESIGN PROCEDURES

3.2 Base line Runoff Analysis (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

The Runoff Analysis requires

- ***Watershed Boundary Delineation***
- ***Soil-Land cover classification***
- ***Converting Rain to Runoff (volumes and peak discharges):*** *mathematical models which account for rainfall losses (inital losses and continuous losses)*





Delineating areas of Land-Cover and Soil Type
(Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

3. DESIGN PROCEDURES

3.3 Basic Design Strategies (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

Good site planning can avoid increases in runoff and reduce impacts on surface water quality

Design performance criteria should consider: Peak discharges, runoff volumes, watershed infiltration capacity, ground water recharge and water recharge. These issues can be addressed by focusing on the following strategies

a) Reproducing or improving Pre-Development Hydrological Condition:

- *CONTROL SURFACE SPEED: surface friction, surface shape and slope. These characteristics are determined by the types of surfaces included in the proposal and **their relation to each other***
- *RETAIN on SITE: it also might reduce runoff speed, decrease erosion and lower impact on water quality*
- *INCREASE INFILTRATION: The use of infiltration techniques replicates or even increases natural infiltration*

3. DESIGN PROCEDURES

3.3 Basic Design Strategies (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

b) Place Development in Least Critical Areas:

Avoid shorelines, natural drainage ways, steep slopes, areas of dense vegetation and areas with porous or erodible soils

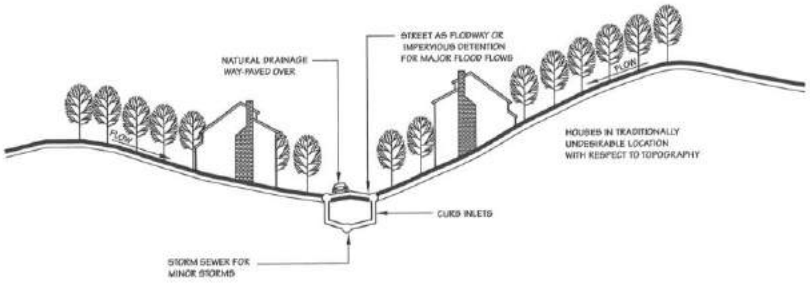


Figure 330-8. Location of imperviousness relative to drainageways in conventional development.

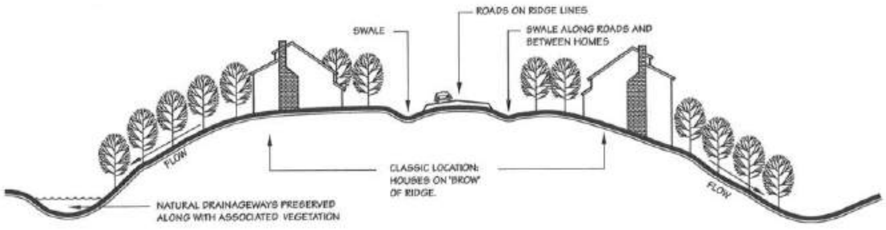


Figure 330-9. Impervousness placed high in the landscape. *Note the lack of storm sewers.*

c) Fit development to Terrain:

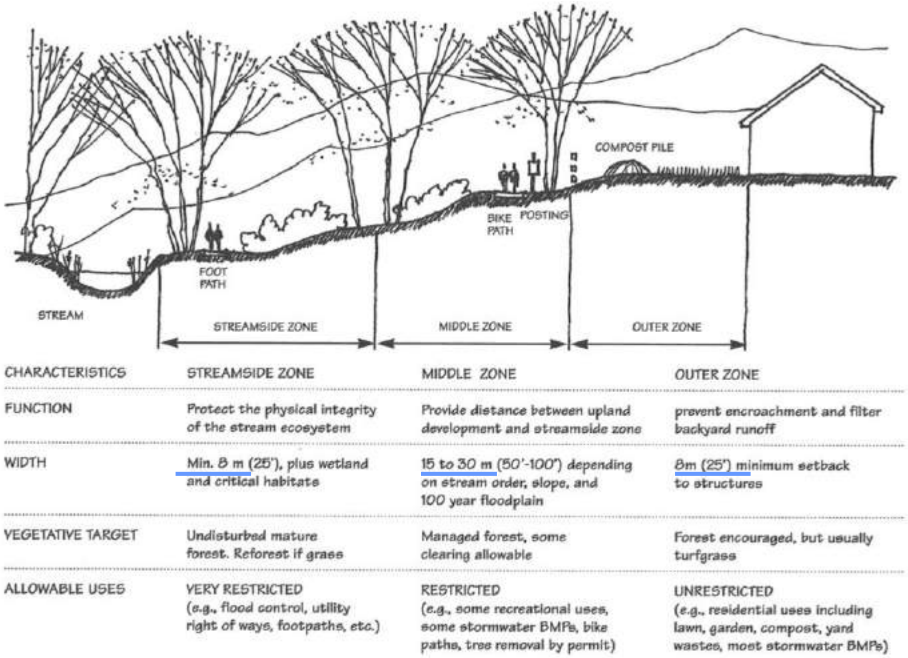
Road patterns and building types and directions should fit landform. Keep impervious surfaces samll and place them at higher elevations

