DESIGN, CONSTRUCTION, INSPECTION, AND MAINTENANCE

PERMEABLE PAVEMENT

NCTCOG WORKSHOP

DECEMBER 9TH, 2021

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NCTCOG RESOURCES

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HTTP://ISWM.NCTCOG.ORG/RESOURCES.HTML

HTTP://ISWM.NCTCOG.ORG/TECHNICAL-MANUAL.HTML

REFER TO THE "SITE DEVELOPMENT CONTROLS" MANUAL

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WHAT IS PERMEABLE PAVEMENT?

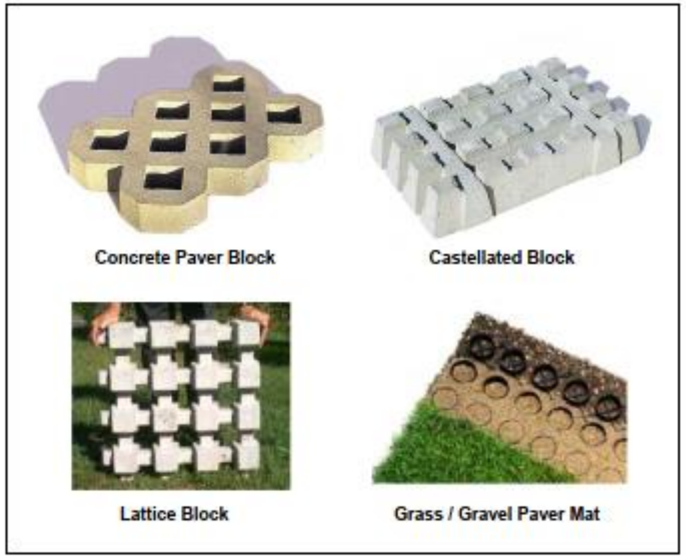
PERMEABLE PAVEMENT | OVERVIEW

Photo Credit: Green Paving Solutions

Photo Credit: US EPA

PERMEABLE PAVEMENT | OVERVIEW

- Allows for rainfall infiltration
- Ideal for low traffic surfaces (driveways, parking lots, walk ways, on street parking)
- Provides peak flow mitigation, volume storage, and some water quality improvement
- Can provide streambank protection in certain areas



EXAMPLES OF MODULAR POROUS PAVERS (SOURCE: ISWM TECHNICAL MANUAL)

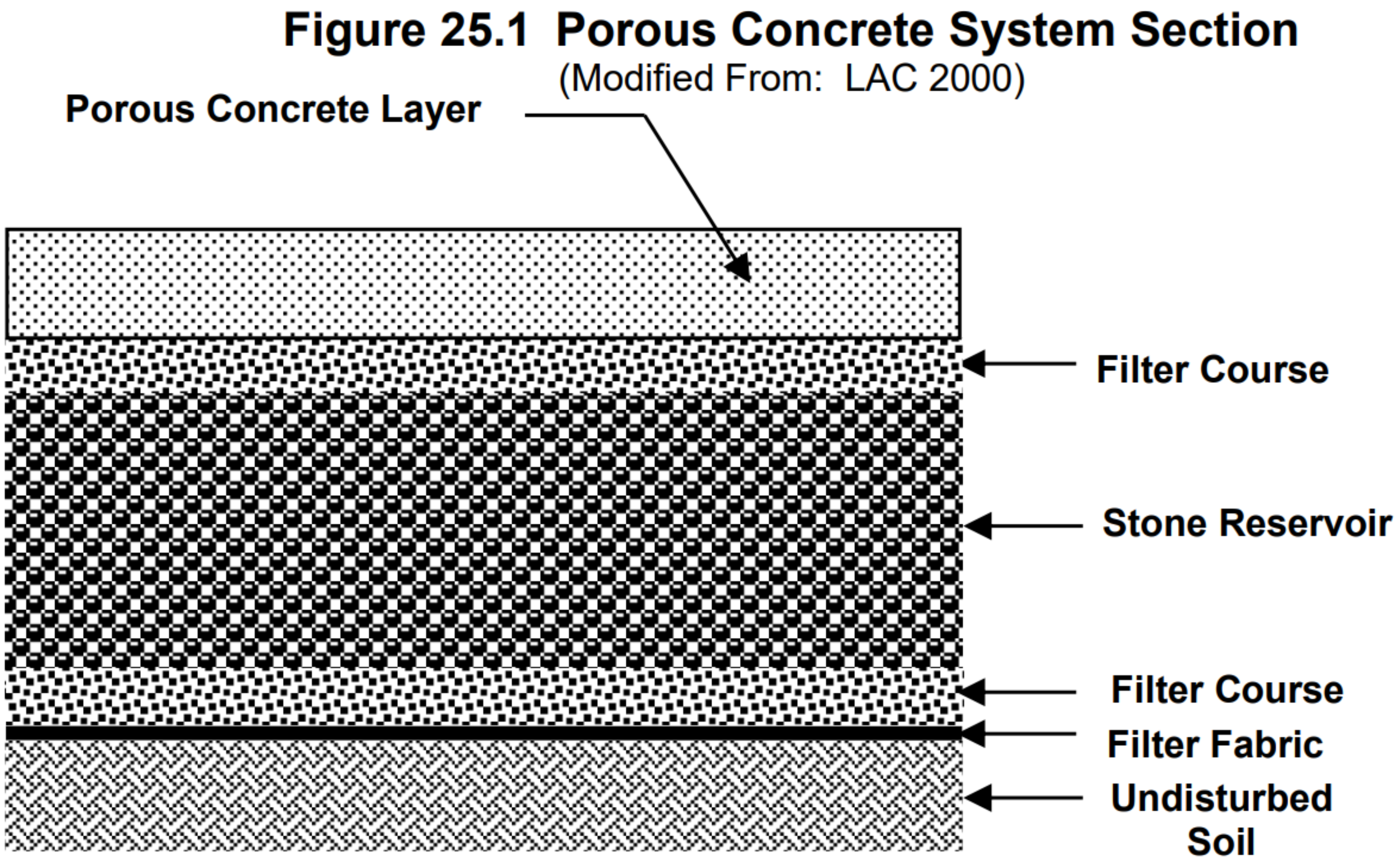


Figure 25.1 Porous Concrete System Section
(Modified From: LAC 2000)
Porous Concrete Layer
Filter Course
Stone Reservoir
Filter Course
Filter Fabric
Undisturbed
Soil

