Doing It the Right Way: Porous Pavement with Underground Recharge Beds

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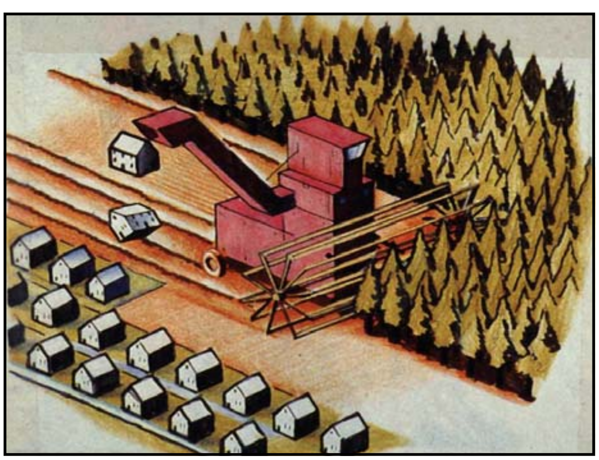
The Problem




9/27/2001

SUSTAINABILITY

Sustain the quality and quantity of our natural resources for use by future generations

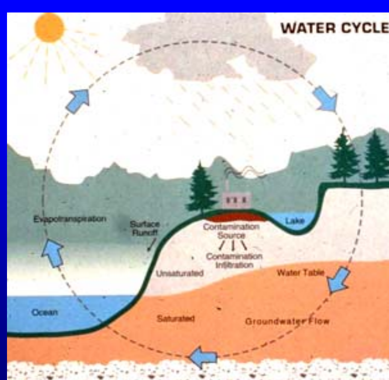
Stormwater Management

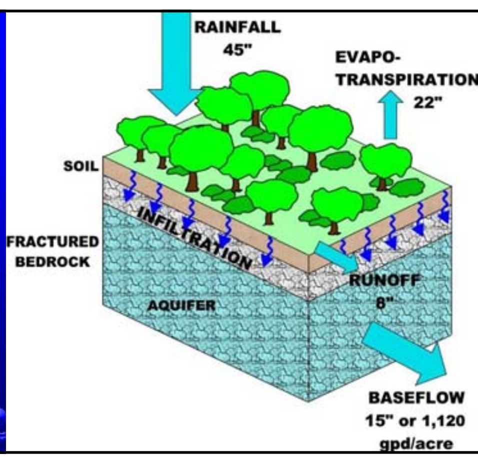
Only considered during the past thirty years

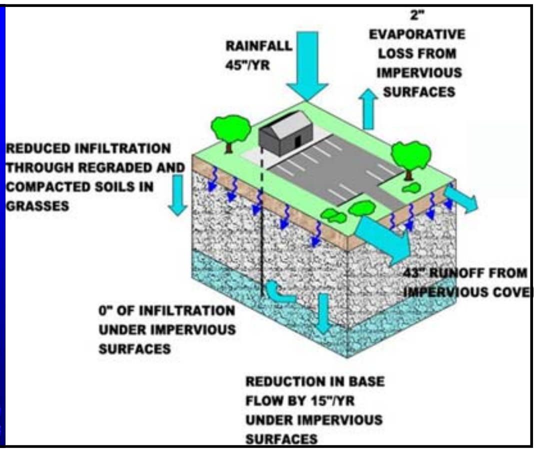
Land Development Alters the Hydrologic Cycle

- Reduces Infiltration
- Increases Direct Runoff
- Increases Pollutants

Hydrologic Cycle





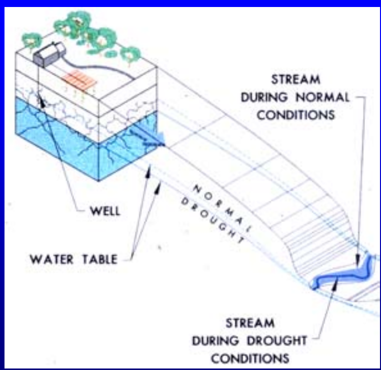


Surface runoff increases by 36" (3 ft) per year

INCREASED RUNOFF

- ET ADDED (PLANTS) – 21” TO 30”/YR
- INFILTRATION PREVENTED – 6” TO 15” /YR

Groundwater Discharge to Surface Streams



BASE FLOW

- Accounts for stream flow 11 months/yr.
- Comprises some 60% of total annual flow

NPS POLLUTION

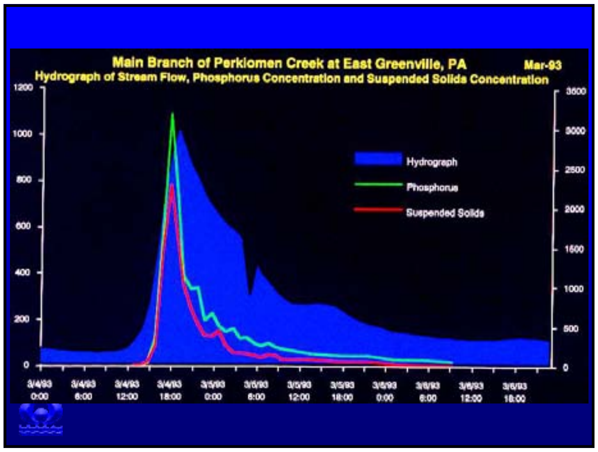
- Overwhelming mass transport during runoff in most watersheds – 25 days/yr
- NPS transport accumulates largely in lacustrine and estuarine systems
- Excessive enrichment is major impact

The Problem: Water Quality

Phosphorus
Nitrogen
Sediment
Hydrocarbons
Pathogenic bacteria
Metals/toxics

NON-POINT SOURCE POLLUTANTS

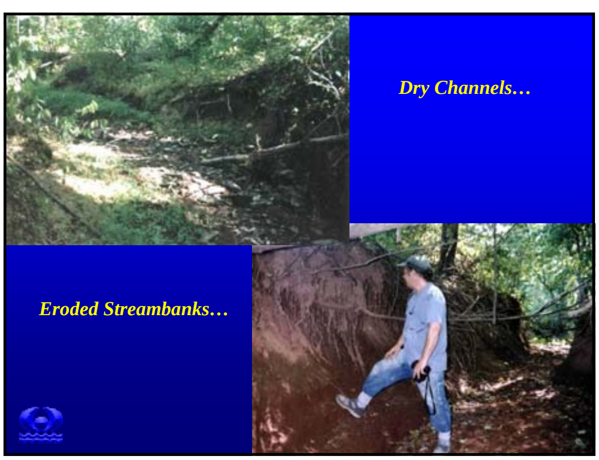
- Particulate associated – travel with sediment; phosphorus, metals, organic matter, debris (human) and detritus (plant matter)
- Solutes – dissolved in stormwater; nitrates, salts, herbicides and pesticides


Main Branch of Perkiomen Creek at East Greenville, PA
Mar-93
Hydrograph of Stream Flow, Phosphorus Concentration and Suspended Solids Concentration
Hydrograph
Phosphorus
Suspended Solids

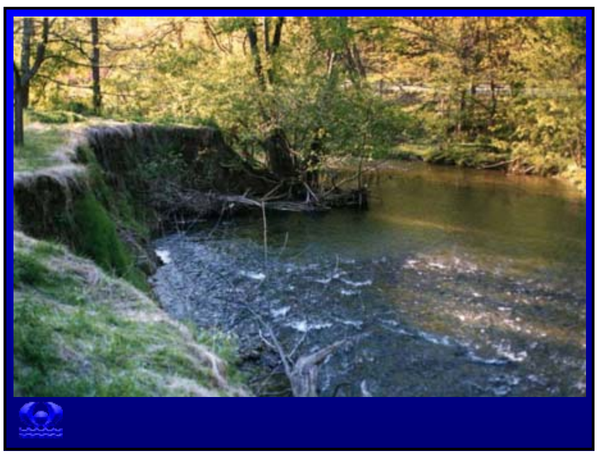

Water quality problems

Land Development Impacts on Stream Morphology:

- Channel widening, downcutting, scouring
- Stream bank erosion
- Imbedded stream substrate with benthic impacts
- Loss of pools, riffles




Bank scouring
MAY 21 2004




Unstable habitat

Effects of Urbanization on Watershed

- Flash Flooding and Streambank Erosion.
- Diminished Flow During Dry Periods.
- Degraded Water Quality.

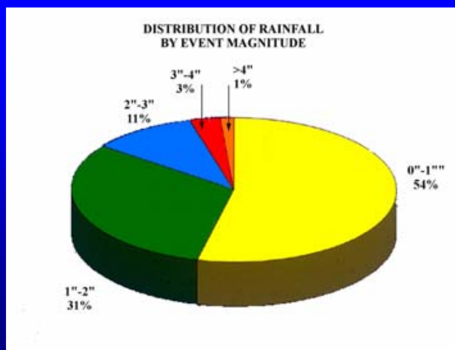
Flood and drought are opposite sides of the same coin

STORMWATER MANAGEMENT

- Water Quantity
- Water Quality
- Rate is minor issue

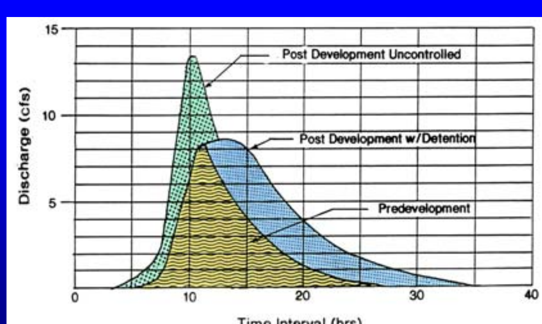
"Sustainable" Stormwater Management means Maintaining the Hydrologic Balance that Existed Before Development

- Infiltrating the Net Increase in Volume of Runoff for the 2-Year Storm Event.



Traditional Stormwater Management

- Control Peak Rate of Runoff after Development to Pre-Development Rate.
- Detention Basins
  - Temporary Storage
  - Sediment Control
- Does Not Address Increase in Volume of Runoff



Sustainable Site Design and Water Resources Management

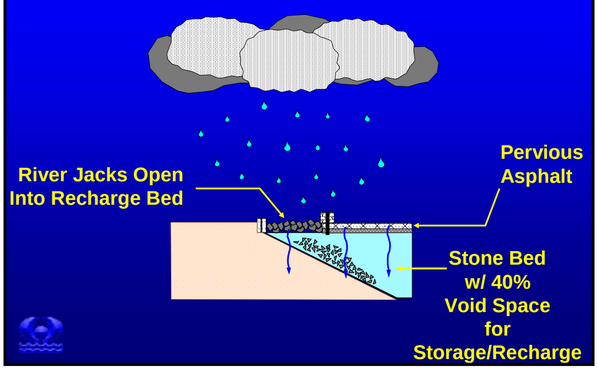
Specific design methods and materials

INFILTRATION BMPS

- Infiltration Beds Beneath Porous Pavement
- Infiltration Trenches, Drains
- Infiltration Swales w/ Vegetation
- Infiltration Berms (sloped areas)

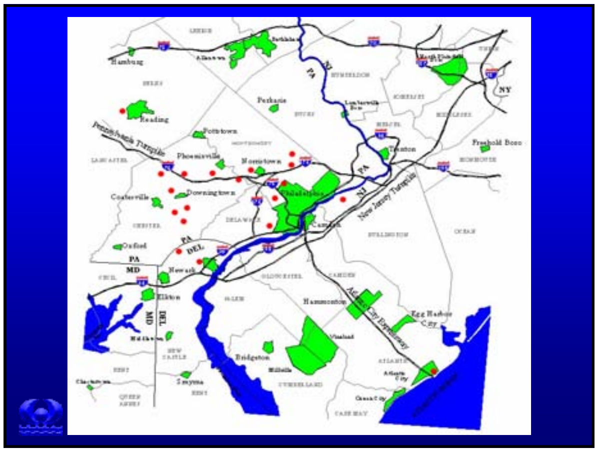
Porous Bituminous Pavement with Underground Recharge Beds

Porous Pavement with Recharge Bed



Porous bituminous pavement

- Developed by the Franklin Institute – 1972
- Tested in pilot projects during 1970's
- Development of geotextiles in 1979
- Current design since 1980
- CA has built over 150 projects since 1980
- Outstanding engineering project - 2000



Porous Pavement

- Over 30 installations at schools
- Oldest systems 1980-82
- Schools
  - Penn State University – State College & Reading (2)
  - University of Rhode Island – 1,000 cars
  - University of North Carolina (2) 1,500 cars
  - University of Michigan – 2 sites
  - Penn New School in Philadelphia - playground
  - St. Joseph's School in Downingtown, PA
  - Springside School in Philadelphia

Porous Pavement Commercial installations

- DuPont, Verizon, SmithKline, Siemen's
- National Park Service, Fish & Wildlife, National Forest Service
- Libraries, Religious Centers, Prisons
- Industrial – Ford and Alcoa
- Office Parks, Shopping Malls, Municipal Buildings

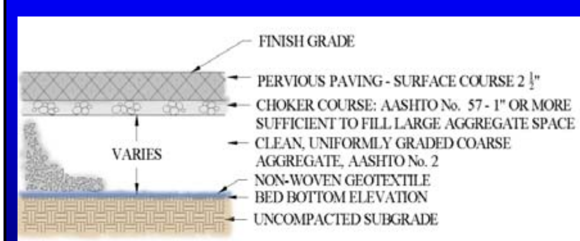
Porous Pavement

- ***What is it?***
  - Asphalt in which fine particles are kept to a minimum
- ***Why?***
  - This allows rainfall to drain through the pavement rather than running off
- ***Where does the rainfall go?***
  - A bed beneath the pavement receives rainfall from the pavement as well as inflow from other areas

