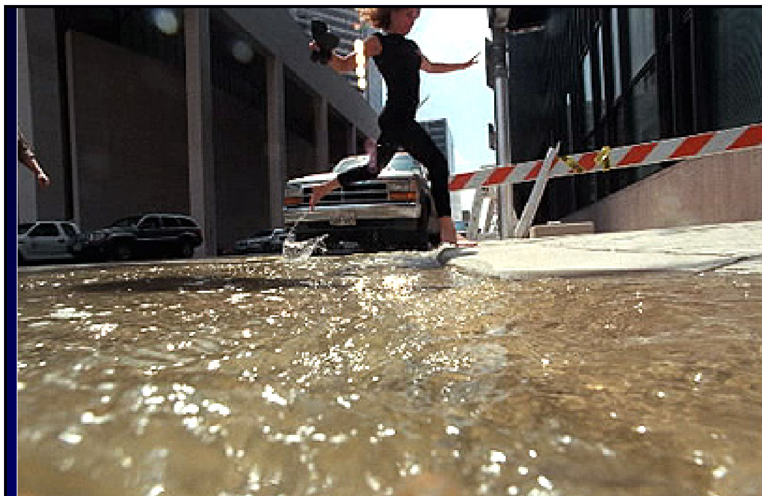
Module 10b: Gutter and Inlet Designs and Multiple Design Objectives

Bob Pitt
University of Alabama
and
Shirley Clark
Penn State – Harrisburg

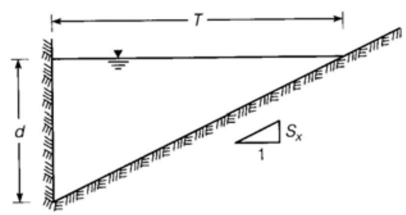
Evening traffic plows through high water at the intersection of Sampson at N. MacGregor Drive in Houston Tuesday as Tropical Storm Allison blossomed into the first storm of the 2001 season. Allison brought high winds and street flooding to Houston, after doing the same earlier in the day in Galveston. Photo from *Houston Chronicle*.



With shoes in hand, a woman hops through a flowing stream of water near Jones Hall during the lunch hour Tuesday. Pumps working to eliminate floodwater from the Theater District have filled streets with water, presenting a minor hazard to walkers.

Photo from *Houston Chronicle*.

Street Gutters and Inlets



d is the depth of water along the curb and T is the distance the water floods into the street from the curb face. S_x is the street cross slope and normally is in the range of 1.5 to 6%. The longitudinal slopes of streets are usually in the range of 0.5 to 5%, depending on the topography. The flowrate in a triangular gutter can be estimated from a modification of the Manning's equation:

$$Q = 0.376\left[\frac{1}{nS_x}\right]d^{8/3}S_0^{1/2}$$

Recommended Pavement Cross Slopes

Surface Type	Range of Cross Slope
High-type surface	
2-lanes	0.015 – 0.020
3 or more lanes, each direction	0.015 minimum Increase 0.005 to 0.010 per lane 0.040 maximum
Intermediate surface	0.015 – 0.03
Low-type surface	0.020 – 0.060
Shoulders	
Bituminous or concrete with curbs	0.020 – 0.060 ≥0.040

Type of gutter or pavement	Manning *n*
Concrete gutter, troweled finish	0.012
Asphalt pavement	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter with asphalt pavement	
Smooth	0.013
Rough	0.015
Concrete pavement	
Float finish	0.014
Broom finish	0.016

Source: USFHWA (1984b).

Street type	Minor storm runoff	Major storm runoff
Local*	no curb overtopping†; flow may spread to crown of street	Residential dwellings, public, commercial and industrial buildings shall not be inundated at the ground line, unless buildings are flood-proofed. The depth of water over the gutter flow line shall not exceed an amount specified by local regulation, often 30 cm (12 in.).
Collector‡	no curb overtopping†; flow spread must leave at least one lane free of water	Same as for local streets.
Arterial§	no curb overtopping†; flow spread must leave at least one lane free of water in each direction	Residential dwellings, public, commercial, and industrial buildings shall not be inundated at the ground line, unless buildings are flood-proofed. Depth of water at the street crown shall not exceed 15 cm (6 in.) to allow operation of emergency vehicles. The depth of water over the gutter flow line shall not exceed a locally prescribed amount.
Freeway¶	no encroachment allowed on any traffic lanes	Same as for arterial streets.