3. DESIGN PROCEDURES

3.3 Basic Design Strategies (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

d) Utilize the Natural Drainage System:

Natural drainage paths should be identified as part of the site analysis along with sufficient buffers



CHARACTERISTICS	STREAMSIDE ZONE	MIDDLE ZONE	OUTER ZONE
FUNCTION	Protect the physical integrity of the stream ecosystem	Provide distance between upland development and streamside zone	prevent encroachment and filter backyard runoff
WIDTH	Min. 8 m (25'), plus wetland and critical habitats	15 to 30 m (50'-100') depending on stream order, slope, and 100 year floodplain	8m (25') minimum setback to structures
VEGETATIVE TARGET	Undisturbed mature forest. Reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	VERY RESTRICTED (e.g., flood control, utility right of ways, footpaths, etc.)	RESTRICTED (e.g., some recreational uses, some stormwater BMPs, bike paths, tree removal by permit)	UNRESTRICTED (e.g., residential uses including lawn, garden, compost, yard wastes, most stormwater BMPs)

Urban stream buffer system
(Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

Cluster development used to preserve natural drainageways
(Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

3. DESIGN PROCEDURES

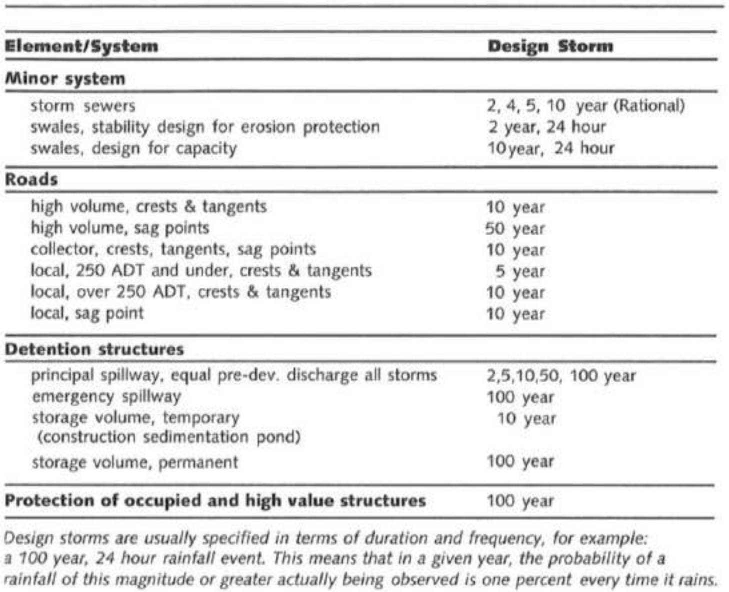
3.4 Types of runoff analysis (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

The major and minor flood protection systems should be analyzed for each schematic design

***Major System**: In US they are usually designed for the 100 year 24 design storm using SCS runoff methods or similar methods*

***Minor Systems:** In US they are usually designed for a frequent short duration storm: typically a 2, 5, 10 years, using the Rational Method or SCS runoff methods.*

***Water Quality Protection System**: They should be designed using small storm hydrology methods. They are typically designed to treat the volume of runoff from a 30 mm rainfall and protect against erosion from 2 year*



Element/System	Design Storm
Minor system	
storm sewers	2, 4, 5, 10 year (Rational)
swales, stability design for erosion protection	2 year, 24 hour
swales, design for capacity	10 year, 24 hour
Roads	
high volume, crests & tangents	10 year
high volume, sag points	50 year
collector, crests, tangents, sag points	10 year
local, 250 ADT and under, crests & tangents	5 year
local, over 250 ADT, crests & tangents	10 year
local, sag point	10 year
Detention structures	
principal spillway, equal pre-dev. discharge all storms	2,5,10,50, 100 year
emergency spillway	100 year
storage volume, temporary (construction sedimentation pond)	10 year
storage volume, permanent	100 year
Protection of occupied and high value structures	100 year

Design storms are usually specified in terms of duration and frequency, for example: a 100 year, 24 hour rainfall event. This means that in a given year, the probability of a rainfall of this magnitude or greater actually being observed is one percent every time it rains.