Construction of Porous Pavement/Recharge Bed Systems

- Level, uncompacted subgrade
- Geotextile
- Clean, uniformly graded stone aggregate for 40% void space
- Porous bituminous asphalt
- Perimeter drains inlets

Porous or Standard Paving w/ Infiltration



Porous Asphalt Mix

US Standard Sieve Size	Percent Passing
1/2"	100
3/8"	95
#4	35
#8	15
#16	10
#30	2

- 5.75% to 6% Asphalt

Porous AC Pavement

- Fully permeable AC mix – 2.5" application
- Uniformly graded stone base reservoir- 30"
- Geotextile on bottom to stop soil
- Flat bottom to allow uniform infiltration

Median Pollutant Removal (%) of Stormwater Treatment Practices

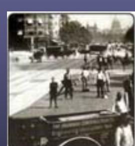
POLLUTANT	INFILTRATION PRACTICES	*Stormwater Wetlands*	*Stormwater Ponds Wet*	*Filtering Practices*	*Water Quality Swales*	*Stormwater Dry Ponds*
Total Phosphorus	70	49	51	59	34	19
Soluble Phosphorus	85	35	66	3	38	-6
Total Nitrogen	51	30	33	38	84	25
Nitrate	82	67	43	-14	31	4
Copper	N/A	40	57	49	51	26
Zinc	99	44	66	88	71	26
TSS	95	76	80	86	81	47

Water quality benefits of porous pavement with infiltration from "National Pollutant Removal Performance Database for Stormwater Treatment Practices" Center for Watershed Protection, June 2000

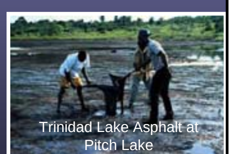
Asphalt Pavements
The Evolution

Early Asphalt Pavements

- First record Babylon around 625 B.C
- First asphalt pavements in US late 19th Century



Early Paving Pennsylvania Ave.



Trinidad Lake Asphalt at Pitch Lake

Bitulithic Pavements

- First successful, reproducible asphalt concrete surfaces
- Maximum aggregate size 75 mm graded down to dust
- F.J. Warren patent issued 1903 (Patent No. 757505)

Composite Bitulithic Pavement

HMA Pavements Today

- Dense graded
  - Coarse & Fine
- Open Graded (Porous)
  - OGFC – used as surface course
  - ATPB – used as drainage layer below pavement
- Stone Matrix Asphalt (SMA)

Open-Graded Mixes

- OGFC - normally used for surface to:
  - Reduce splash and spray
  - Improve skid resistance
  - Reduce hydroplaning
  - Noise reduction
- ATPB – used below pavement surface to:
  - Drain water below pavement to reduce chance of saturating unbound materials

OGFC

- Beginnings 1944 in California as Plant Mix Seal
- 1970's FHWA developed OGFC mix
  - AKA – plant mix seal, popcorn mix, asphalt concrete friction course
- Permeable European Mix (PEM)
  - Using polymers and fibers to increase asphalt content for durability

OGFC on Freeway

Water Normally Viewed as the Enemy of Pavements

- Engineers taught to keep water out.
  - Soils become weaker when saturated
- Compact soils to increase strength
  - Also reduces permeability
- Seal cracks and joints to keep water out
- Install subdrains to drain moisture away from subgrade

Changing Views

- Engineers need to know when and where porous pavements can be used.
- Pavement structure will be thicker for porous pavements
  - Structural requirements
  - Water storage requirements
  - Frost depth

Structural Design

- Needs to be evaluated
- Probably won't control total thickness
- Use standard design procedures such as AASHTO, Asphalt Institute or DOT.

Structural Design Inputs Example - Arizona

Layer	SN	Thick (in)	Layer	SN	Thick (in)
OGFC	0.40	6	AC	0.44	8
ATB	0.20	6	AB	0.14	7
Subbase	0.11	8			
	4.48			4.5	

Structural Design
Min Thicknesses

- Open Graded HMA – 2”
- Reservoir course – 9”

Evolution of Asphalt Binders

Pitch Lake—La Brea, Trinidad

Discovered by Sir Walter Raleigh in 1595 (or 409 years ago)

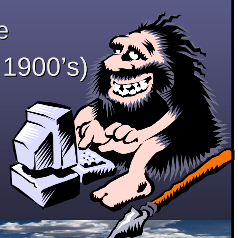
First use on streets in 1815 in Port of Spain, Trinidad and Tobago.

Asphalt Binders

- Asphalt refined from crude oil
  - California 1893
  - Texas 1902
  - Now dominant source of asphalt binder
- Some TLA used still for special applications

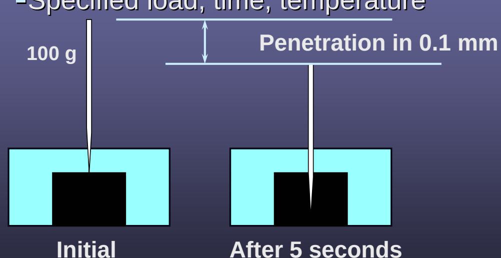
Early Specifications

- Lake Asphalts
  - Appearance
  - Solubility in carbon disulfide
- Petroleum asphalts (early 1900's)
  - Consistency
    - Chewing
    - Penetration machine
      - Measure consistency



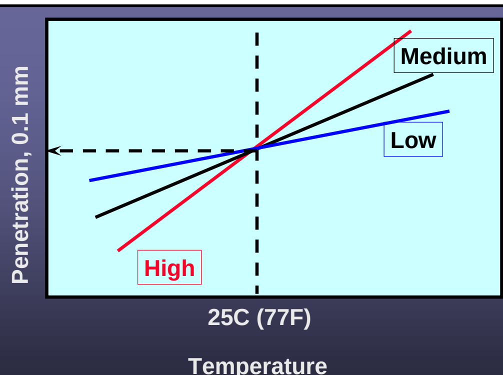
Penetration Testing

- Sewing machine needle
- Specified load, time, temperature



Penetration Specification

- Five Grades
  - 40 - 50
  - 60 - 70
  - 85 - 100
  - 120 - 150
  - 200 - 300



Advantages

- Grades asphalt near average in-service temp.
- Fast
- Can be used in field labs
- Low capital costs
- Precision well established
- Temp. susceptibility can be determined

Disadvantages

- Empirical test
- Shear rate
  - High
  - Variable
- Mixing and compaction temp. information not available
- Similar penetrations at 25°C (77°F) do not reflect wide differences in asphalts

Viscosity Graded Asphalts

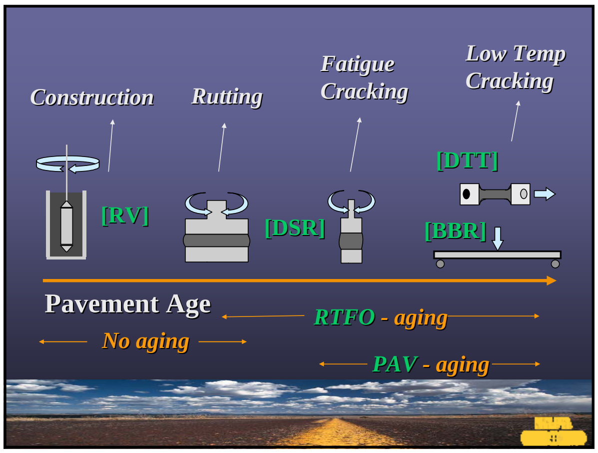
- Fundamental property
- Wide range of temperatures
- Based on max. pavement surface temp.
- Test method precision established
- Temperature susceptibility is controlled
- Limits aging
- Information on mixing & compaction temps.

Disadvantages (Viscosity Grading)

- More expensive
- Longer testing time
- More technician skill needed
- Not applicable for Non-Newtonian materials
- Wide range of properties for same grade`

New Binder Specification
Superpave – Performance Graded (PG)

- Fundamental properties related to pavement performance
- Environmental factors
- In-service & construction temperatures
- Short and long term aging



Superpave Asphalt Binder Specification

- Grading System Based on Climate

PG 58-22

Performance Grade | **Average 7-day max pavement design temp** | **Min pavement design temp**

PG Binders

- Now used in most state
- Most states have developed three grades that are used in state.
  - Standard grade i.e. PG 64-22
  - One grade bump i.e. PG 70-22
  - Two grade bump i.e. PG 76-22
- Southeastern states standard grade PG 67-22
  - Similar to old AC 30 grade
- California uses AR and PB grades

Which binder is right for Porous Asphalt Pavements?

- Recommend one or two grade bumps from standard grade
- Example:
  - Standard Grade PG 64-22
  - One grade bump PG 70-22
  - Two grade bump PG 76-22

Polymer Modifiers

- Reasons for use of polymer modifiers
  - Increased demand on HMA pavements (ESALs)
  - Superpave specifications may require a wider range of binder performance.
  - Disposal of waste products
    - Tires, plastic, etc.
  - Willingness to pay more up front for long term benefit
  - Reduce draindown

Polymer Modifiers

- Types of Polymer Modifiers
  - Elastomers
    - Offer stiffness, but also flexibility
    - SBS, SBR, SB, Crumb Rubber, etc.
  - Plastomers
    - Offer high stiffness, but have reduced flexibility
    - LDPE, EVA, Polyolefins, etc.

Polymer Modifiers

- *"Possible"* improvements offered by polymer modifiers
  - Stiffer mixes at high temperatures
  - Softer mixes at low temperature
  - Improved fatigue resistance
  - Reduced life cycle costs

Is a PG a Modified Binder ?

Effect of Loading Rate

Reliability

"Rule of 90 or 92"

PG 64 - 34 > 64 - - 34 = 98

Probably modified !!

(Depends on Asphalt Source!)

Rounding

Effect of Traffic

Morris Arboretum
Philadelphia, PA

1984

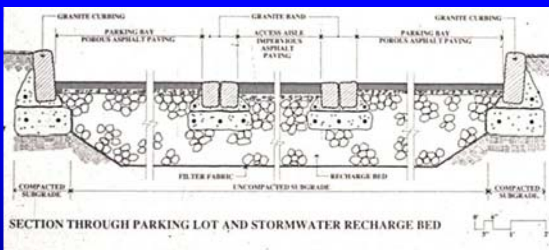
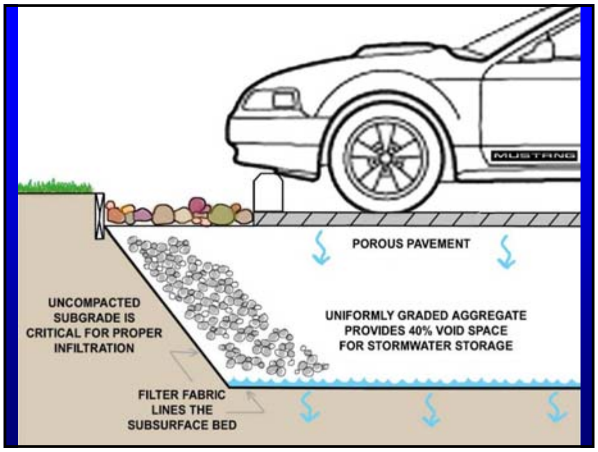


Diagram of infiltration bed at Morris Arboretum

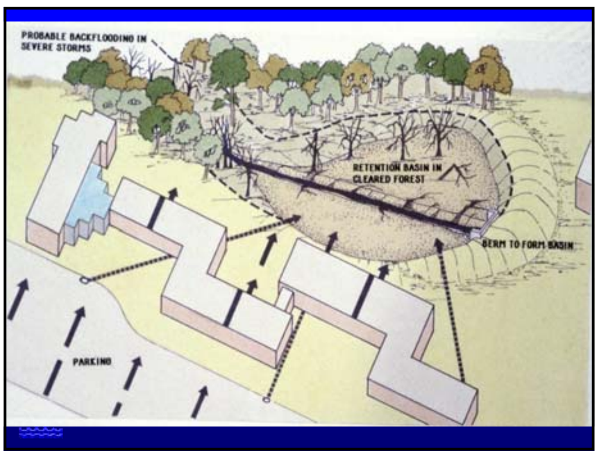
Shared Medical Systems
Malvern, PA

1982

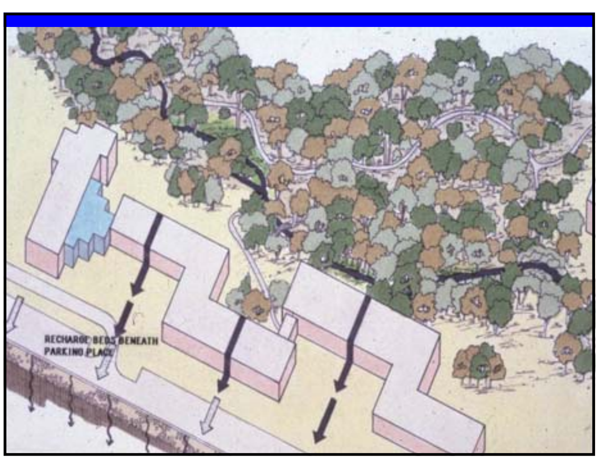


DuPont Barley Mills Office Complex

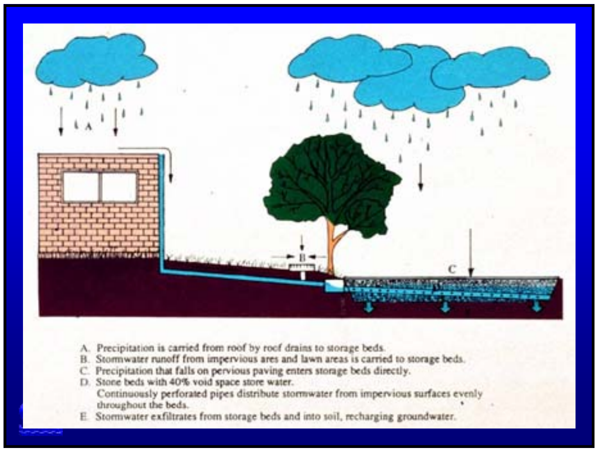
- Preserve Woodlands
- Porous Pavement w/ Groundwater Recharge
- Reduce Site Disturbance



PROBABLE BACKFLOODING IN SEVERE STORMS
RETENTION BASIN IN CLEARED FOREST
BERM TO FORM BASIN
PARKING



RECHARGE BEDS BENEATH PARKING PLACE


A
B
C
A. Precipitation is carried from roof by roof drains to storage beds.
B. Stormwater runoff from impervious ares and lawn areas is carried to storage beds.
C. Precipitation that falls on pervious paving enters storage beds directly.
D. Stone beds with 40% void space store water.
Continuously perforated pipes distribute stormwater from impervious surfaces evenly throughout the beds.
E. Stormwater exfiltrates from storage beds and into soil, recharging groundwater.