Inlet Design Overview

Table 3-1: Suggested Minimum Design Frequencies and Spreads for Gutter Sections on Grade

Road Classification		Design Return Period	Design Spreads
High Volume or Bi-directional	<70 km/hr (45 mph)	10-year	Shoulder + 1 m (3 ft)
	>70 km/hr (45 mph)	10-year	Shoulder
	Sag Point	50-year	Shoulder + 1 m (3 ft)
Collector	Low Volume	10-year	½ Driving Lane
	High Volume	10-year	Shoulder
	Sag Point	10-year	½ Driving Lane
Local Streets	Low Volume	5-year	½ Driving Lane
	High Volumes	10-year	½ Driving Lane
	Sag Point	10-year	½ Driving Lane

Inlet Design (Example 5.46, Chin 2006)

A four lane collector roadway has 3.66m wide lanes, a cross slope of 2% (S_x = 0.02) and a longitudinal slope of 0.5% (S_o = 0.005). The pavement is rough asphalt (n = 0.016). If the minor roadway drainage system is to be designed for a rainfall intensity of 150 mm/hr, determine the spacing of the inlets, assuming no other flow enters the inlets except from the roadway and there are no rainfall abstractions (all the rainfall is converted into direct runoff).

The level of service table indicates that at least one lane must be free of water on each side of the road crown. Therefore, the extent of flooding can be up to one lane (T, the allowable top width of flooding is 3.66m). The maximum depth of flow at the curb is therefore:

$$d = TS_x = (3.66m)(0.02) = 0.0732m = 7.32cm$$

The maximum allowable flowrate is given by the Manning's equation:

$$Q = 0.376\left[\frac{1}{nS_x}\right]d^{8/3}S_0^{1/2} = 0.376\left[\frac{1}{(0.016)(0.02)}\right](0.0732m)^{8/3}(0.005)^{1/2} = 0.0779m^3/s$$

The contributing area required to produce a runoff rate of 0.0799 m³/sec (again, this problem assumes no rainfall abstractions) is:

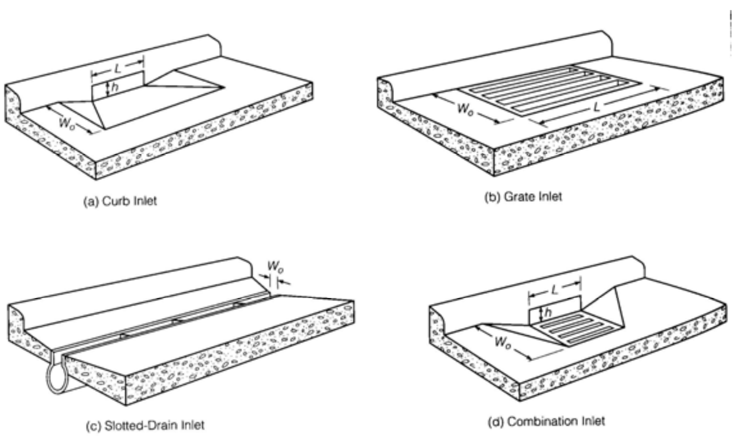
$$A = \frac{Q}{i} = \frac{0.0779m^3/s}{4.17x10^{-5}m/s} = 1868m^2$$

The roadway has two lanes contributing runoff to each gutter. Therefore, the width of the contributing area is 2 times 3.66 m, or 7.32 m and the length of roadway required for a contributing area of 1,868 m² is therefore:

$$L = \frac{A}{width} = \frac{1868m^2}{7.32m} = 255m$$

The required spacing of the inlets is therefore 255 m, which is rather long. The required placement of inlets at roadway intersections may therefore govern the location of these inlets.