PERMEABLE PAVEMENT | OVERVIEW

Advantages	Limitations
• Replaces completely impervious surfaces with partially impervious surfaces • Reduces stormwater runoff rate and volume • Reduces loads of some pollutants in surface runoff by reducing the volume of stormwater leaving a site • Reduces stormwater infrastructure footprint and promotes multi-benefit uses by using treatment area for parking/driving with possible cost reductions • Increases ground water recharge • **Adaptable to urban retrofits** • Many options available depending on specific site needs and aesthetics • Applicable for use in recharge zones, karst, expansive clays, and hotspots when properly designed	• Potential for clogging of porous media by sediment, which could lead to reduced effectiveness without proper maintenance • **Should not receive runon from adjacent pervious surfaces or areas with high sediment/debris yield** • Typically, not cost effective for high-traffic areas or for use by heavy vehicles (requires increased structural design and maintenance frequency) • **Permeable pavement should be installed only by contractors qualified and certified for permeable pavement installation** • Grades of 5% or less • Potential for groundwater contamination

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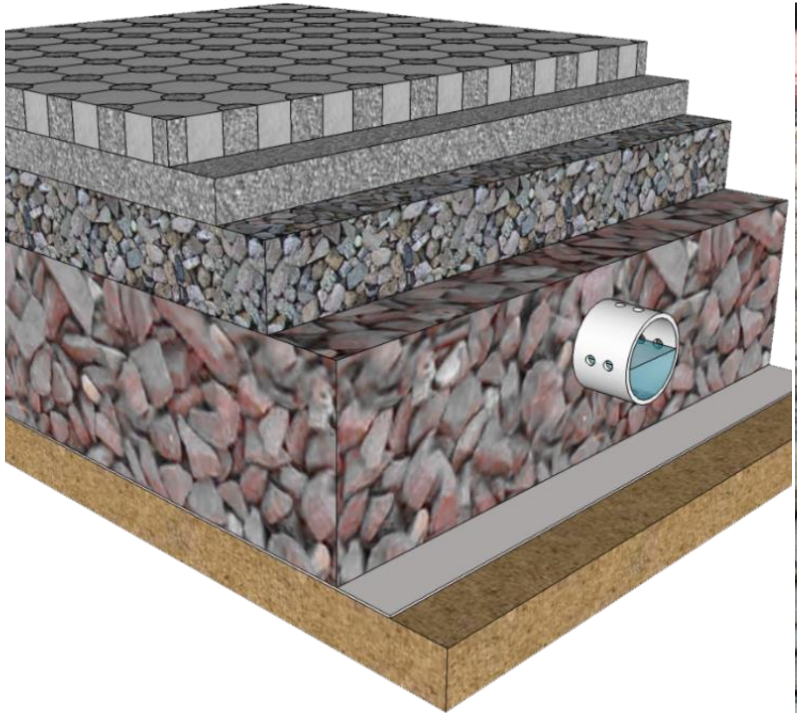
PERMEABLE PAVEMENT | OVERVIEW

- Permanent stormwater BMP comprised of paving surfaces that filter runoff through voids in the pavement surface into an underlying reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil.



PERMEABLE PAVEMENT | OVERVIEW

STORMWATER BENEFITS:

- Reduce stormwater volume and rate
- Improve water quality
- Promote infiltration and groundwater recharge

OTHER BENEFITS:

- Can be an attractive landscape element

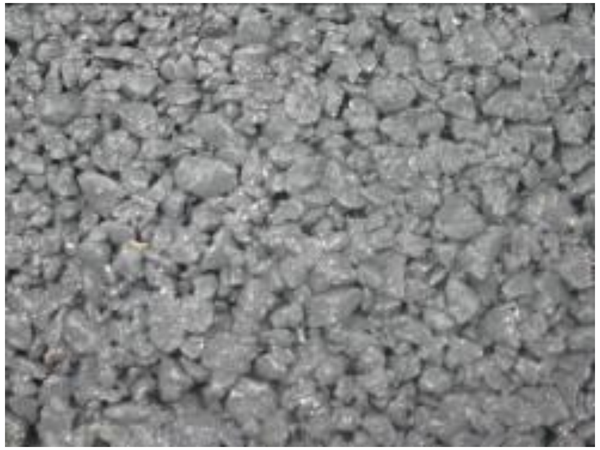
WHAT IS PERMEABLE PAVEMENT?

TYPES OF PERMEABLE PAVEMENT

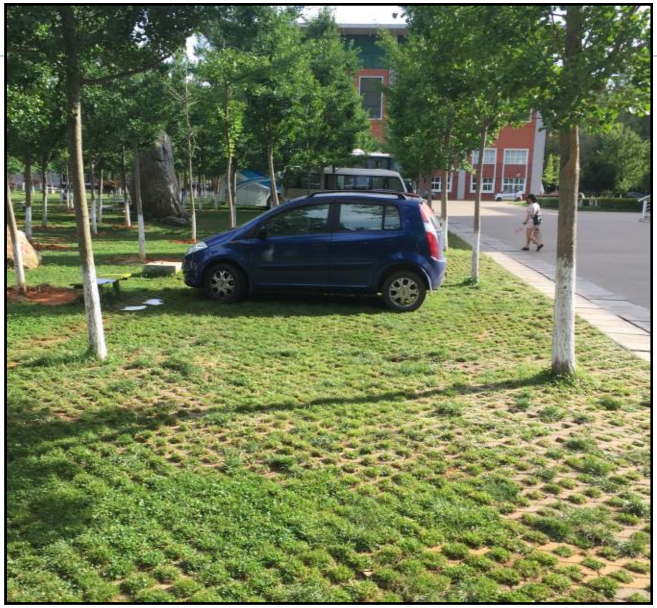
TYPES OF PERMEABLE PAVEMENT

- Permeable Interlocking Concrete Pavers (PICP)
- Pervious Concrete
- Porous Asphalt
- Plastic Reinforcing Grids (PG)