University of North Carolina-Chapel Hill

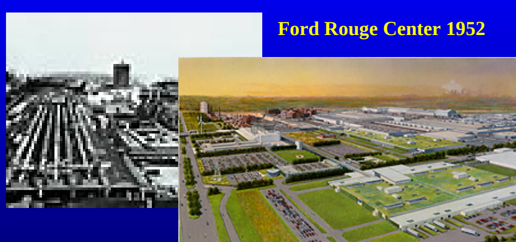
Friday Center

Estes Drive


Standard Pavement
Porous Pavement

Ford Rouge Center
Dearborn, Michigan

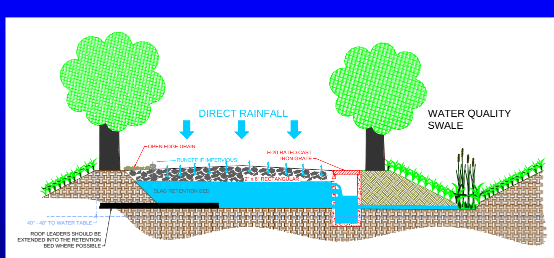
Ford Rouge Center 1952



Artist Richard Rochon's rendering of an aerial view of the Ford Rouge Center that includes the new Ford assembly plant.

Ford Motor Company

Strategy for Water Quality

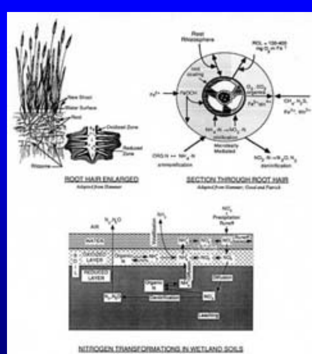


Ford Motor Company


Ford Motor Company


Ford Motor Company

Vegetated Swale Pollutant Removal Efficiency



Ford Motor Company

Benefits of Porous Pavement

- **Economic**
  - Reduces/Eliminates the land space consumed by conventional detention facilities
  - Reduces the need for curbs, gutters, inlets, and storm sewers
  - Helps prevent excessive flooding
- **Aesthetic**
  - Eliminates the need for unsightly detention basins, rip-rap channels, etc.
  - Preserves areas such as woods or open space that would have been destroyed for detention basins
  - Eliminates puddling and flooding on parking lots

Ford Motor Company

Environmental Benefits of Porous Pavement

- Reduces the amount of impervious surface on a site
- Reduces the discharge of pollutants and improves water quality
- Storage Bed limits the peak discharge and reduces stress on existing conventional sewers

Ford Motor Company

NPS Pollutant Removal Efficiency (% EPA 1993)

	TP	TN	Pb	Zn
•Infiltration Swale	65	60	65	65
•Grass Swale	20	10	70	60
•Porous Pavement	65	85	100	100
•Ex Det. Pond	25	30	40	40
•Wet Pond	45	35	75	60
•Wetlands	25	20	65	35

Ford Motor Company

Ford Rouge Center

Ford Motor Company

Industrial Stormwater Quality Management

- Use native species And limit future chemical site maintenance.
- Limit artificial areas such as maintained lawns.
- Avoid discharges of wastewater to streams & lakes.
- Avoid excessive earthwork which creates erosion & sediment problems.
- Maintain native vegetation.
- Use low maintenance, water quality BMPs.

Ford Motor Company

Commercial: WalMart Aurora

- Porous Parking
  - Asphalt
  - Concrete
- Recycled Rubber Walkways
- Bioswales
- Native Prairie Restoration
- Use of Recycled Materials
  - Fly Ash, Concrete, Recycled Asphalt

First use of RAP in Porous Asphalt – 5% & 10%

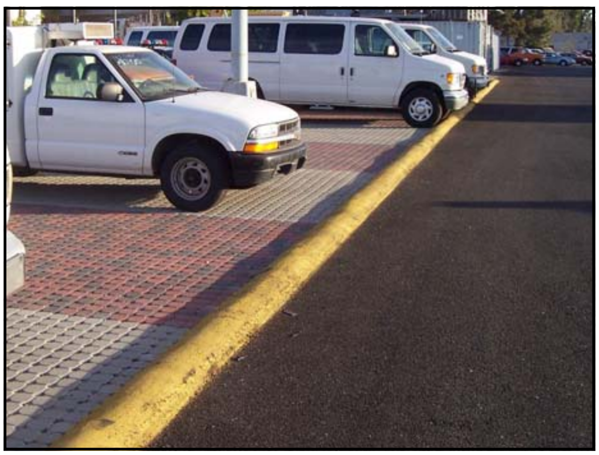
Bioswales (just planted)

Stormwater Details

San Diego County Porous Pavement Demonstration

- Porous Asphalt, Porous Concrete, Pavers
- Existing paved site – 50 years old
- Soil mantle disturbed, cut 3 feet, compacted
- Water quality and quantity monitored


#2 - STORMWATER POROUS PAVEMENT
WORK AREA at COC (approx. 65,000 s.f.)
N
Pavers
11,160 s.f.
Pervious Concrete
27,006 s.f.
Porous Asphalt
26,932 s.f.
7
11
M12A



West Hollywood Site Considerations

- Average seasonal rainfall = 14.5”
- Urban setting
- Retrofit
- CALTRANS specification w/CA mod.


CITY OF WEST HOLLYWOOD
SPAULDING AVENUE
PARKING LOT
INFILTRATION BED UNDER
POROUS PAVEMENT
PARKING LOT

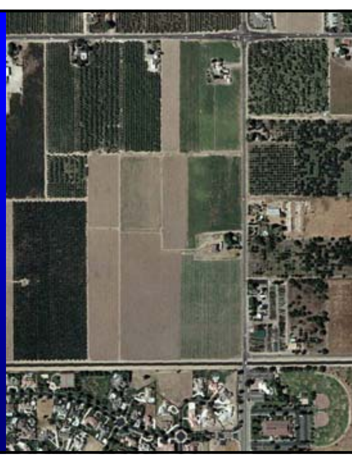

West Hollywood – Existing Site


West Hollywood – Under
Construction

West Hollywood – Pervious Asphalt

Kaiser-Permanente Hospital

- 50-acre parcel on the outskirts of Modesto, CA
- 10 acres of porous AC pavement built
- Total recharge of annual rainfall for the site

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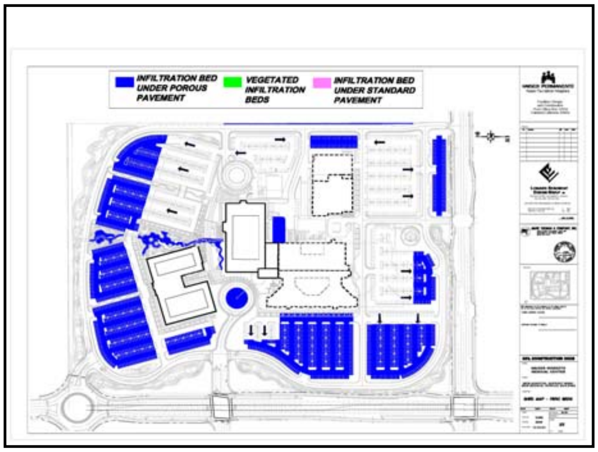

INFILTRATION BED UNDER POROUS PAVEMENT
VEGETATED INFILTRATION BEDS
INFILTRATION BED UNDER STANDARD PAVEMENT

University of Rhode Island

750 space parking lot
Designed with BETA Engineers


21. 10. 2002


21. 10. 2002


Swarthmore College

Penn New School Philadelphia K-8

- Soccer Field underlain by Infiltration Bed
- Porous Asphalt Playfield
- Rain Gardens fed by Roof Leaders
- Urban setting – 43rd and Locust

University of Pennsylvania-Alexander School, Philadelphia, PA

LOS ANGELES,CA

VERY ARID CLIMATE

ANNUAL RAINFALL

- 15” PER YEAR
- 4” DIRECT RUNOFF FROM NATURAL
- 7” ET
- 4” RECHARGE

West Hollywood – Existing Site

West Hollywood – Existing Site

West Hollywood Site Considerations

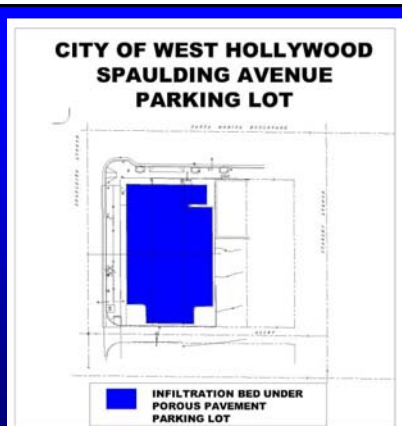
- Average seasonal rainfall = 14.5”
- Urban setting
- Retrofit
- CALTRANS specification w/CA mod.

Surface runoff increases by 11” (0.92 ft) per year

298,000 GALLONS/ACRE

INCREASED RUNOFF

- ET ADDED (PLANTS) – 7”/YR
- INFILTRATION PREVENTED – 4”/YR



General Rules for Soils Testing for Infiltration BMPs

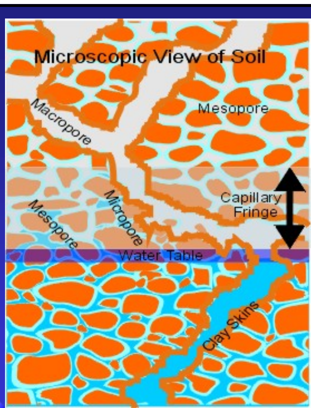
Purpose of Infiltration Testing

- Determine Suitability for Infiltration BMPs
- Determine Rate of Infiltration
- Design appropriate BMP
- Using Soil for Stormwater Management

How Does Water Move through Soil?

Soil is composed of solid particles of different sizes (minerals and organic matter) often "glued" together into tiny aggregates by organic matter, mineral oxides and charged clay particles. The gaps between the particles link together into a meandering network of pores of various sizes. Through this pore space the soil exchanges water and air with the environment. The movement of air and water also allows for heat and nutrients to flow.

Saskatchewan Centre for Soil Research



Soil Macropores

> 0.1 mm in diameter

Formation of Soil Macropores

- Root Systems (living and decaying)
- Water Movement
- Large and small organisms
- Freeze-thaw cycle
- Soil shrinkage (dessication of clays)
- Weathering processes

Characteristics of Soil Macropores

- Provide primary mechanism for air and water movement
- Decrease with depth
- Destroyed by compaction, soil disturbance, loss of organic material
- Convey water under saturated conditions

The conductivity of soil macropores (pores > 0.1 mm in diameter) can be as much as ten times the conductivity of the soil matrix.

Soil Tests

- Lab tests to determine hydraulic conductivity based on grain size, shape, and porosity based on a homogeneous sample will not represent field conditions.
- Darcy's Law may not represent movement through macropores.
- Tests need to be conducted in the field.