Curb Inlet Types:



(a) Curb Inlet

(b) Grate Inlet

(c) Slotted-Drain Inlet

(d) Combination Inlet

Inlet Types

According to ASCE (1992) the final design should show roughly one 1.2 m long inlet for every 0.08 m³/sec flow increment on a street with a longitudinal slope of 2%, or less, and opening heights should not exceed 15 cm (6 in) to reduce risks to children.

The weir flow equation, with Q_i in m³/sec, with L the length of the curb opening in m, W_o is the width of the inlet depression, and d is the depth of flow at the curb:

$$Q_i = 1.27(L + 1.8W_o)d^{1.5}$$

Without a depressed gutter, the inflow to the curb inlet is given by:

$$Q_i = 1.27(L)d^{1.5} \qquad d \le h$$

When the flow depth, d, exceeds the open height by a factor of 1.4, the orifice equation can be used (A is the area of the curb opening, hL):

$$Q_i = 0.67A\left[2g\left(d - \frac{h}{2}\right)\right]^{1/2}$$

Inlet Design (example 5.48, Chin 2006):

A roadway has a maximum allowable flow depth at the curb of 8 cm and a corresponding flow rate in the gutter of 0.08 m³/sec (Q_i). Determine the length of a 15 cm (6 inch) high curb inlet that is required to remove all the water from the gutter.

Inlet Depression Width of 0.4 m (W_o):
The curb inlet acts as a weir, as the flow depth (8 cm) (d=0.08m) is less than the height of the inlet (15 cm).

$$L = \frac{Q_i}{1.27d^{1.5}} - 1.8W_o = \frac{0.08m^3/\text{sec}}{1.27(0.08m)^{1.5}} - 1.8(0.4m) = 2.06m$$

No Inlet Depression:
The inlet equation, with no inlet depression results in:

$$L = \frac{Q_i}{1.27d^{1.5}} = \frac{0.08m^3/\text{sec}}{1.27(0.08m)^{1.5}} = 2.78m$$

which is 0.72 m longer than if a depression was used.

Safety and Maintenance

Inlet Design Overview

- Roads and highways must include sufficient drainage provisions in order to minimize the dangers resulting from stormwater runoff and to optimize traffic efficiency under most weather conditions.
- The key objective when designing inlets is to minimize the spread of water across a roadway and in the gutter.
- The gutter is the channel alongside the road through which stormwater runoff is conveyed to storm sewer inlets.
- Spread is the top width of the flowing water on the road, measured from the curb.
- The allowable spread length (generally determined by state or local regulations) is based on the road's classification.

Inlet Design Overview

- The incoming surface flow (and spread) observed can be controlled by the efficiency and spacing of the inlets located upstream along the road.
  - One additional factor to consider is whether the inlet is located on grade or in a sag, as the design criteria and equations involved differ.
- Inlets on grade are located on a slope and intercept a portion of the water as it flows past.
- Inlets in sag are located at a point where runoff from a given area will ultimately collect, and these inlets are normally designed to capture 100% of the surface flow (otherwise, get flooding).

Objectives for Urban Drainage Systems are Varied

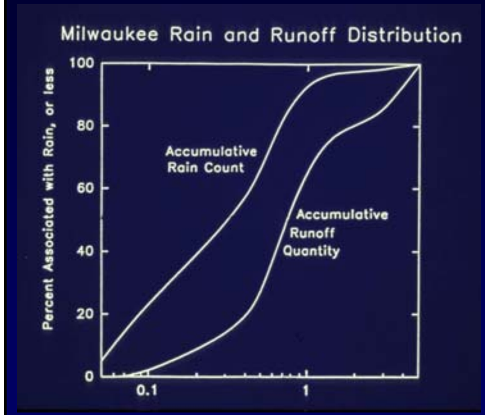
- Ensure personal safety (minimize local flooding)
- Minimize economic damage (water in homes and businesses and nuisance conditions)
- Preserve environmental health (aquatic life, non-contact recreation, aesthetics)