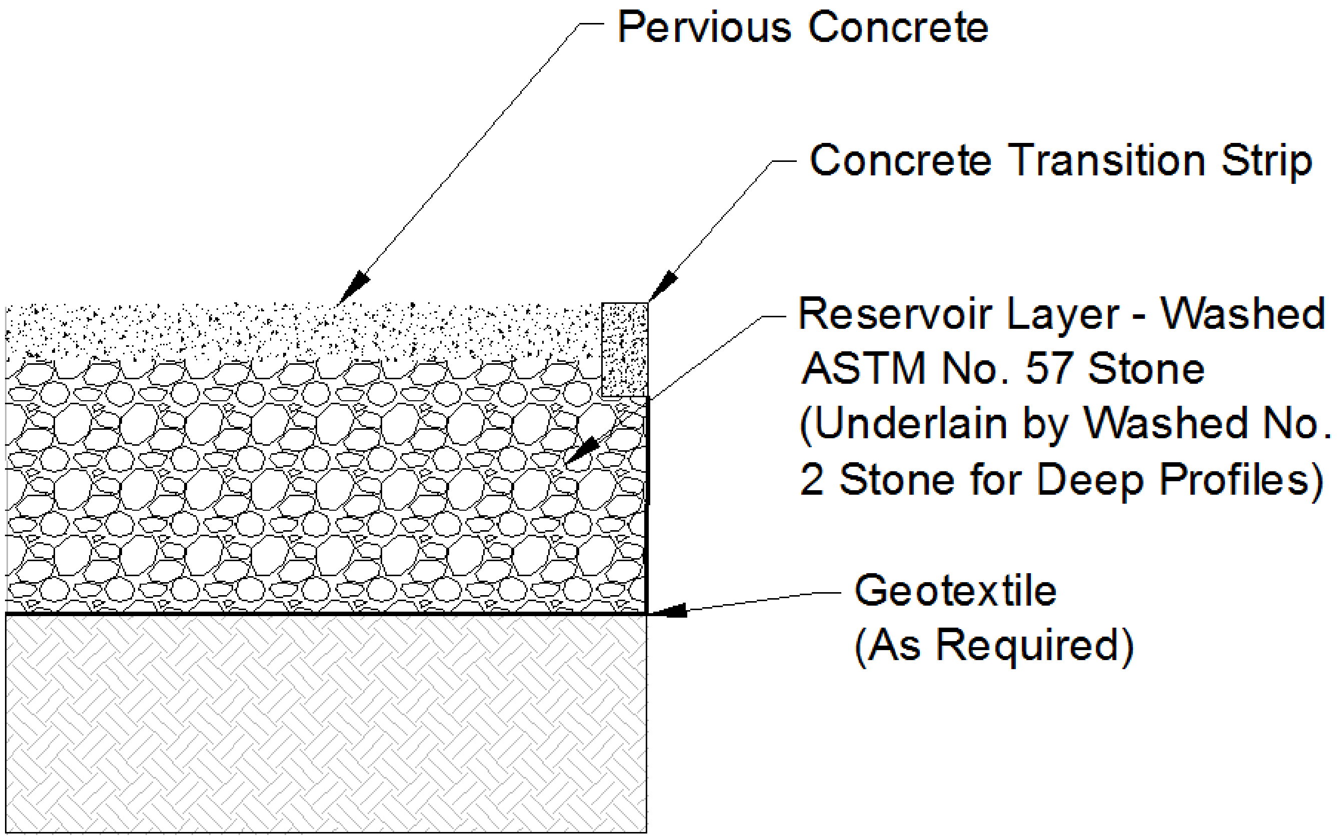
Note: PICP and PG are included in the iSWM Site Development Controls Manual - Chapter 24.0 Modular Porous Pavement Systems.