Engineering analysis of soils

- Analyzed soil as a structural material
- Bearing capacity, consolidation, etc.
- Little understanding of biological and chemical processes
- Compaction of soil considered essential

Wastewater analysis of soils

- Design of a stone/sand bed that allows both aerobic decomposition and infiltration
- Shallow bed to provide oxygen transfer
- Daily loading of wastewater

Deep Hole and Percolation Tests

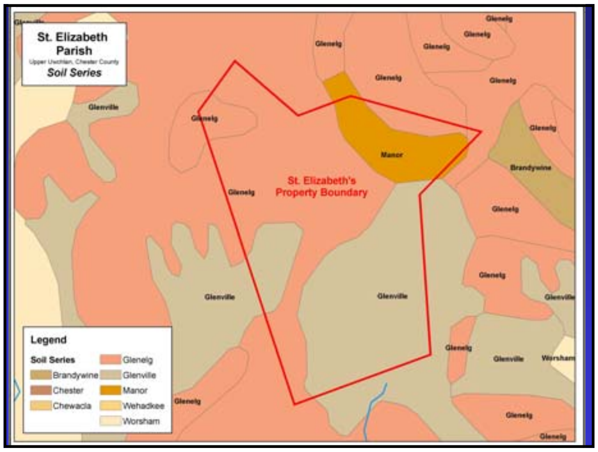
Soil Testing Recommended Approach

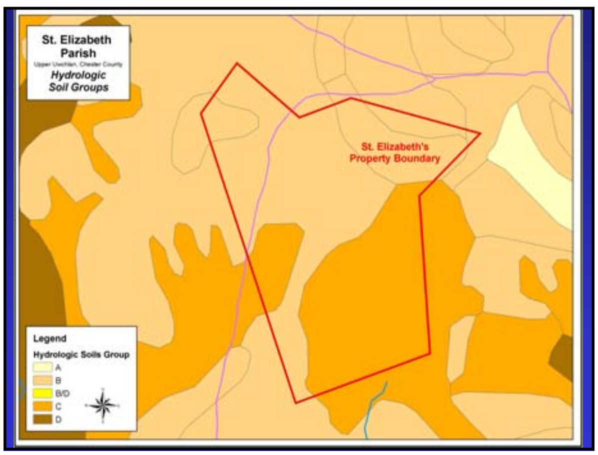
Desktop Evaluation
- Site Conditions
- Potential BMP locations

- Deep Hole observation
  - Multiple Testing Locations
- Infiltration Tests
  - Percolation tests
  - Infiltrometer
- Design Considerations
  - Safety factor

Desktop Evaluation

- Underlying Geology
- Soils
- Hydrologic Soil Group
- Topography and Drainage Patterns
- Streams, Wetlands, Wells,
- Land Use
  - Currently in Ag?
  - History of fill/disturbance?





Know Your Soils

- Select the right locations for Testing
  - Low, Wet areas will not drain
- Multiple Testing Locations
- Importance of Deep Hole for Visual Inspection
- Evaluate Soils – Percolation Tests
  - Test near bottom of proposed bed

Deep Hole Tests

- 72” to 90” Deep
- 2-1/2’ to 3’ Wide
- Physically Observe Conditions

Excavation of deep hole by backhoe

What is your telephone number with the area code first?
Your name?
If you have not called in before, you will be asked for company information.
Who is the contact person at the dig site?   Their phone number?
What is the best time to call the contact person?
In what county will the work be done?
In what city, twp or borough will the work be done?
In Erie, Pgh, Allentown or Phila, What is the ward #.
What is the starting address number?
What is the ending address number?
What is the street name for the work site?
What is the nearest intersecting street name?
Do you have any other site-specific location information?
Will the proposed dig site be marked in white?
If a state road, do you have a PennDOT permit number?
Latitude ?
Longitude ?
What type of work will be done?
Approximately how deep will you be digging?
What type of equipment will be used?
What are the dimensions (width, length, diameter)?
Will the work take place in the street? Will the work take place on the sidewalk? Will the work take place on public property? Will the work take place on private property? Where on private property? (use drop down box)
Private prop owner or company name working for?
Work date? (utilities need 3 working days notice) *
What is the time you will begin the work?
Is there anything else you would like to add?

Deep Hole Observations

- Soil Horizons
- Soil Texture and Color
- Pores, Roots
- Type and Percent Coarse Fragments
- Depth to Water Table
- Depth to Bedrock
- Hardpan or Limiting Layers

Number and Location of Deep Hole Tests

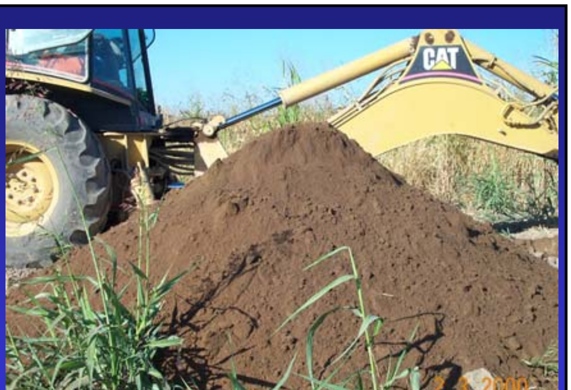
- Single family – 1 test at BMP location
- Larger Systems- 4 to 6 tests per acre
- Additional Tests based on changes in variability in soils, topography, geology, land use, etc.

Better to do many test holes

Test Multiple Locations


Visual Inspection Important!

Hardpan Layer



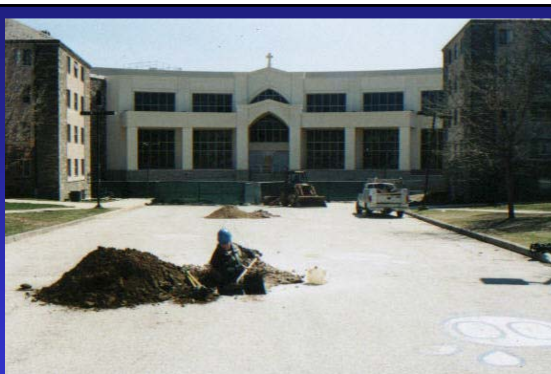
Depth of Hardpan Varies

Deep Hole Observation Affects Design

- Depth of Hardpan Varies
- Layer is Shallow –
  - Excavate
  - Place Beds Beneath
- Hardpan is Deep
  - Place Bed Bottom 2’ above Hardpan
  - “Punch Through” with Borings

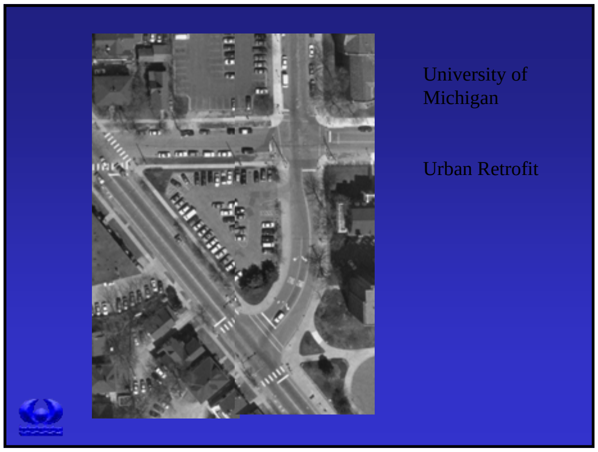
Testing Previously Disturbed Areas

- Historic fill
- Surface compaction
- Deep Hole Observation even more important




Urban Retrofit – Villanova Plaza


Safety Issues


University of Michigan
Urban Retrofit


1. 5. 2003


1. 5. 2003

How Well Does the Site Infiltrate?

- Percolation Test
- Double Ring Infiltrometer
  - ASTM D 3385-03
  - ASTM D 5093-90
- Hydraulic Conductivity – Lab Test
- Amoozemeter
- Constant Head

Limits of Budget and Time

Not an Exact Science!

Number and Location of Infiltration Tests

- Minimum 2 per Deep Hole
- At least one test at bed bottom
- Test different horizons
- Methodology- Pa Code Chapter 73

Percolation Tests

- 6” to 10” diameter
- 12” depth
- Scarify sides and bottom
- Minimum of 8 readings or stabilized rate for 4 consecutive readings

Recommendation

- Supplement Perc Tests with Infiltrometer Tests
- Compare variations
- 10% of tests with infiltrometer

Turf-Tec Infiltrometer at shallow bench and percolation hole at deeper bench

Turf-Tec Infiltrometer – example of double ring infiltrometer

Recommended Approach

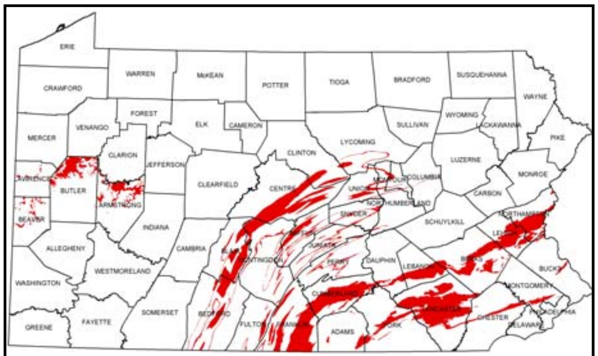
- Desktop Evaluation
- Deep Hole observation
- Infiltration Tests
- Design Considerations
  - Observed Infiltration Rate for Site Suitability
  - Safety Factor for Design: 2

What Not to Do

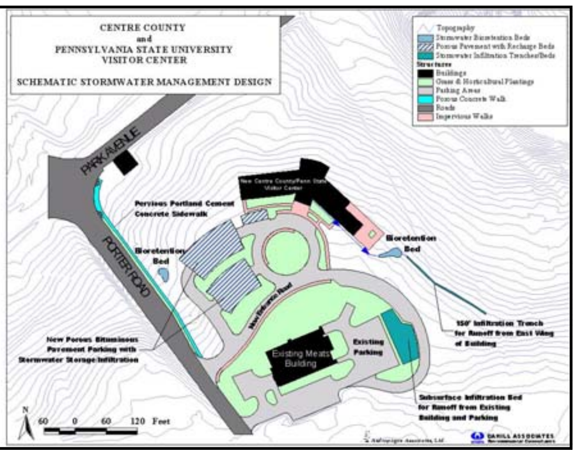
- Test the Wettest Areas
- Do only 1 or 2 tests for a large area
- Try to Perc Bore Holes (30' Deep)
- Excessive Grading and disturbance
- Claim that the Site Does Not Infiltrate

Limestone Considerations

- Geotechnical Investigation
  - Depth to rock
  - Pinnacles
  - Sinkhole potential
- Design Considerations
  - Spread It Out! 3:1
  - Avoid concentrating/conveying/deep excavation

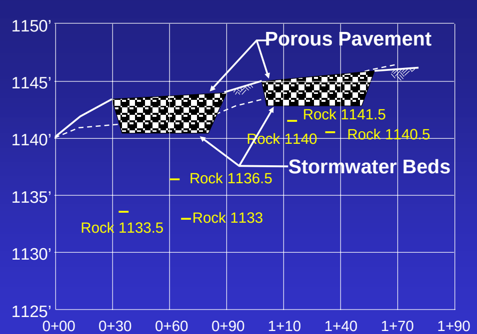


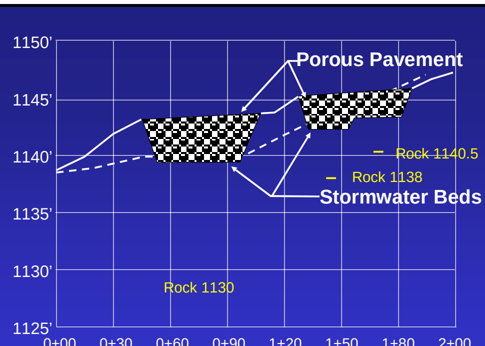
Areas of Carbonate Lithology



Geotechnical and Soils Testing

- Shallow Borings
  - 15 feet deep
  - 25 feet OC
  - Test Infiltration Areas
- Soils Tests
  - Deep Holes
  - Perc Tests





Construction Criteria

- Protect soils - Do not compact!
- Protect infiltration BMPs from sediment until drainage area is completely stabilized
- Sequencing
- Staging/stockpiling
- Use clean aggregate
- Establish/protect dense vegetation

Protect Integrity of Soils

Options

1. "Septic System" Approach? Fence off ?
2. Build and Protect?
3. Construct at end of Job
   - Use as Temporary E & S
   - Final Grading at end of Job
   - Site is stabilized

Common Bulk Density Measurements

Undisturbed Lands Forests & Woodlands 1.03g/cc	Residential Neighborhoods 1.69 to 1.97g/cc
Golf Courses - Parks Athletic Fields 1.69 to 1.97g/cc	CONCRETE 2.2g/cc

David B. Friedman, District Director *Ocean County Soil Conservation District*

Designing Infiltration Systems

Site Criteria

- Soil Permeability greater than 0.25 in./hr
- Minimum Bedrock Separation of 2 feet
- Infiltration device at least 3 feet above seasonally high water table

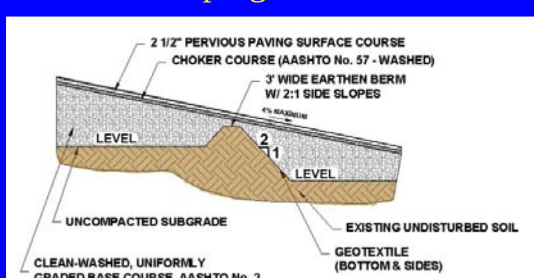
Design Criteria

- Spread It Out!
- 5:1 Impervious to Recharge Area
- Minimize excavation / maximize soil buffer
- Pre-treatment for “hot-spots”
- Construction oversight!!
- Level Bed Bottoms
- Keep it Clean – E&S Control

Construction Criteria

- Protect infiltration BMPs from sediment until drainage area is completely stabilized
- Do not compact soil under infiltration areas
- Protect infiltration BMPs from sediment
- Do not compact soil