Design Considerations

Use appropriate design tools for the job at hand:

- Problems arise when trying to use drainage design hydrology models for water quality analyses.
- As an example, TR-55 greatly under predicts flows from small rains: NRCS recommends that TR-55 not be used for rains less than 0.5 inch.
- Most drainage models assume that all/most flows originate from directly connected impervious areas, with very little originating from pervious areas.
- Most stormwater managers overlook the importance of small and intermediate sized rains when investigating water quality problems.

Example of design of integrated program to meet many objectives



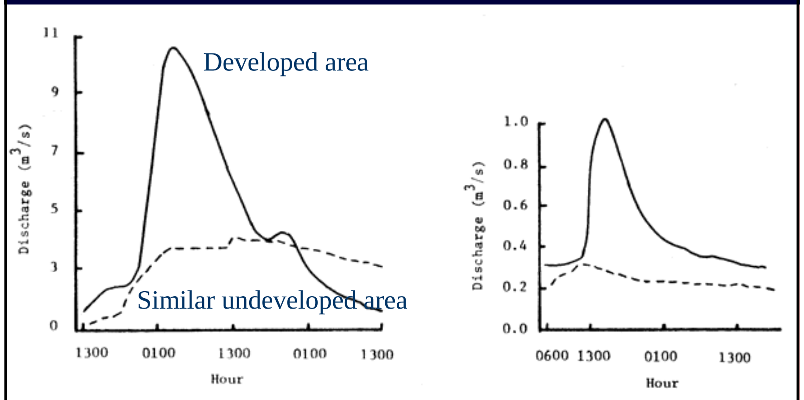
Example of monitored rain and runoff distributions during NURP. Similar plots for all locations, just shifted.

•Smallest rains (<0.5 in.) are common, but little runoff. Exceed WQ standards, but these could be totally infiltrated.

•Medium-sized storms (0.5 to 1-1/2 in.) account for most of annual runoff and pollutant loads. Can be partially infiltrated, but larger rains will need treatment.

•Large rains (>1-1/2 in.) need energy reduction and flow attenuation for habitat protection and for flood control.

Land Development Results in Increased Peak Flow Rates and Runoff Volumes

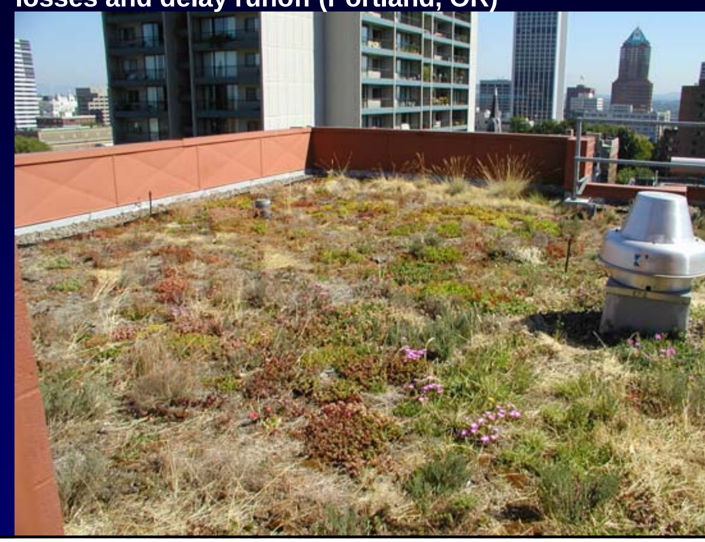


Large Rain Small Rain

Historical concerns focused on increased flows during rains and associated flooding. However, decreased flows during dry periods are now seen to also cause receiving water problems.

Historical approach to urban drainage has been devastating to environment and recharge of groundwaters

“Green roof” can be used to enhance evapotranspiration losses and delay runoff (Portland, OR)



Roof downspout disconnections enhance infiltration of runoff and reduce volume and help recharge groundwater (AL, WI, and Sweden).