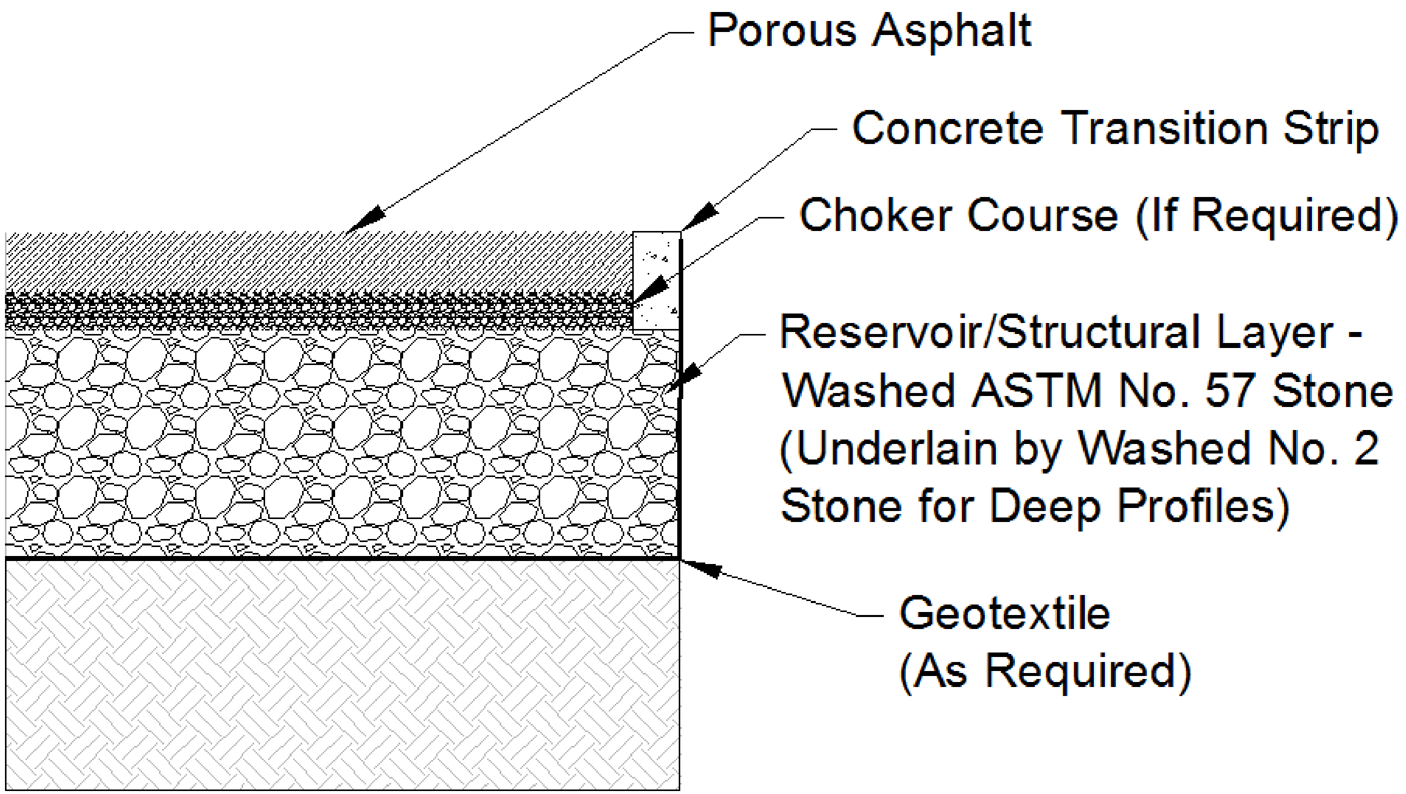

PERMEABLE PAVEMENT



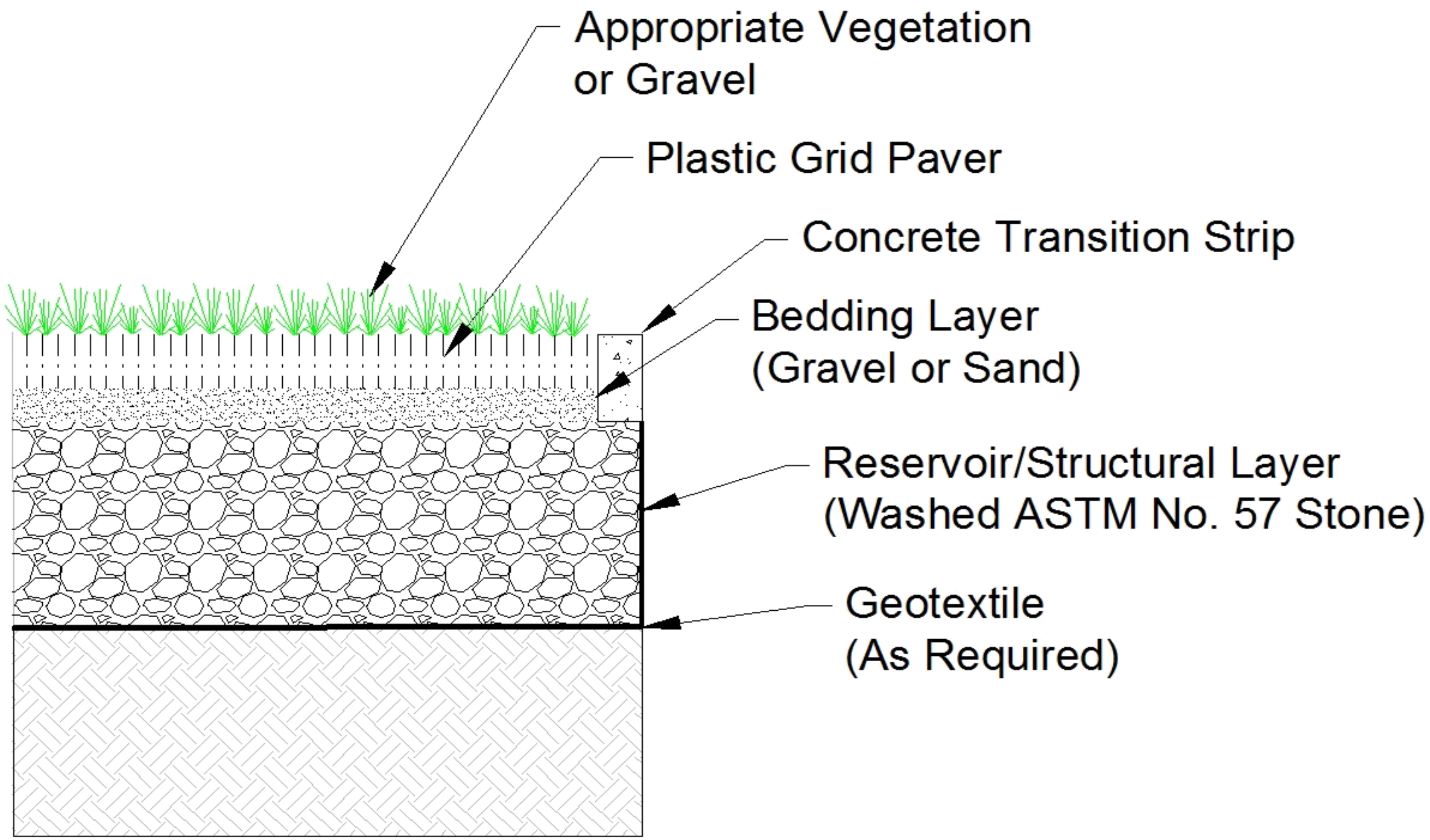
PERVIOUS CONCRETE



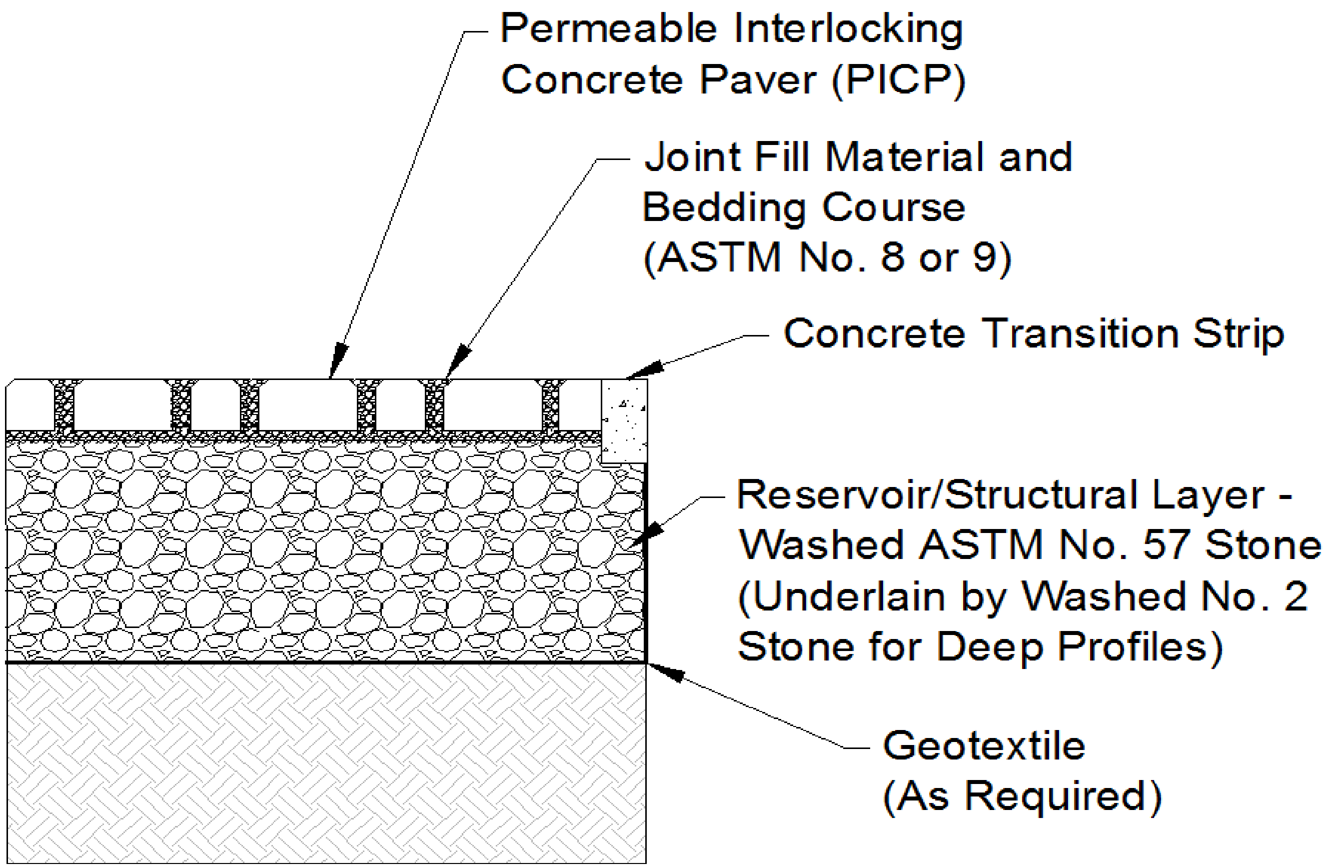
PERVIOUS ASPHALT



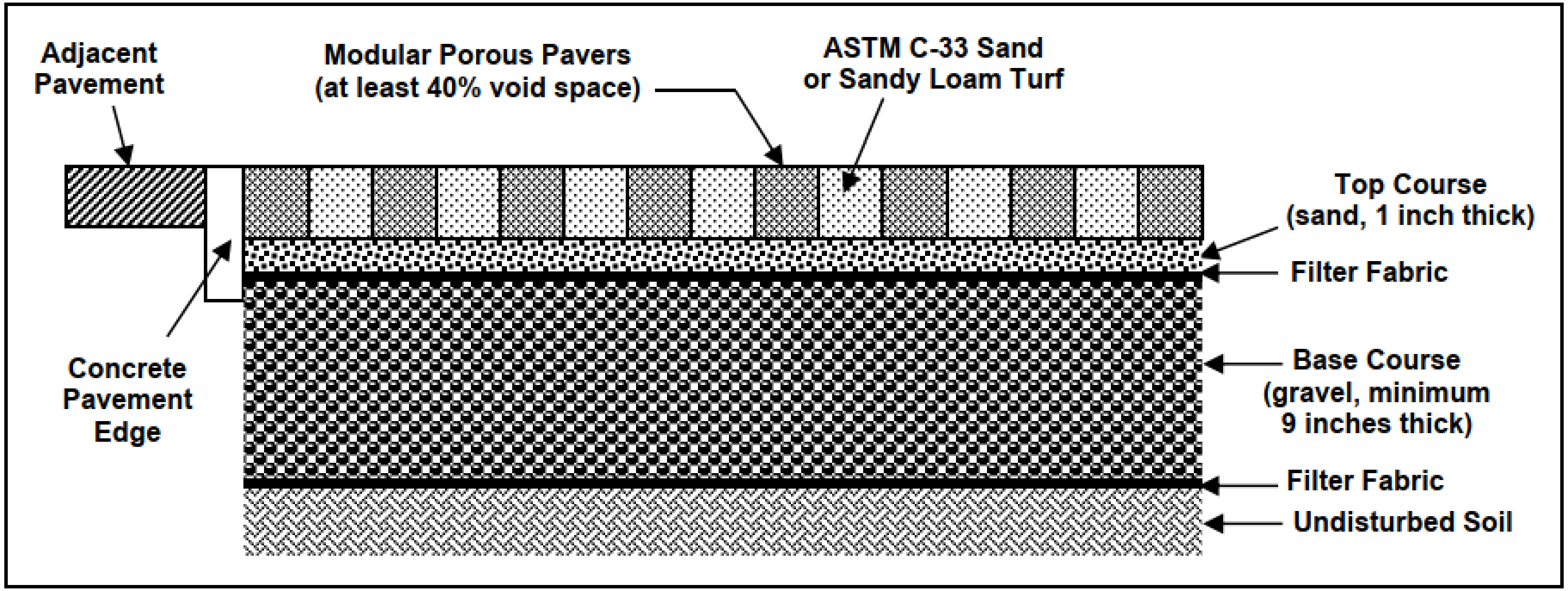
PLASTIC GRID PAVERS



PERMEABLE INTERLOCKING CONCRETE PAVER (PICP)



MODULAR POROUS PAVER SYSTEMS



PERMEABLE PAVEMENT | MATERIAL SELECTION

- Porous paver infill is selected based on the intended application and required infiltration rate
  - Masonry sand has a high infiltration rate → use where no vegetation is required or desired
  - Sandy loam soil has a lower infiltration rate → will support grass growth
- Selection is based on site requirements and location
  - Porous concrete is thought to maintain its porosity through hot weather better than porous asphalt because of surface sealing from asphalt binder.

WHAT IS PERMEABLE PAVEMENT?