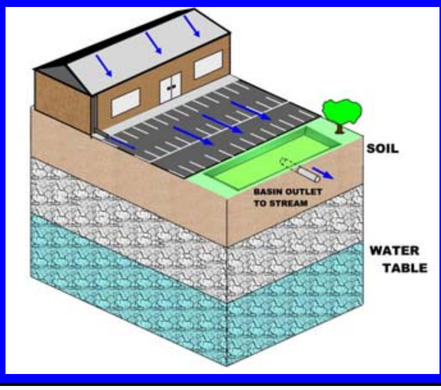
Level Infiltration Beds with Sloping Surface



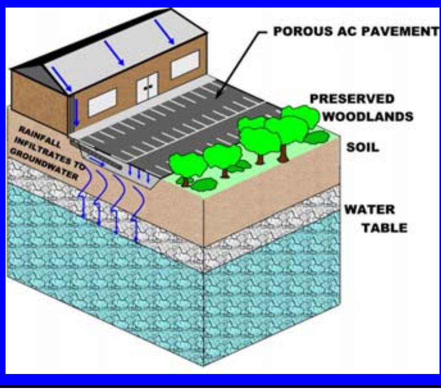
Hydrologic Calculations

- Net increase in Volume for 2-year storm
- Mitigate Peak Rate for larger storms

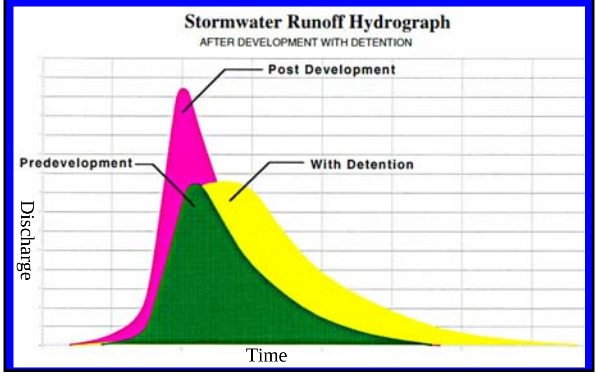
Hypothetic Site Design w/ Detention Basin



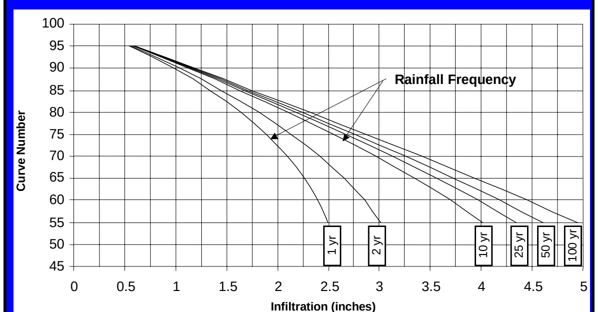
Hypothetic Site Design w/ Infiltration Bed



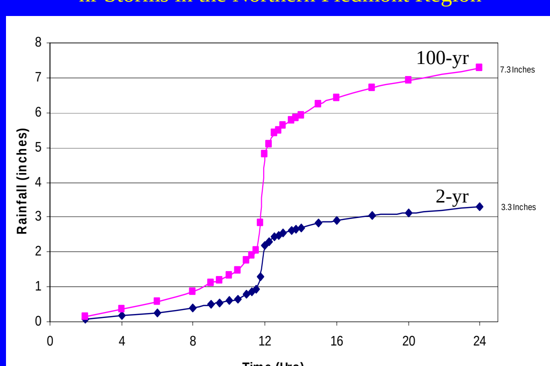
Effect of Detention: Peak Rate may be Controlled but Volume Increase is Not Mitigated



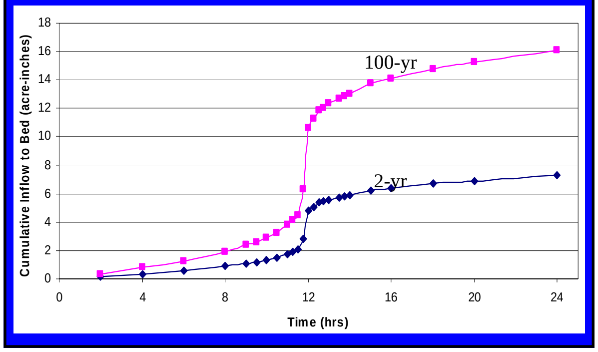
“Lost” Infiltration as Curve Number Increases



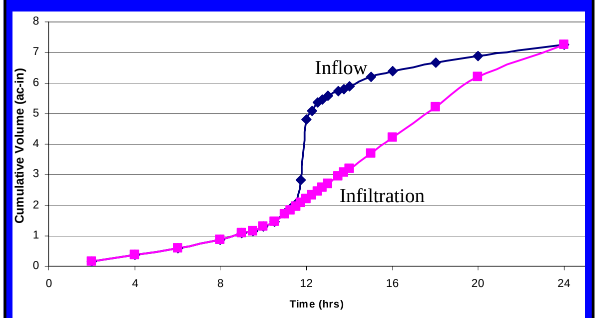
SCS Type II Rainfall Distribution for the 2 and 100-yr, 24-hr Storms in the Northern Piedmont Region



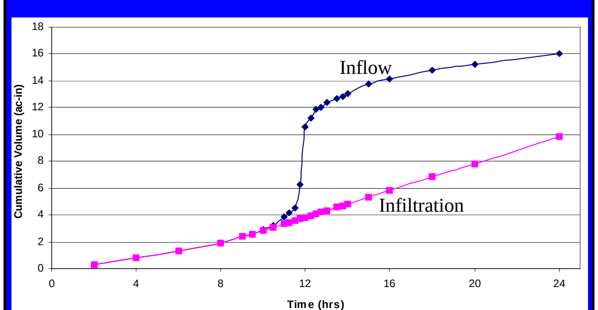
Rainfall Inflow to Recharge Bed over 24-hour Period

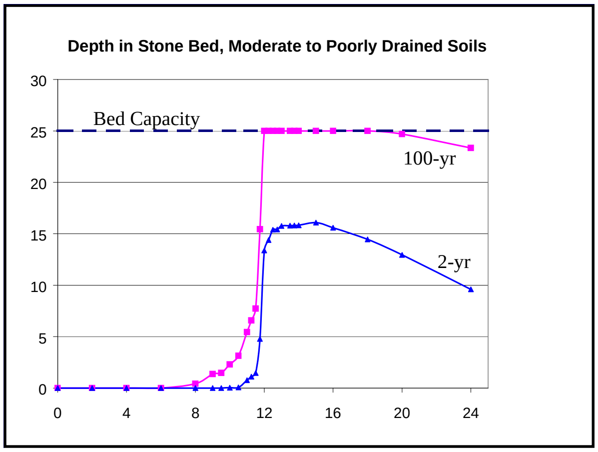


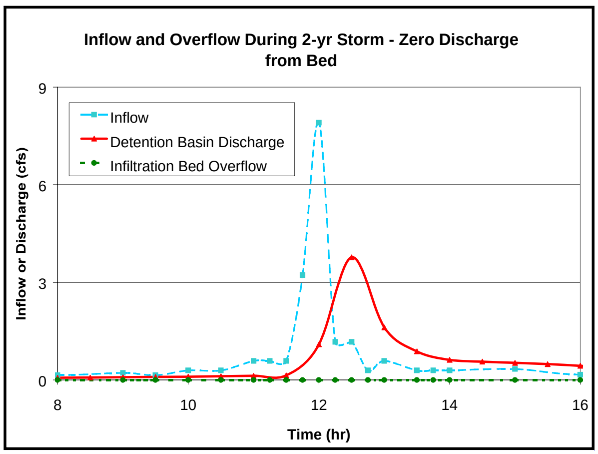
Cumulative Inflow and Bed Infiltration – 2 yr Storm w/ Moderate to Poorly Drained Soils

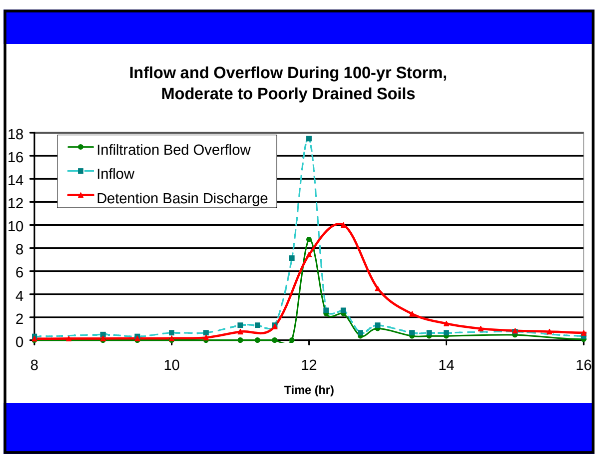


Cumulative Inflow and Bed Infiltration – 100 yr Storm w/ Moderate to Poorly Drained Soils

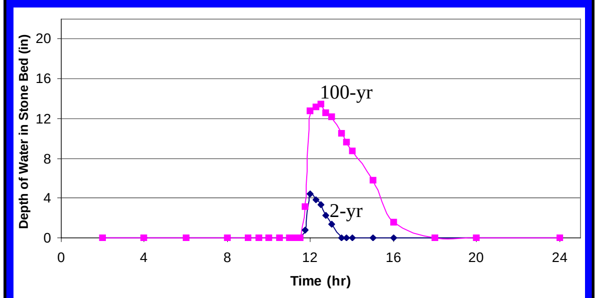



Depth in Stone Bed, Moderate to Poorly Drained Soils
Bed Capacity
100-yr
2-yr
30
25
20
15
10
5
0
0
4
8
12
16
20
24

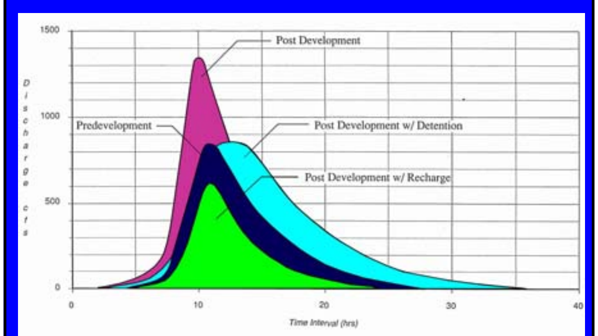

Inflow and Overflow During 2-yr Storm - Zero Discharge from Bed
Inflow
Detention Basin Discharge
Infiltration Bed Overflow
Inflow or Discharge (cfs)
9
6
3
0
8
10
12
14
16
Time (hr)


Inflow and Overflow During 100-yr Storm, Moderate to Poorly Drained Soils
Infiltration Bed Overflow
Inflow
Detention Basin Discharge
18
16
14
12
10
8
6
4
2
0
8
10
12
14
16
Time (hr)

Storage Depth in the Stone Bed Assuming a 40% Void Space – Well Drained Soils



Comparison of Detention vs. Infiltration Design Systems



POROUS AC PAVEMENT IN PORTLAND

PORT OF PORTLAND

PIER 6

AUTO STORAGE YARD

Existing pavement is both impervious AC and gravel

Goal is to apply pervious AC pavement in gravel areas

40 acre tract

Soil is dredge material from river bed – sandy soil

Original sub-soil is sediment deposits of ancient flood plain

Columbia River Valley

Gravel surface varies 4” to 8” periodically regraded

Significant surface puddles

Distributed over tract

Porous pavement design begins by understanding and measuring the sub-surface soil conditions

Porous pavement is the icing on the cake of a stormwater infiltration system

Modeling Infiltration BMPs

CAHILL ASSOCIATES
Environmental Consultants
West Chester, PA
(610) 696 - 4150
www.thcahill.com

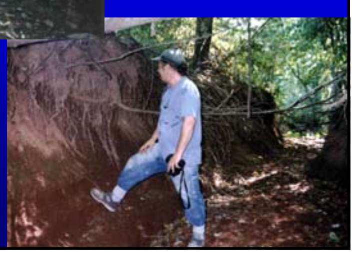
Design Goals for Calculations

1. Mitigate Peak Rates 2-Year to 100-Year
2. No Volume Increase for 2-Year Event
3. Maintain Groundwater Infiltration

Provide Calculations for Municipal Approval

Dry Channels…

Eroded Streambanks…



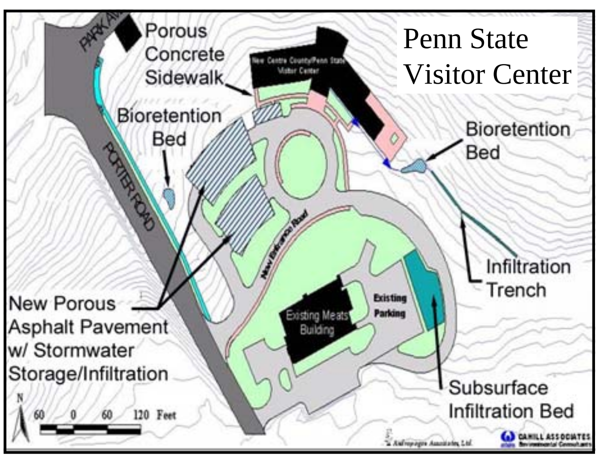
Bankfull Flow Forms and Maintains Channel

- Recurrence Interval 1.5 Years
- Higher Flows Exceed Channel Capacity
- More Frequent Bankfull more important than large floods in shaping channel.