Typical Design Storm Standards (USA, 1998)
(Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

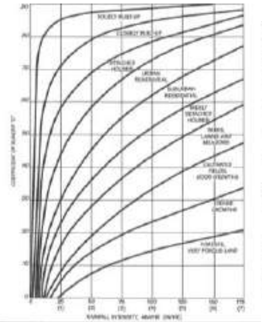
4. RUNOFF CALCULATIONS

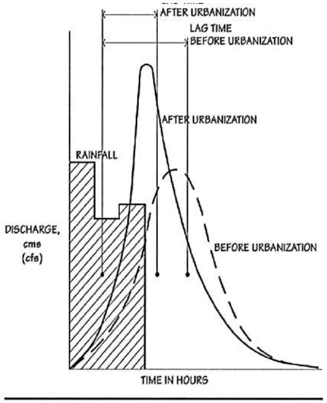
4.1 General Principles (adapted from Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

From rainfall to Runoff

Design Storms + **Soil type** + **Land-cover & coefficients** + **Slope** → **models**

- **Time of concentration**
- **Intensity**
- **Depth of runoff**
- **RUNOFF VOLUME**
- **PEAK DISCHARGE**





4. RUNOFF CALCULATIONS

4.2 Small Storm Hydrology_ a guided exercise (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

*Design for water quality management focuses on capturing and treating the **VOLUME** of water rather than the peak discharge… Most of annual runoff is produced by small storms… Generally, water quality treatment from a 25 mm – 30 mm rainfall event will treat 85 to 90 percent of the annual rainfall volume.*

The Small Storm Hydrology WQV Method permits an easy conversion of rainfall in runoff (Volume and Peak Discharges) for small storms and for water quality treatment. It requires the following Data:

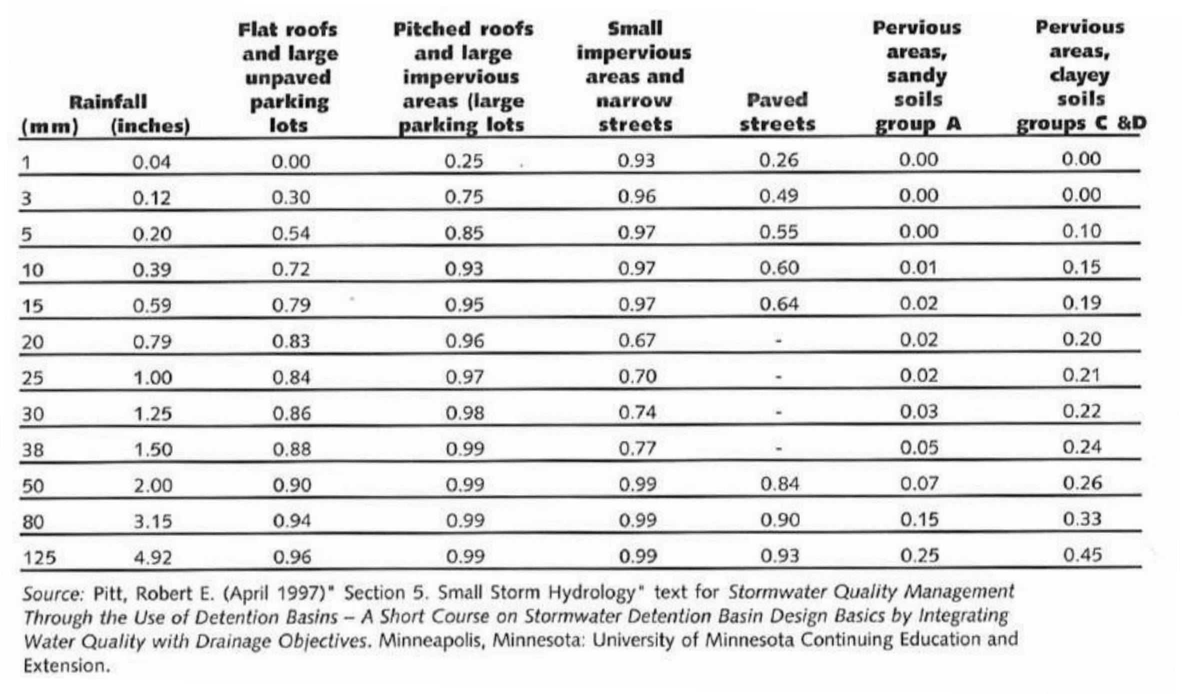
- *Design Rainfall event = P (m)*
- *Total Area (hectares) and Areas covered with different surfaces (hectares)*
- *Type of soil: (sandy or silty-clayey)*
- *Weighted volumetric runoff Coefficient (use table 1)*
- *Weighted area = Rv (m^2)*
- *Coefficient for Disconnected Impervious Surfaces (use table 2)*