HOW AND WHERE IS IT TYPICALLY USED

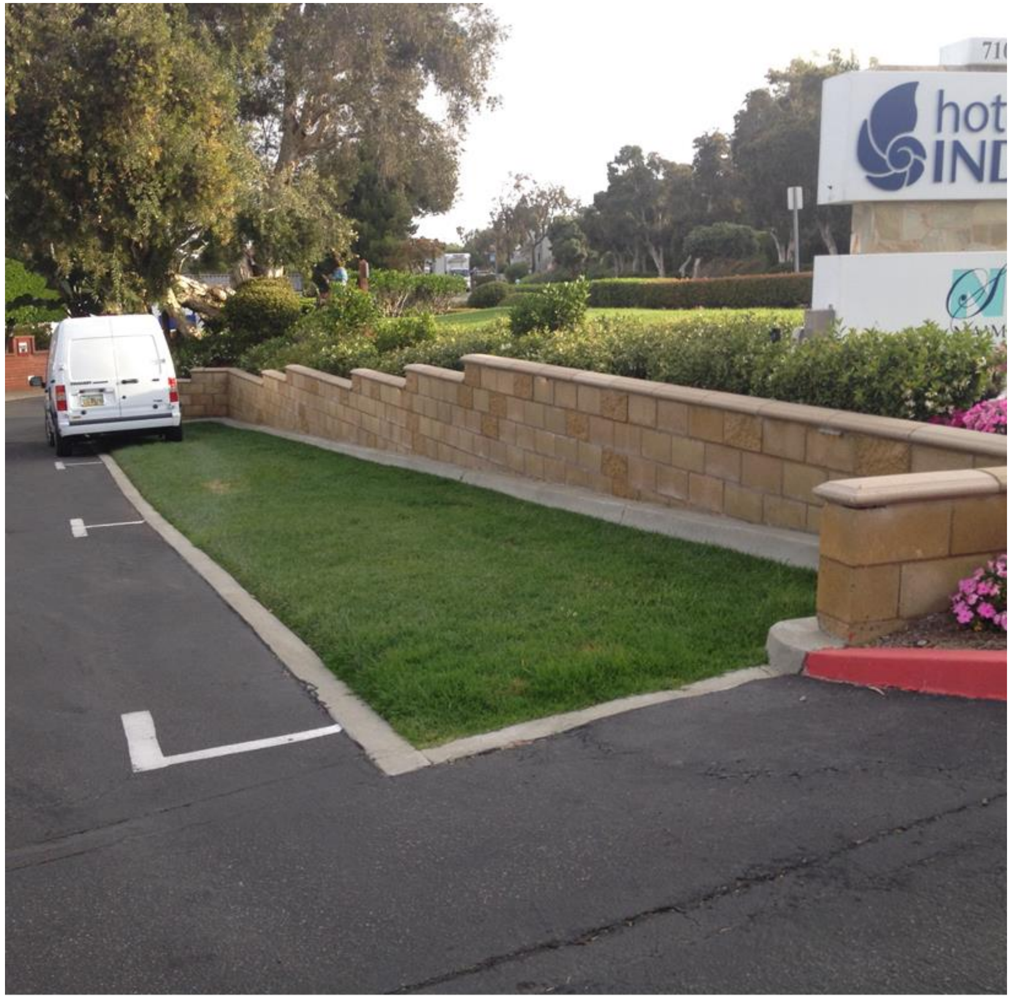
PARKING LOTS

RIGHTS-OF-WAY

ARTISTIC USES

DRIVEWAYS AND ALLEYS

VEGETATED AREAS



HOW TO DESIGN PERMEABLE PAVEMENT

HOW TO DESIGN PERMEABLE PAVEMENT

SITE SELECTION AND SITE REQUIREMENTS

PERMEABLE PAVEMENT | SITE SELECTION

- Intended for low traffic areas
  - Residential parking
  - Overflow parking
  - Limitations on heavy vehicle loads
- Drainage should come from impervious areas only
  - Contributing impervious area to porous paver surface ratio of 3:1
  - Avoid allowing runoff from pervious areas that can carry mulch, sediments, leaves, debris and will increase maintenance and lead to clogging.
  - If it can't be avoided, runoff from fully stabilized pervious areas must include pretreatment.
  - Roof runoff can typically be piped directly onto pervious pavements (not through landscaping).
- Systems should be:
  - 10 feet downgradient of buildings
  - 100 feet away from drinking water wells

PERMEABLE PAVEMENT | SITE REQUIREMENTS

- Consider soil tests and perform an infiltration test
  - Minimum of one test hole per 5,000 ft^2 and 2 borings per facility
  - Allowable where infiltration is between 0.5 and 3.0 in/hour
  - Minimum of 2’ of clearance between bottom of gravel layer and seasonally high groundwater table or bedrock
- Unlined porous concrete should not be used in wellhead protection zones, recharge areas of water supply aquifer recharge zones or hotspots
- Slopes should be less than 2% (maximum of 5%) but can be essentially flat since all drainage occurs underground.

IMPORTANT NOTE!

Special care must be taken during construction to avoid compaction of the soils if designing for infiltration.