The Channel is shaped by the Bankfull Flow

Three (Real Life) Case Studies

1. Institutional LID – Penn State Visitor Center
2. Commercial – Small Retail Shopping Center
3. Residential – High Density Townhouse, Quad, and Singles



Proposed Development 1: Penn State Visitor Center

- 4.5 Acre Site
- 1.4 acres Impervious (31%)
  - 15,500 Square Foot Building
  - 2,100 Square Feet Paths
  - 44,250 Square Feet Parking, Roads

28% for People, 72% for Cars!

Penn State Case Study

- Existing (CN = 74):
  - 4.55-acre meadow on HSG "C" soils
  - SCS Lag Time of 18 minutes
- Proposed (CN = 81):
  - Commercial Site
    - 1.1-acres pavement & building
    - 3.1-acres lawn
    - 0.32-acres porous parking (CN 98 used for calcs)
  - SCS Lag Time of 12 minutes

Note: No "adjustment" in CN or Lag for LID design!

2-Year Volume Increase

Design Storm	Rainfall	Existing Runoff*	Future Runoff	Net Increase in Runoff Volume	
	(in)	(in)	(in)	(in)	(ft^3)**
1-Year	2.2	0.45	0.73	0.29	4,748
2-Year	2.6	0.67	1.01	0.35	**5,765**
5-Year	3/1	0.97	1.39	0.35	6,913
10-Year	3.6	1.31	1.79	0.48	7,936
25-Year	4.2	1.74	2.29	0.55	9,019
50-Year	4.7	2.13	2.72	0.59	9,818
100-Year	5.3	2.61	3.25	0.65	10,671

*Based on $Q=\frac{(P-0.2S)2}{(P+0.8S)}$ S=100/CN-10 **Based on 4.55 acres*

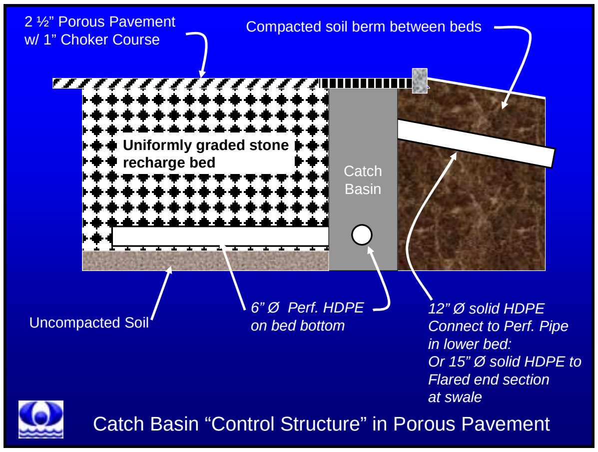
Storage Available

	Volume of Stone Below Invert	Storage Volume *	Bottom Area (min)
	(ft^3)	(ft^3)	(ft^2)
Upper Parking Bay	4,955	1,982	3,750
Lower Parking Bay	11,374	4,550	5,225
Bioretention		0	1500
Infiltration Trench	1,420	0	450
Porous Sidewalk		0	1,500
TOTAL:	**17,749**	**6,532**	**12,425**
* Based on 40% void space in stone bed			
Infiltration Bed	3,255	1,302	2,025

Design "Rules of Thumb"

- Retain 2-Year Net Increase in Volume
  - Net Increase: 5,765 CF
  - Available Storage before Overflow: 6,532 CF
- Infiltrate at a Maximum 5:1 Ratio Impervious:Infiltration Area
  - Impervious Area: 61,000 SF
  - Infiltration Area: 12, 425 SF

Ratio 5:1



For the purposes of routing, the two Storage/Infiltration Beds beneath the Porous Parking have been combined into one basin. The storage of the infiltration trench is not included.

Elev (ft)	Volume (ft3)	Infiltration Discharge (cfs)	Overflow Discharge (cfs)	Combined Discharge (cfs)
0.1	417	0.57	0.00	0.57
1.25	6108	0.57	4.20	4.77
2.25	7834	0.57	7.25	7.82
3	15000	0.57	7.25	7.82

Infiltration Discharge is calculated assuming a conservative soil infiltration rate of 2 inches per hour over the entire bed bottom. Measured infiltration is in excess of 12 in/hr.

Infil. Q = Bottom Area x 2 in/hr
12,425 SF x 2in/hr = 0.57 cfs

Time hr	Q After (Uncontrolled) (cfs)	Infiltration Rate (cfs)	Volume into Beds CF	Volume Infiltrated CF	Total Storage Volume CF
11	0.42				
11.3	0.58	0.57	624	616	8.6
11.6	0.83	0.57	899	616	291.9
11.9	1.78	0.57	1,923	616	1598.8
12	3.26	0.57	1,174	205	2567.1
12.1	6.27	0.57	2,255	205	4617.4
12.2	10.82	0.57	3,895	205	8307.3
12.3	**13.69**	0.57	4,927	205	10437.2
12.4	13.27	0.57	4,777	205	12410.0
12.5	9.96	0.57	3,587	205	13192.7
12.6	6.89	0.57	2,480	205	12868.5
12.7	4.99	0.57	1,798	205	11861.9
12.8	3.77	0.57	1,357	205	10414.1

100-Year Storm Peak Period

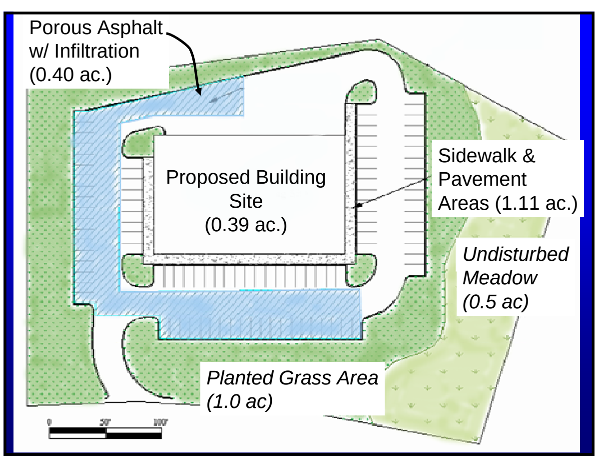
Summary Result
100 Year Peak Rate

- Before Q_p = 9.8 cfs
- After Q_p = 13.7 cfs
- With BMPs Q_p = 7.2 cfs

Proposed Development 2: Commercial Shopping Center

- 3.0 Acre Site
- 1.5 acres Impervious (50%)
  - 17,000 Square Foot Building
  - 48,340 Square Feet Parking, Roads

26% for People, 74% for Cars!



Case Study

- Existing (CN = 58):
  - 3.0-acre meadow on HSG “B” soils
  - SCS Lag Time of 12 minutes
- Proposed (CN = 79):
  - Commercial Site
    - 1.5-acres pavement & building
    - 1-acre lawn
    - 0.5-acre undisturbed meadow
  - SCS Lag Time of 6 minutes

Design/Calculation Approach

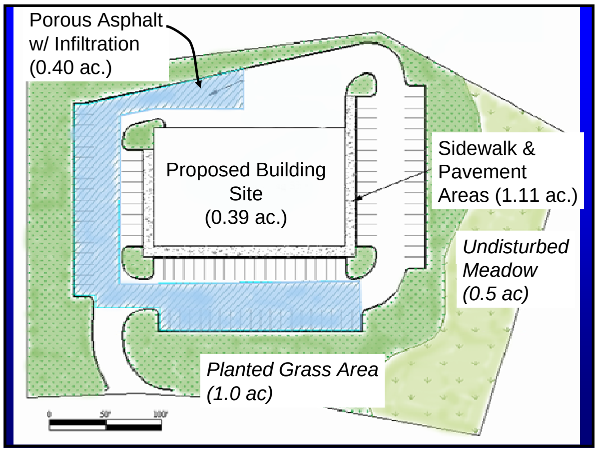
- Size Infiltration System for Net increase in Volume for 2-year storm
- Mitigate Peak Rate for larger storms
- Compare to Typical Detention Basin Paradigm

Net increase in Volume for 2-year storm

Condition	Area (ac)	Weighted CN	S (in)	I_a (in)	Runoff Q (in)	Runoff Volume (cf)
EXISTING	3.00	58.0	7.24	1.45	0.31	3,341
Post-Development						
Pervious	1.50	60.0	6.67	1.33	0.37	2,015
Impervious	1.50	98	0.20	0.04	2.87	15,616
TOTAL POST-DEV	3.00	79.0	2.66	---	1.62	17,631
NET CHANGE IN RUNOFF VOLUME (CF):						**14,290**

Stormwater Management Techniques

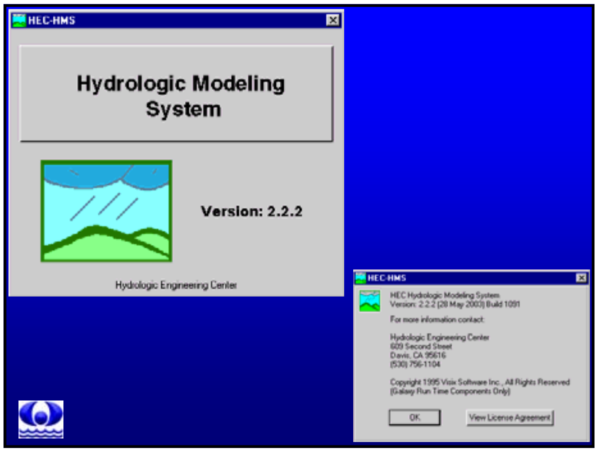
- Innovative Design
  - 0.4 ac (17,500 SF) Porous Asphalt w/ Infiltration Beds (2 foot storage depth)
  - Storage Volume = 14,000 CF (0.32 ac-ft)
  - Steady-state Infiltration Rate = 2 inches/hour
    - Modeled in HEC-HMS as a Diversion
    - Infiltration Rate included in Stage-Storage-Discharge Table
- Conventional Design
  - Detention Basin instead of undisturbed meadow (2 foot storage depth)
  - Storage Volume = 20,000 CF (0.46 ac-ft)



Hydrologic Calculations

- USDA-NRCS Cover-Complex Method (TR-55)
- US Army Corp of Engineers' *Hydrologic Engineering Center – Hydrologic Modeling System* (HEC-HMS), Version 2.2.2 (28 May 2003)

http://www.hec.usace.army.mil/software/hec-hms/hechms-download.html


HEC-HMS
Hydrologic Modeling System
Version: 2.2.2
Hydrologic Engineering Center
HEC-HMS
HEC Hydrologic Modeling System
Version: 2.2.2 (28 May 2003) Build 1091
For more information contact:
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616
(530) 756-1104
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(Galaxy Run Time Components Only)
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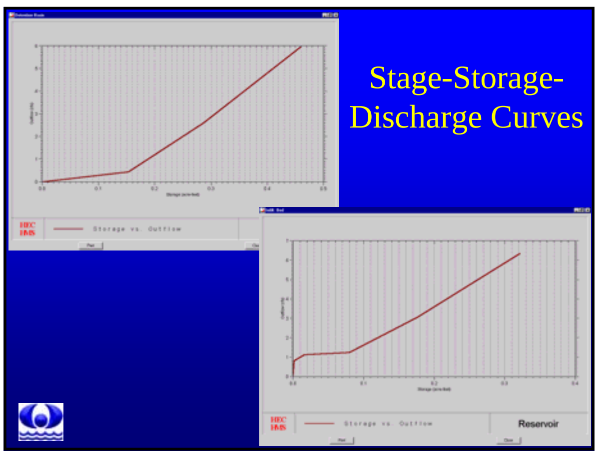
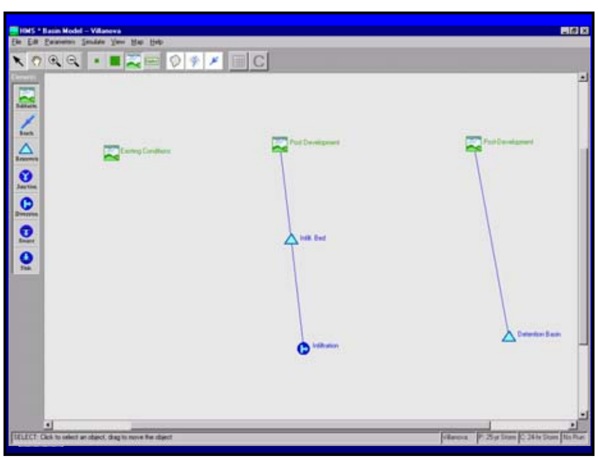
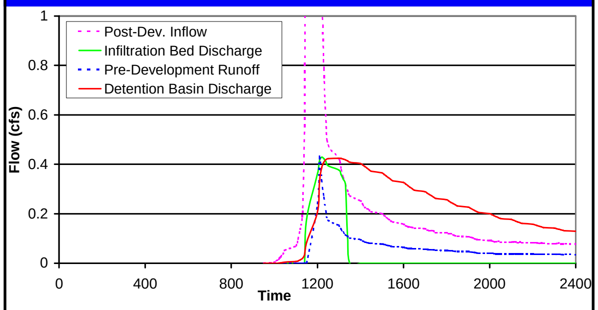
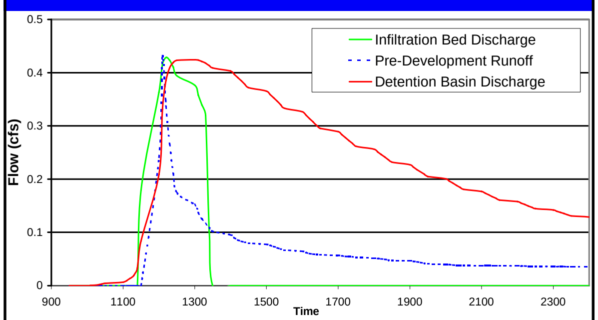