WQV (runoff volume) = P x Rv

4. RUNOFF CALCULATIONS

4.2 Small Storm Hydrology_ a guided exercise (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

Small Storm Volumetric Coefficients (Rv) for Urban Runoff



Rainfall (mm)	Rainfall (inches)	Flat roofs and large unpaved parking lots	Pitched roofs and large impervious areas (large parking lots	Small impervious areas and narrow streets	Paved streets	Pervious areas, sandy soils group A	Pervious areas, clayey soils groups C &D
1	0.04	0.00	0.25	0.93	0.26	0.00	0.00
3	0.12	0.30	0.75	0.96	0.49	0.00	0.00
5	0.20	0.54	0.85	0.97	0.55	0.00	0.10
10	0.39	0.72	0.93	0.97	0.60	0.01	0.15
15	0.59	0.79	0.95	0.97	0.64	0.02	0.19
20	0.79	0.83	0.96	0.67	-	0.02	0.20
25	1.00	0.84	0.97	0.70	-	0.02	0.21
30	1.25	0.86	0.98	0.74	-	0.03	0.22
38	1.50	0.88	0.99	0.77	-	0.05	0.24
50	2.00	0.90	0.99	0.99	0.84	0.07	0.26
80	3.15	0.94	0.99	0.99	0.90	0.15	0.33
125	4.92	0.96	0.99	0.99	0.93	0.25	0.45

TABLE.1

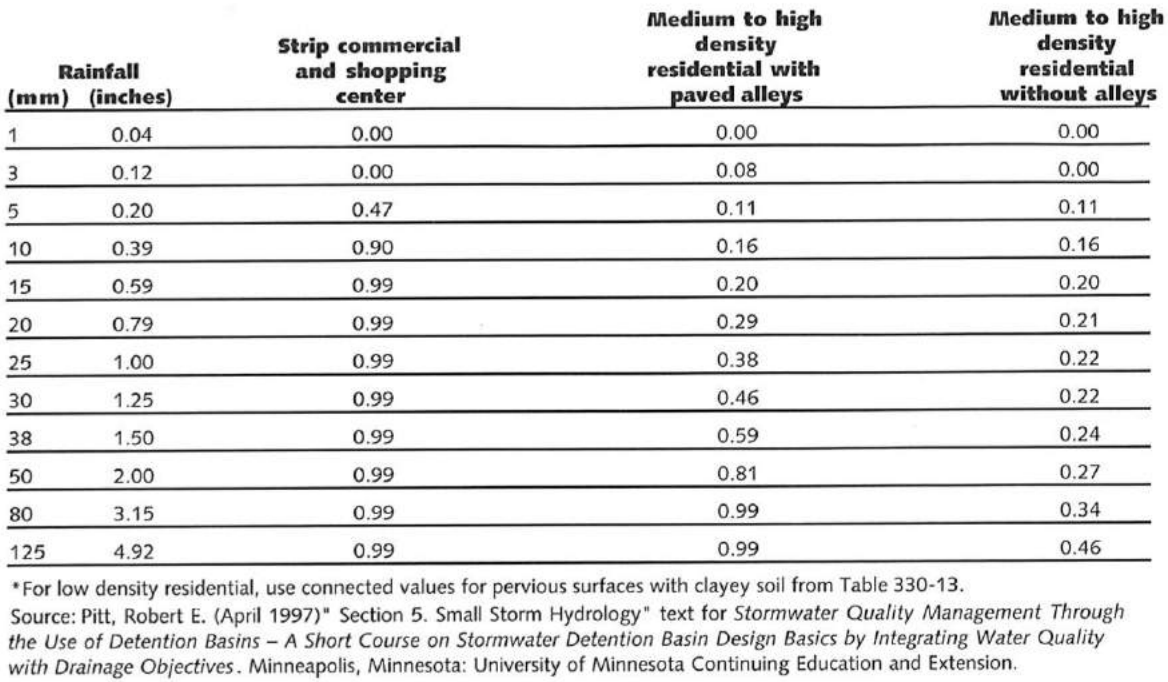
Source: Pitt, Robert E. (April 1997)" Section 5. Small Storm Hydrology" text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives.* Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