PERMEABLE PAVEMENT | SITE APPLICATIONS

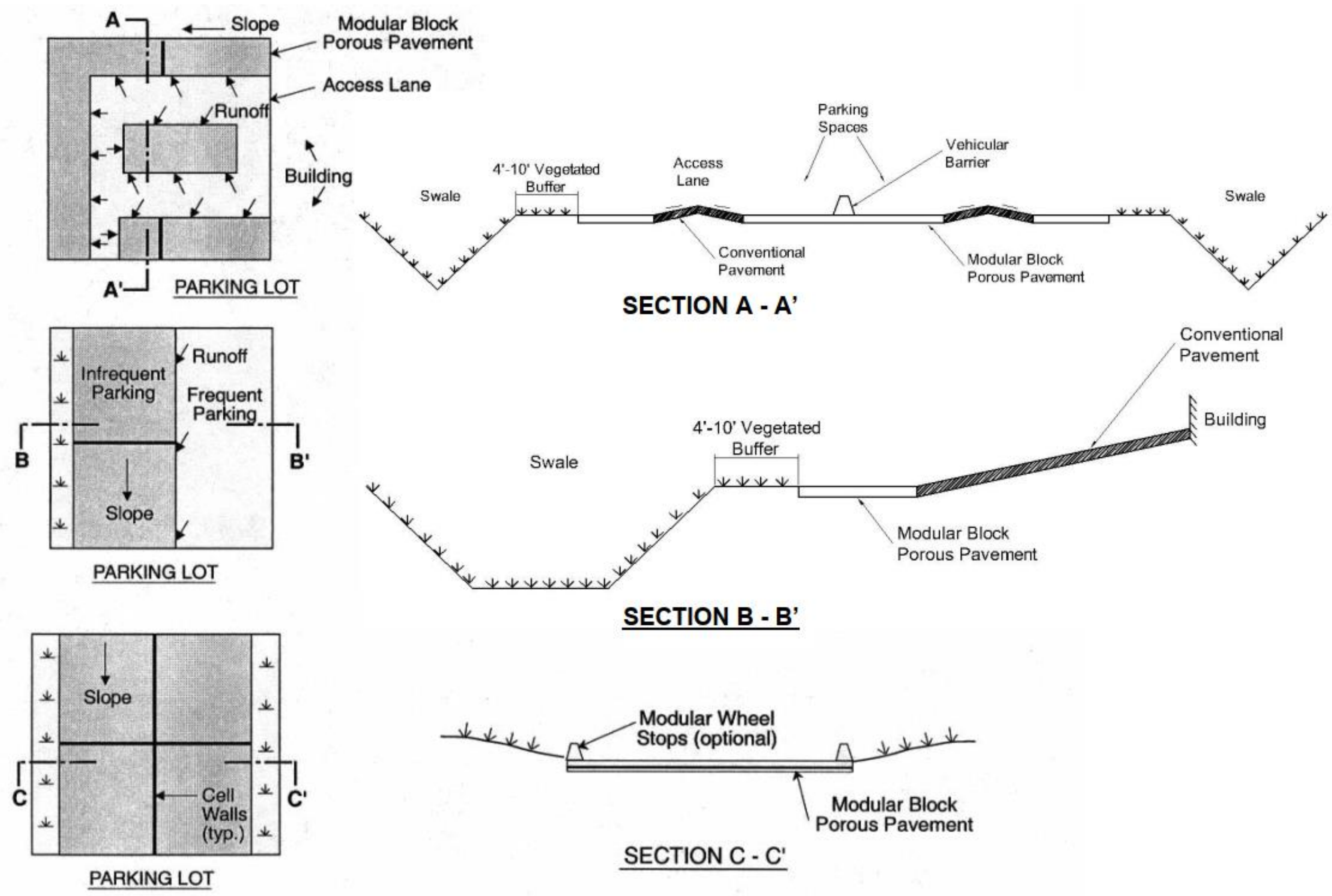


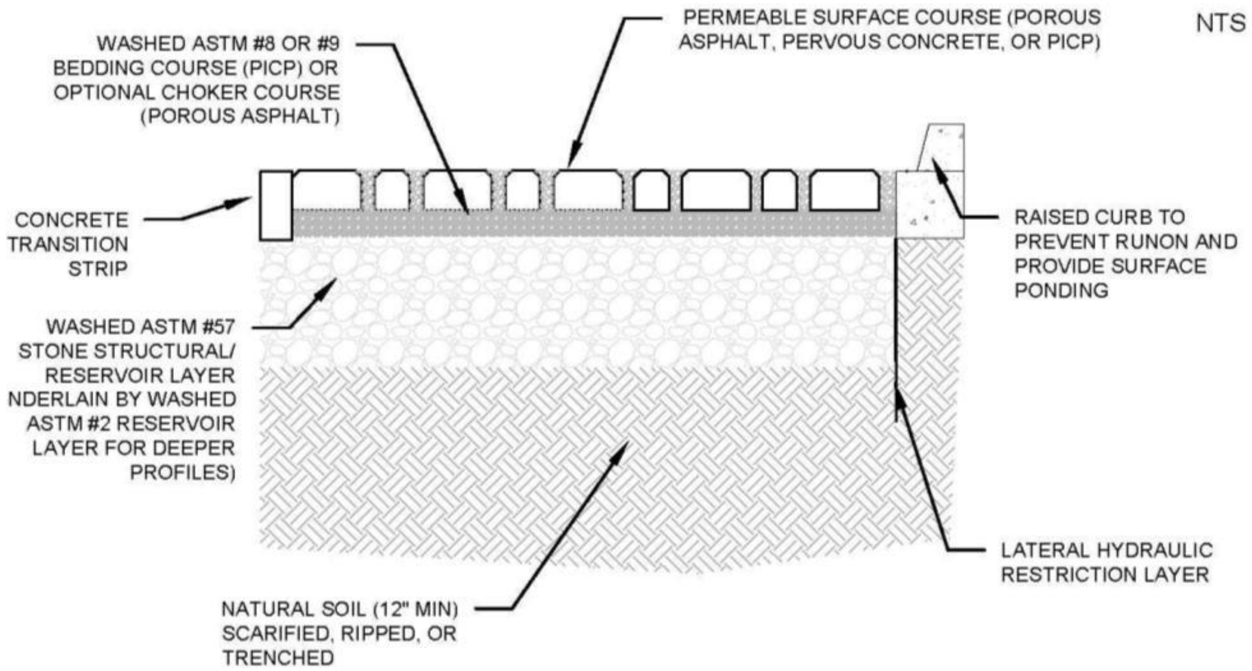
Figure 24.3 Typical Modular Porous Paver System Applications
(Source: UDFCD, 1999)

HOW TO DESIGN PERMEABLE PAVEMENT

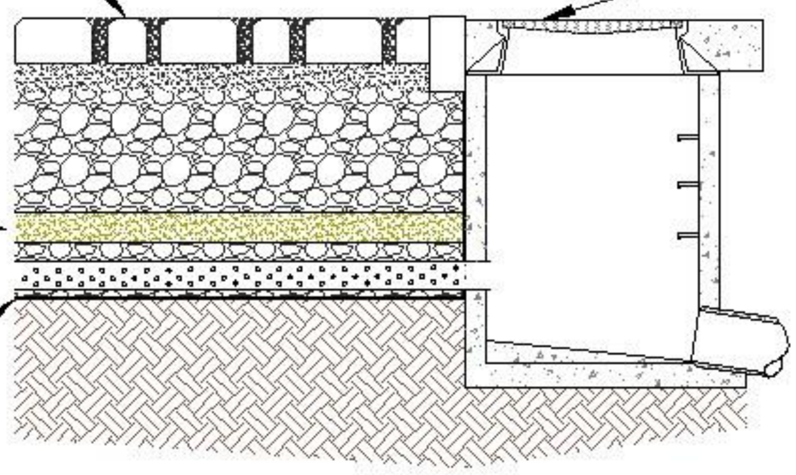
WATER QUALITY BENEFITS

PERMEABLE PAVEMENT | DESIGN THE PROFILE

- For best treatment, PP must capture the water quality treatment volume and filter through a soil or sand filter layer
  - Infiltrate capture volume in 24-48 hours
  - Store design storm volume within base and sub-base reservoirs for 2 to 5 days
  - Main variable is layer depth
- Account for contributing areas



- Min. of 4 inches of ASTM C-33 washed sand above the aggregate of the underdrain drainage layer (Barrett 2005)
- Enhance water quality