Stage-Storage-Discharge Curves
Reservoir



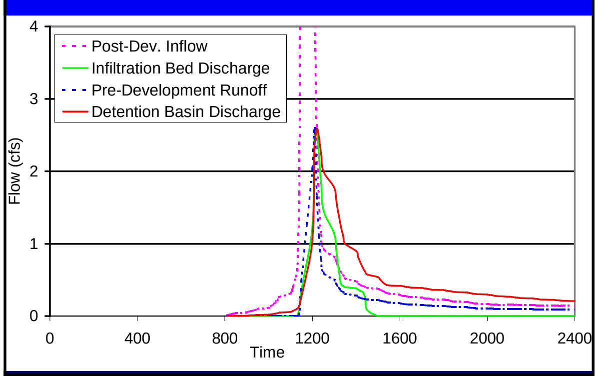
2-yr Storm Hydrographs (3.1”/24 hr)



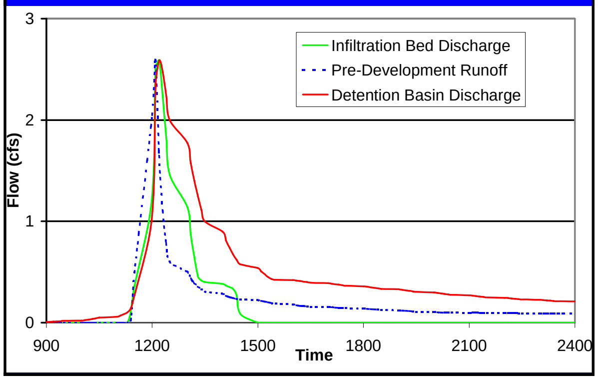
2-yr Storm Peak Rates



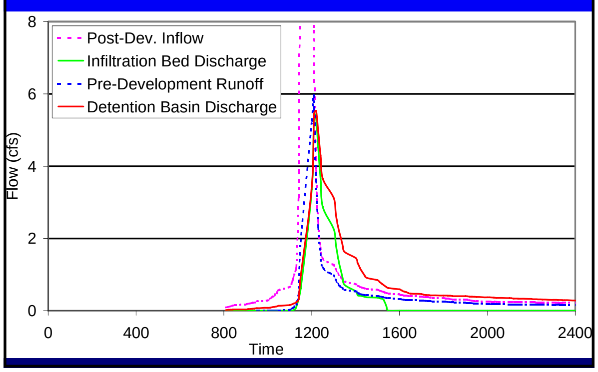
10-yr Storm Hydrographs (4.9”/24 hr)



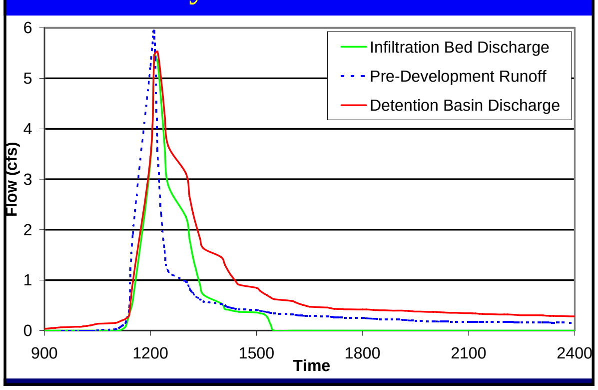
10-yr Storm Peak Rates



100-yr Storm Hydrographs (6.9”/24 hr)



100-yr Storm Peak Rates



Summary Results – Peak Rates

Storm Frequency (year)	Existing Runoff Rate (cfs)	Unmitigated Post-Dev. Runoff Rate (cfs)	Infiltration Bed Discharge (cfs)	Detention Basin Discharge (cfs)
2	0.43	4.58	**0.43**	**0.42**
10	2.59	9.89	**2.59**	**2.59**
25	3.52	11.75	**3.40**	**3.48**
100	5.93	16.14	**5.45**	**5.53**

Summary Results – Infiltration

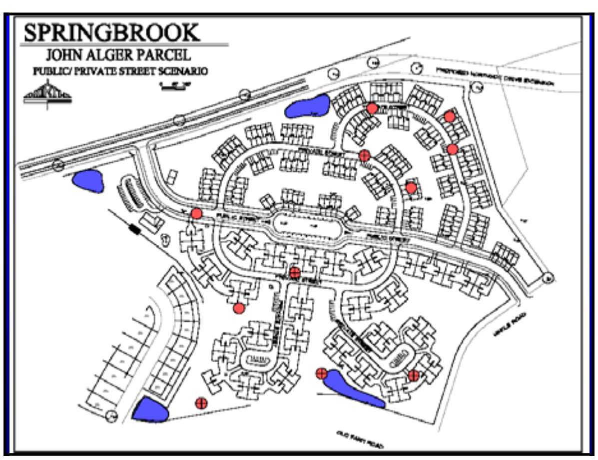
Storm Frequency (year)	Existing Runoff Depth (in)	Unmitigated Post-Dev. Runoff Depth (in)	Total Infiltration (in)	Infiltration Bed Discharge (in)	Percentage of Existing Volume
2	0.30	1.26	1.01	**0.25**	**83%**
10	1.11	2.71	1.68	**1.03**	**93%**
25	1.44	3.23	1.87	**1.36**	**94%**
100	2.33	4.48	2.30	**2.18**	**94%**

Detention

Storm Frequency (year)	Existing Runoff Depth (in)	Post-Dev. Runoff Depth (in)	Percentage of Existing Volume
2	0.30	1.26	**420%**
10	1.11	2.71	**244%**
25	1.44	3.23	**224%**
100	2.33	4.48	**192%**

Stormwater Management for The Village at Springbrook Farms

- Site marked by closed depressions and some sinkholes
- Proposed plan consists of:
  - Revised layout with setbacks from depressions and sinkholes
  - Distributed infiltration system, heavily vegetated


SPRINGBROOK
JOHN ALGER PARCEL
PUBLIC/ PRIVATE STREET SCENARIO

Example Drainage Area

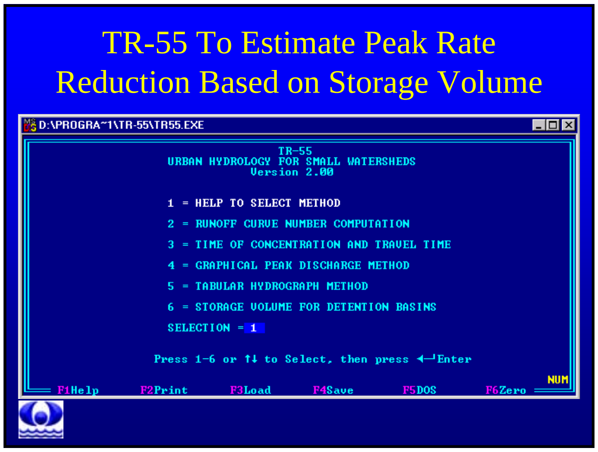
- Existing (CN = 70.6):
  - 24 acres of Row Crops
  - **Because of Closed Depressions, only 7.5 acres discharge offsite!!!**
- Proposed (CN = 81.3):
  - 24 acres of townhouse development
  - To avoid collecting stormwater in existing Closed Depressions, **all 24 acres discharge offsite!!!**

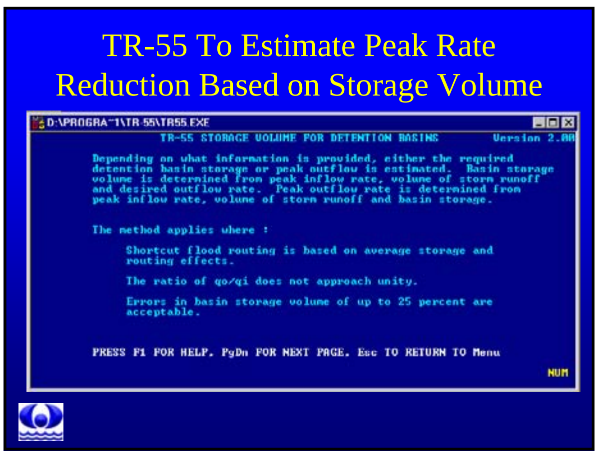
Summary Results – Infiltration

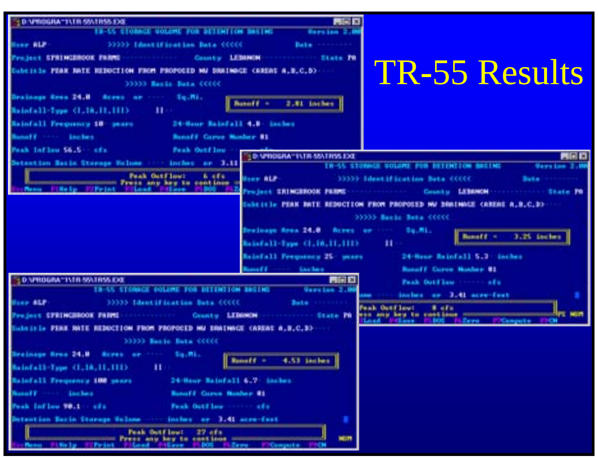
Storm Frequency (year)	Existing Runoff Depth (in)	Unmitigated Post-Dev. Runoff Depth (in)	Total Infiltration (in)	Infiltration Bed Discharge (in)	Percentage of Existing Volume
2	0.24	1.33	1.27	**0.06**	**27%**
10	0.62	2.84	1.78	**1.06**	**170%**
25	0.74	3.28	1.91	**1.37**	**185%**
100	1.10	4.56	1.97	**2.59**	**236%**

Detention

Storm Frequency (year)	Existing Runoff Depth (in)	Post-Dev. Runoff Depth (in)	Percentage of Existing Volume
2	0.24	1.33	**561%**
10	0.62	2.84	**458%**
25	0.74	3.28	**443%**
100	1.10	4.56	**415%**


TR-55 To Estimate Peak Rate
Reduction Based on Storage Volume
D:\PROGRA~1\TR-55\TR55.EXE
TR-55
URBAN HYDROLOGY FOR SMALL WATERSHEDS
Version 2.00
1 = HELP TO SELECT METHOD
2 = RUNOFF CURVE NUMBER COMPUTATION
3 = TIME OF CONCENTRATION AND TRAVEL TIME
4 = GRAPHICAL PEAK DISCHARGE METHOD
5 = TABULAR HYDROGRAPH METHOD
6 = STORAGE VOLUME FOR DETENTION BASINS
SELECTION = 1
Press 1-6 or ↑↓ to Select, then press ←Enter
NUM
F1Help F2Print F3Load F4Save F5DOS F6Zero


TR-55 To Estimate Peak Rate
Reduction Based on Storage Volume
D:\PROGRA~1\TR-55\TR55.EXE
TR-55 STORAGE VOLUME FOR DETENTION BASINS Version 2.00
Depending on what information is provided, either the required detention basin storage or peak outflow is estimated. Basin storage volume is determined from peak inflow rate, volume of storm runoff and desired outflow rate. Peak outflow rate is determined from peak inflow rate, volume of storm runoff and basin storage.
The method applies where :
Shortcut flood routing is based on average storage and routing effects.
The ratio of qo/qi does not approach unity.
Errors in basin storage volume of up to 25 percent are acceptable.
PRESS F1 FOR HELP. PgDn FOR NEXT PAGE. Esc TO RETURN TO Menu
NUM


TR-55 Results

Summary Results – Peak Rates

Storm Frequency (year)	Existing Runoff Rate (cfs)	Unmitigated Post-Dev. Runoff Rate (cfs)	Estimated Infiltration Bed Discharge (cfs)	Typical Detention Basin Discharge (cfs)
2	10	42.7	**1**	**10**
10	14	56.5	**6**	**14**
25	17	65.2	**8**	**17**
100	27	90.1	**27**	**27**

Designing Infiltration Systems

Site Criteria

- Soil Permeability greater than 0.25 in./hr
- Minimum Bedrock Separation of 2 feet
- Infiltration device at least 3 feet above seasonally high water table

Design Criteria

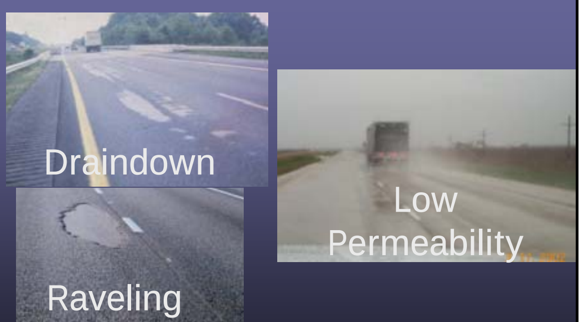
- Spread It Out!
- 5:1 Impervious to Recharge Area
- Minimize excavation / maximize soil buffer
- Pre-treatment for "hot-spots"
- Construction oversight!!
- Level Bed Bottoms
- Keep it Clean – E&S Control

Construction Criteria

- Protect infiltration BMPs from sediment until drainage area is completely stabilized
- Do not compact soil under infiltration areas
- Protect infiltration BMPs from sediment
- Do not compact soil

Design of Open-Graded (Porous) HMA

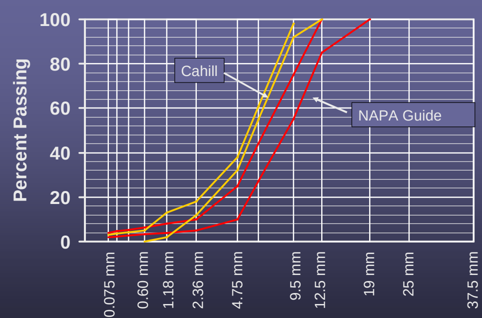
What we don't want



Key mix properties

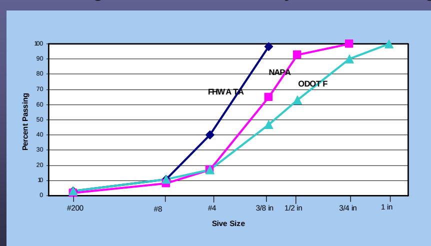
- Voids - permeability
- Asphalt content - durability
- Draindown - performance
- Moisture susceptibility - performance

Porous Pavement Gradations



Voids

- Starts with gradation – but may not be enough



Step 1. Select design gradation

- Do three blends of aggregate near the coarse, fine and middle of the gradation band.
- Determine VCA_{DRC} of each blend
- Prepare 3 batches of mix from each blend at 6.0 – 6.5% asphalt content.
- Compact 2 specimens each blend
- Test remaining sample each blend G_{mm}

Step 1. Select design gradation

- Determine the density of the mix
  - Dimension
  - CoreLock – note may be lower than by dimension
- Calculate the VCA_{MIX}
- Select gradation where $VCA_{MIX} < VCA_{DRC}$ with high air voids.