Rain Garden Designed for Complete Infiltration of Roof Runoff

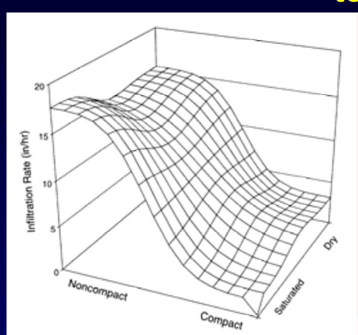
Grass Swales Designed to Infiltrate Large Fractions of Runoff (AL, WI, and OR).

Porous paver blocks have been used in many locations to reduce runoff to combined systems, reducing overflow frequency and volumes (Germany, Sweden, and WI).

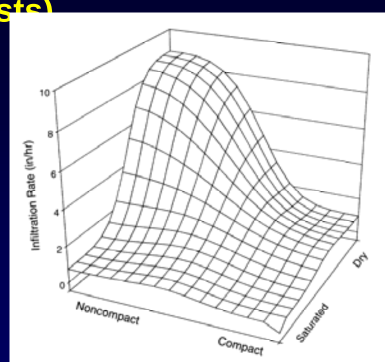
Bioretention areas can be located between buildings and parking areas to infiltrate almost all roof and paved area runoff (Portland, OR).

Other types of on-site infiltration can be built to fit in area (MD and WI).

Infiltration Rates in Disturbed Urban Soils (AL tests)



Sandy Soils



Clayey Soils

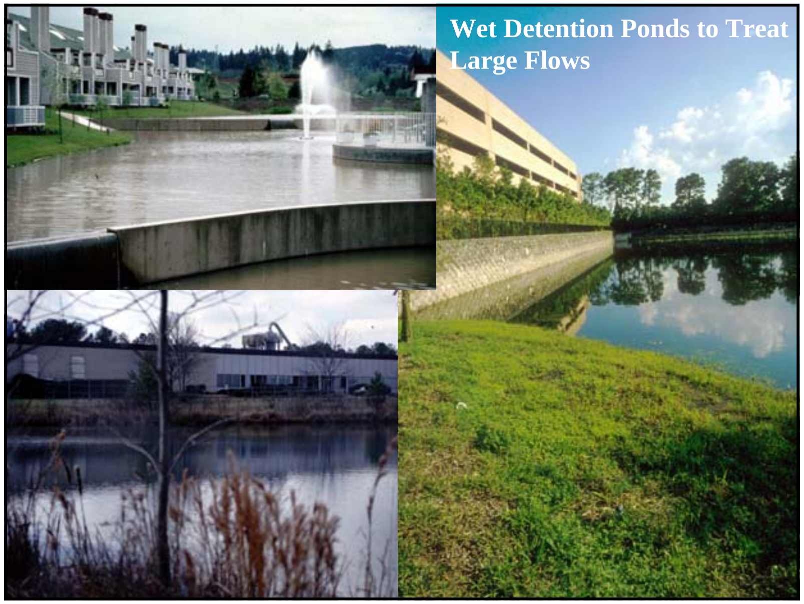
Recent research has shown that the infiltration rates of urban soils are strongly influenced by compacted, probably more than by moisture saturation.

Developed soil modifications that result in greatly enhanced infiltration in marginal soils.