4. RUNOFF CALCULATIONS

4.2 Small Storm Hydrology_ a guided exercise (Harris, C. W; Dines, N. T.; Sykes, R. D.; Brown, K. D.; 1998)

Reduction factors to Volumetric Runoff Coefficients (Rv) for disconnected impervious surfaces

TABLE.2



Rainfall (mm)	Rainfall (inches)	Strip commercial and shopping center	Medium to high density residential with paved alleys	Medium to high density residential without alleys
1	0.04	0.00	0.00	0.00
3	0.12	0.00	0.08	0.00
5	0.20	0.47	0.11	0.11
10	0.39	0.90	0.16	0.16
15	0.59	0.99	0.20	0.20
20	0.79	0.99	0.29	0.21
25	1.00	0.99	0.38	0.22
30	1.25	0.99	0.46	0.22
38	1.50	0.99	0.59	0.24
50	2.00	0.99	0.81	0.27
80	3.15	0.99	0.99	0.34
125	4.92	0.99	0.99	0.46

*For low density residential, use connected values for pervious surfaces with clayey soil from Table 330-13.

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4. RUNOFF CALCULATIONS

4.2 Small Storm Hydrology_ a guided exercise (adapted from Harris, C.; Dines, N..; Sykes, R..; Brown, K.; 1998)

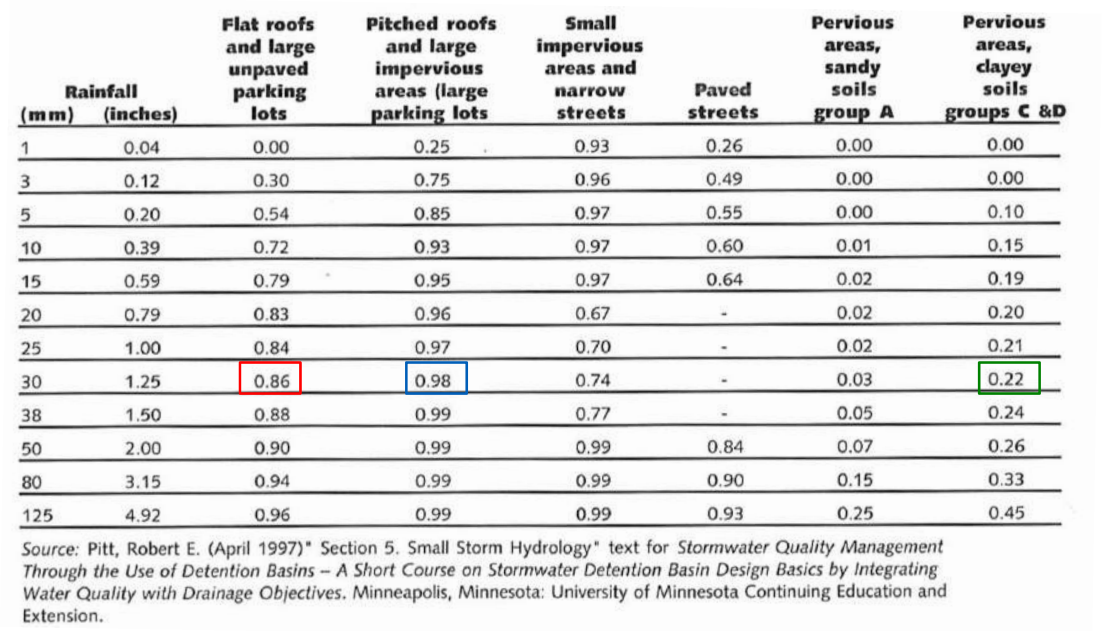
Example: calculate the runoff volume for a 1,05 hectares small shopping center watershed having a 0,32 ha flat roof, 0,61 ha of paved parking lot and 0,12 ha of open space (clayey soils). Assume a 30 mm rainfall event and no disconnection of impervious surface

The weighted volumetric runoff coefficient is:

- *Flat roof :* 0,32 ha x 0,86 = 0,27
- *Parking lot:* 0,61 ha x 0,98 = 0,60
- *Green Space:* 0,12 ha x 0,22 = 0,03

Weighted Area (Rv): **= 0,90 Ha (9000 m2)**

Weighted Runoff Coefficient = 0,9 / 1,05 = 0,86



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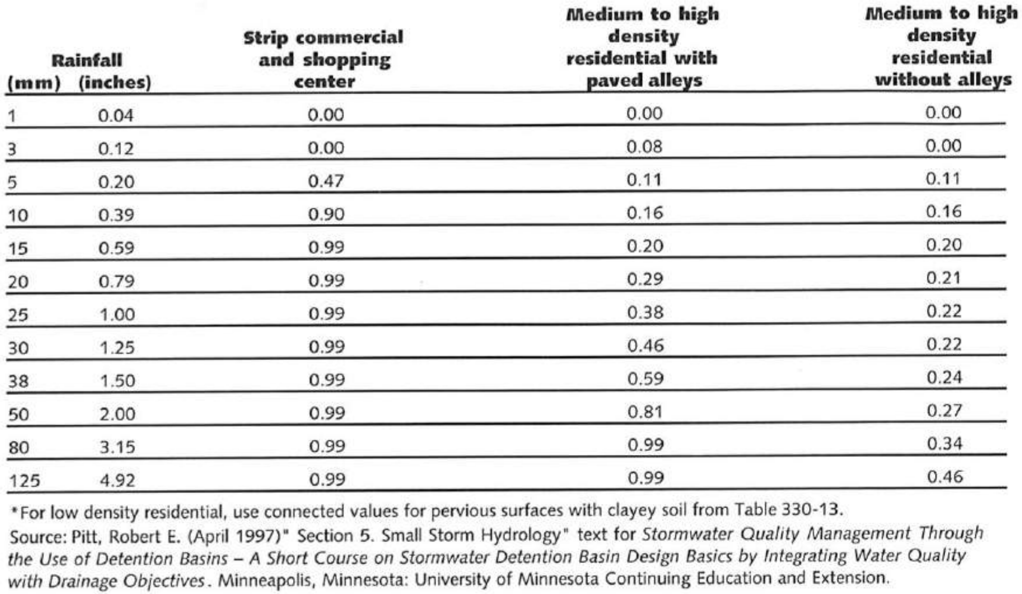
No reduction of Rv since there is no disconnection of impervious surface

Volume of Runoff = P (m) x Rv (m^2)

Volume of Runoff = 0,03 x 9000 = 270 m^3

In this case, since the rainfall event is 30 mm and that is also the rainfall event for calculating Water Quality treatment volumes (USA), 258 m3 would also be the WQV (Water Quality Volume) for that areas

Reduction factors to Volumetric Runoff Coefficients (Rv) for disconnected impervious surfaces



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5. SUMMARY

MAIN GOALS:

- INCREASE INTERCEPTION
- INCREASE INFILTRATION
- RETAIN on SITE and DECREASE SPEED
- MAXIMIZE DISCONNECTED IMPERVIOUSNESS

BASIC DESIGN STRATEGIES

- REPRODUCE OR IMPROVE PRE-DEVELOPMENT HYDROLOGICAL CONDITION
- PLACE DEVELOPMENT IN LEAST CRITICAL AREAS
- FIT DEVELOPMENT TO TERRAIN
- UTILIZE THE NATURAL DRAINAGE SYSTEM

INTEGRATED STORM WATER MANAGEMENT

- UTILIZE AND COMBINE DIFFERENT STORM WATER MANAGEMENT SYSTEMS (natural & technological): iWater
- DESIGN FOR MINOR AND MAJOR STORM WATER SYSTEMS
- MAXIMIZE STORM WATER DESIGN ISSUES AND ASSOCIATED ECOSYSTEM SERVICES (Water Quality Protection, Ground water recharge, Soil Stability, Wildlife habitat, Water supply, Quality of Life)
- CONSIDER FLOODING RISK AS a COMBINATION OF HAZARD AND VULNERABILITY
- INTEGRATE DEFENSIVE AND ADAPTIVE STRATEGIES

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INTEGRATED STORM WATER MANAGEMENT

- ADAPTATIVE / MULTIFUNCTIONAL / COMBINING DIFFERENT STORM WATER MANAGEMENT SYSTEMS

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INTEGRATED STORM WATER MANAGEMENT

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