Step 2: Select Optimum Asphalt Content

- Prepare samples at 3 binder contents, 0.5% increments (5.5, 6.0, 6.5)
- Draindown test at 15°C higher than anticipated production temperature
- Compact mix and determine air voids
- Run Cantabro abrasion test

Step 2: Select Optimum Asphalt Content

- Select binder content
  - Air Voids ≥ 18%
  - Cantabro Abrasion Test (unaged) ≤ 20%
  - Cantabro Abrasion Test (aged) ≤ 30%
  - Draindown ≤ 0.3%

Step 4: Evaluate Mix for Moisture Susceptibility

- Use Modified Lottman test
  - Compact using 50 gyrations
  - Vacuum saturate for 10 minutes
  - Use 5 freeze thaw cycles
  - Keep specimens submerged in water during freezing
- TSR ≥ 80%

DOT OGFC Specs

- Open-Graded Friction Course (OGFC)
  - Don't confuse with Asphalt Treated Permeable Bases (ATPB)
    - Not suitable for surfaces
- Common practice some states
- Probably best way to specify mix
  - Contractors are familiar with it.
  - Need to check for key properties are spec'd

Key Properties to Look for in DOT OGFC Specifications

- Air Voids – key to permeability
  - Recommend ≥ 18%
- Draindown – performance & permeability
  - Draindown ≤ 0.3%
- Asphalt Content – for durability
  - Recommend 6.0% minimum
  - Absolute minimum 5.5%
- Max Agg Size – 100% passing 19 mm

Construction of Porous Pavements

Planning

- Plan to build late in construction process
  - Wait till “dirty work is done”
  - Wait till vegetation is established
    - Or keep runoff controls in place until established
  - Can excavate bed to about 1’ above planned elevation and use for SW control
    - Excavate to plan elevation when ready


Bed Excavation
Excavate bed to plan elevation using equipment w/ "soft footprint"
Don't compact subgrade


Berms
Do not excavate earth berms between beds (if used)
Should not need compaction


Non-woven Geotextile
Spread geotextile immediately after fine grading
Overlap fabric >16"
Install drainage pipes if used
Excess fabric (>4') folded over agg. later

Stone Recharge Bed

- Place clean, single size, washed aggregate.
- Do not drive trucks on fabric
- Spread and grade with tracked equipment 8” lifts.
- Light compaction - static
- Protect pipes

Choker Course

- Place “Choker” course – ½” clean washed aggregate.
  - Purpose to lock up surface for stable paving platform
  - 1 – 2” thick
  - Grade and compact
    - Static
    - Vibratory? – (maybe low amplitude, high frequency)

Mix Production

- Watch temperature
  - Don’t produce higher than tested by draindown
- Don’t store for extended periods in silos
- Batch plant lower production due to screens
- Fibers reduce draindown
  - Requires special equipment
  - Batch plant increase dry and wet mixing time
  - Equipment must be calibrated

Paving

- First fold fabric over agg.
- Paving as usual?
  - Recommend track paver
- Avoid truck movement over agg.
  - Stability may be issue
  - Avoid disturbing agg surface – but it will happen
- Production will be less
- Limit handwork with polymers

Hauling

- With polymers heavy and thorough coating of release agent.
- Raise bed after spraying to drain puddles
- Tarping a must
- Limit haul distance

Compaction

- Static compaction
- 1 to 2 passes 10 ton roller steel wheel roller
- Less stable than thin OGFC
  - May have to let cool some

After Compaction

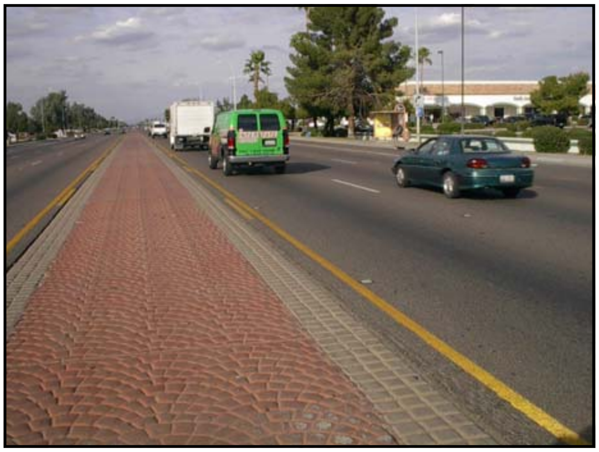
- Limit traffic for 24 hours to allow to set up
- Keep sediment control in place till vegetation established

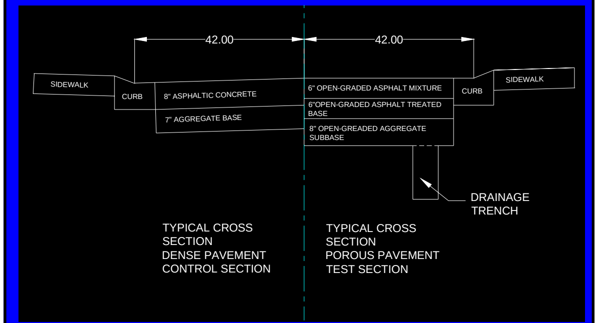
What about building roadways with porous pavement?

Arizona Highway Dept.
1986

Route 87, Chandler, AZ

- Two lanes of a 4 lane roadway, 3,500 ft.
- Traffic volume – 45,000 ADT
- 2-6” pavements over 8” stone base
- edge drain discharges to shoulder





Typical Section of AZ DOT's Experimental Porous Pavement

The End

Porous Asphalt in Colorado

Lisa Klotz
Golden, Colorado

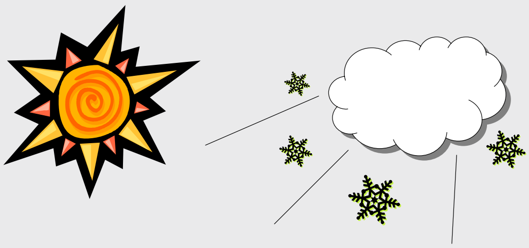
History of Porous Asphalt

- Originally developed in the 1970's
- Franklin Institute in Philadelphia, PA
- Tested throughout the 1980's
- Oldest systems – 1980-81 on east coast
- Why not in Colorado???

Major Concerns of Porous Asphalt Installment in Colorado

- Climate – Freeze/Thaw Impacts
- Expansive Soils
- Cost Effectiveness

Freeze / Thaw Impacts



KLEINFELDER >EXPECT MORE

Winter Weather and Pavement

- Many freeze/thaw cycles
- Expansion and shrinking of moisture/ice
- Breakdown of pavements
  - Thermal cracking
  - Potholes
  - Heaving/ Settlement

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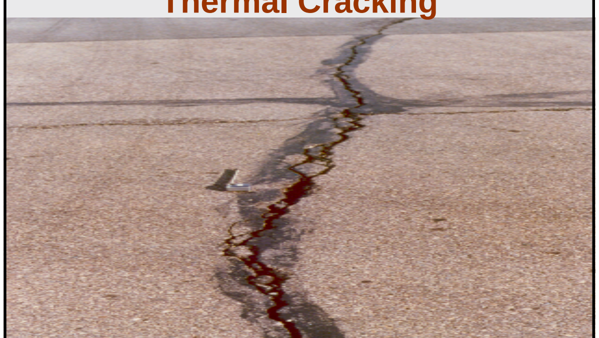
Thermal Cracking



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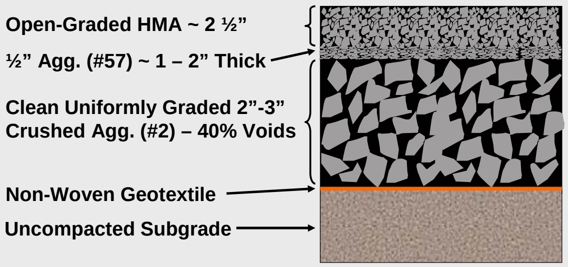
How does porous asphalt endure freeze/thaw??

- Porous asphalt allows water to pass through
- Water does not stay on the surface long enough to freeze
- Increased void space does not "trap" water on the pavement
- Less need for snow removal due to heat from the "reservoir" layer

Porous Asphalt

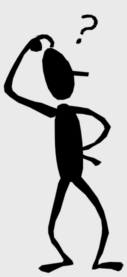
Dense graded asphalt

Cross-Section of Porous Asphalt with Recharge Bed



Cold Climate Success Stories

- Walden Pond
- Lulea, Sweden (within 1^0 of arctic circle)
- Wal-Mart “Green” – Aurora, CO



What about the expansive soils in Colorado?

Expansive Soils

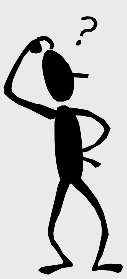
- Colorado = expansive soils
- Denver swell test
- Capable of causing serious damage to pavements
- Typical mitigation is excavation and replacement of sub-base

KLEINFELDER >EXPECT MORE

Structural and Hydrological Concerns

- Structural
  - 12-36” of aggregate base
  - Sealed with a 2-4” choker course
  - Supports structure of pavement
- Hydrological
  - Soil permeability
  - Piping water away from clay subgrades
  - Lower impact on storm water management

K L E I N F E L D E R >EXPECT MORE



Isn’t porous asphalt more expensive??

K L E I N F E L D E R >EXPECT MORE

Savings, Savings, Savings!!

- No proprietary ingredients in the asphalt mix
- No special paving equipment
- Increased costs of stone beds are offset by savings in other storm management costs

KLEINFELDER >EXPECT MORE

Storm Water Management Benefits

- Reduced need for other BMP's
- Elimination of detention basin
- Reduction in runoff, reduces impact on storm water system
- Convey runoff from other impermeable areas on the site (roofs, etc)
- Contaminants collected on the pavement are naturally filtered through the soil

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Maintenance Considerations

- Keeping the sediment out
- No sand, ash or salt for ice
- Vacuum sweeping/ High pressure hosing
- Spot-Clogging
- Annual Inspections

KLEINFELDER >EXPECT MORE

Open Graded Friction Course (OGFC)

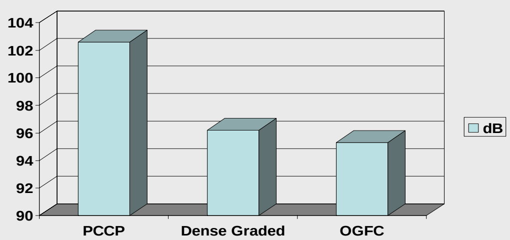
Increased skid resistance

Noise reduction

Increased safety

KLEINFELDER >EXPECT MORE

Noise Reduction



"Colorado DOT Tire/Pavement Noise Study", NCAT, April 2004

KLEINFELDER >EXPECT MORE

Rock Concert

- 100-110 dB

  same average level as PCCP

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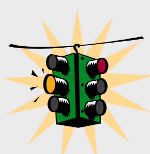
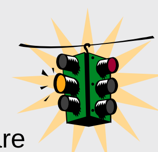
Rockin' Out In Your Vehicle

- 85 – 95 dB (Depending on your system)
  - Comparable to OGFC

Safety





- Reduction of glare
  - Ice and snow
  - Skid resistance
- Reduction of hydroplaning

Pavement of the Future for Colorado??

- Cost effective
- Beneficial to storm water management
- Compatible with Colorado sub-surface conditions
- Increased safety
- Simple technology
- Proven to last more than 20 years

For more info…

- ***Porous Asphalt Pavements***, published by the National Asphalt Pavement Association, Information Series 131
- www.hotmix.org
- www.thecahill.com
- Stormwater magazine, ***"Porous Asphalt Pavement with Recharge Beds",*** Michele C. Adams

K L E I N F E L D E R
>EXPECT MORE

Thanks!!

Questions??

K L E I N F E L D E R
>EXPECT MORE