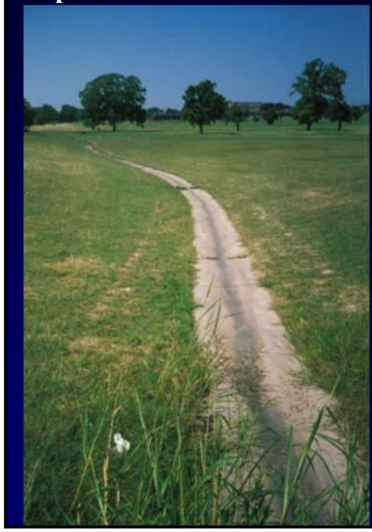
Example Calculations (using SLAMM) to Predict the Benefits of Alternative Roof Runoff Control Options (% reduction of annual roof runoff)

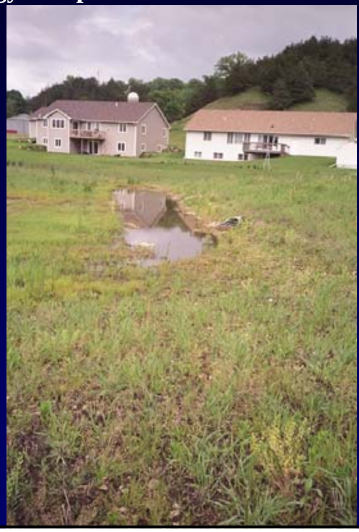
	Phoenix, AZ (9.3 in/yr)	Seattle, WA (33.4 in/yr)	Birmingham, AL (52.5 in/yr)
Roof garden (1 in/hr amended soils, 60 ft^2/home)	96%	100%	87%
Cistern for on-site reuse of roof runoff (375ft^3/home)	88	67	66
Disconnect roof runoff for infiltration into silty soil	91	87	84
Green roof (vegetated roof surface)	84	77	75

Wet Detention Ponds to Treat Large Flows



Dry ponds and extended detention ponds having large storage capacities to reduce runoff energy and peak flow rates.



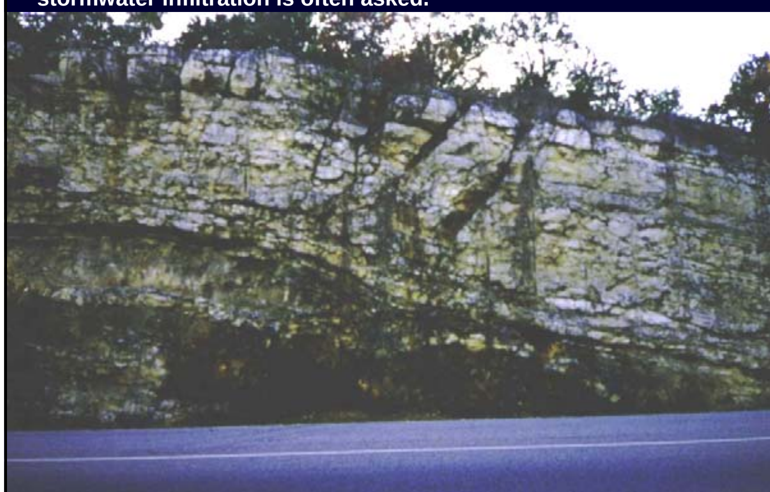


Wetlands can be used to provide additional water quality control, enhance habitat, and increase infiltration for groundwater recharge.

Berlin, Germany

Mature Wetlands and Wet Detention Pond Facility, Malmo, Sweden

The potential for groundwater contamination associated with stormwater infiltration is often asked.



Roadcut showing direct recharge of Edwards Aquifer, Austin, TX

Screening Model Developed to Evaluate Groundwater Contamination Potential:

Contamination potential is the lowest rating of the influencing factors:

- Surface infiltration with no pretreatment (grass swales or roof disconnections)
  - **Mobility and abundance** most critical
- Surface infiltration with sedimentation pretreatment (treatment train: percolation pond after wet detention pond)
  - **Mobility, abundance, and treatability** all important
- Subsurface injection with minimal pretreatment (infiltration trench in parking lot or dry well)
  - **Abundance** most critical

Knowing the Runoff Volume is the Key to Estimating Pollutant Mass

- There is usually a simple relationship between rain depth and runoff depth.
- Changes in rain depth affect the relative contributions of runoff and pollutant mass discharges:
  - Directly connected impervious areas contribute most of the flows during relatively small rains
  - Disturbed urban soils may dominate during larger rains

Where is this stuff coming from and where should we locate controls?