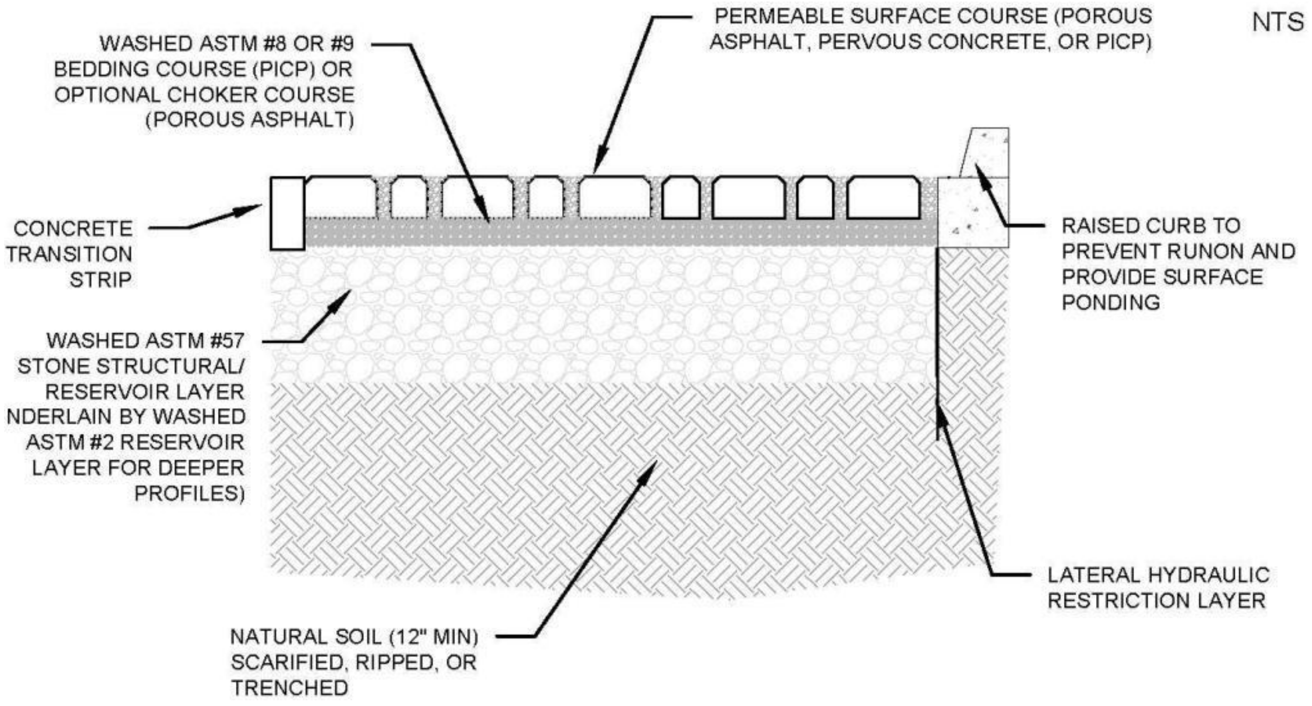


- Store/Treat the design storm volume
- Calculate the depth of the design storage layer

$$d = \frac{V}{A * n}$$

  - d = Gravel Layer Depth (ft)
  - V = Water Quality Volume (ft^3)
  - A = Surface Area (ft^2)
  - n = Porosity (use 0.32)

Note that the minimum depth required is 9”



PERMEABLE PAVEMENT | EXAMPLE SITE DESIGN

- The site plan leaves significant open space opportunities and can meet the treatment requirements with an array of BMPs.

CALCULATE INITIAL WATER QUALITY VOLUME FOR A SITE

$$WQV = C * \left(\frac{P_x}{12}\right) * A$$

WQV = water quality volume (ft^3),
C = 0.584 (for site on previous slide)
P_x = 1.5 in. (iSWM criteria)
A = 42,430 sq. ft. (site 90,841 sq. ft.)

Impervious Only

$$WQV = 0.95 * \left(\frac{1.5}{12}\right) * 42{,}430 = 5038.6\ ft^3$$

Whole Site

$$WQV = 0.584 * \left(\frac{1.5}{12}\right) * 90{,}481 = 6{,}605.1\ ft^3$$

DESIGNING FOR WATER QUALITY VOLUME

Store/Treat the design storm volume within reservoir and sub-base layers

$$A = \frac{V_{wq}}{n * d}$$

$V_{wq} = 5038.6\ ft^3$

n = 0.4 (washed stone)

d = 3.4375 ft (initial depth of reservoir and sub-base/underdrain layers)

A = 5038.6 ft^3 / (0.4*3.4375 ft) = 3664 ft^2 – Typical parking place is 18' x 9' = 162 ft^2

Need approximately 23 parking spots for V_{wq} required to meet 1.5" design storm.

PERMEABLE PAVEMENT | DESIGN THE PROFILE

- Washed Stone
- No. 57

Source: NCSU BAE

PERMEABLE PAVEMENT | DESIGN THE PROFILE

- Design Considerations
  - Total traffic
  - In situ soil strength
  - Environmental elements
  - Bedding and reservoir layer design
- Include an observation well at the downstream end of each facility
- Compare required structural depth to depth required for WQV and Detention
  - Take maximum

- Reference Material
  - AASHTO Guide for Design of Pavement Structures (1993)
  - AASHTO Supplement to the Guide for Design of Pavement Structures (1998)
  - AASHTO Flexible Pavement Method
- Interlocking Concrete Pavement Institute Design Tools
  - Design Manuals https://icpi.org/design-manuals
  - Software https://icpi.org/software
- ASCE Permeable Pavements Book
  - https://ascelibrary.org/doi/book/10.1061/9780784413784

HOW TO DESIGN PERMEABLE PAVEMENT

DETENTION AND DIVERSION REQUIREMENTS

PERMEABLE PAVEMENT | EXAMPLE SITE DESIGN

- What about detention on this site? How can we fit it in? How can we maximize use of the site and occupant/community benefits for health and welfare?

DESIGNING FOR DETENTION VOLUME

Store/Treat the design storm volume within reservoir and sub-base layers

$$A = \frac{V_{wq}}{n * d}$$

$V_{wq} = \frac{9.34\ in}{12} * 42{,}430\ ft^2 = 33{,}025$ ft^3

n = 0.4 (washed stone)

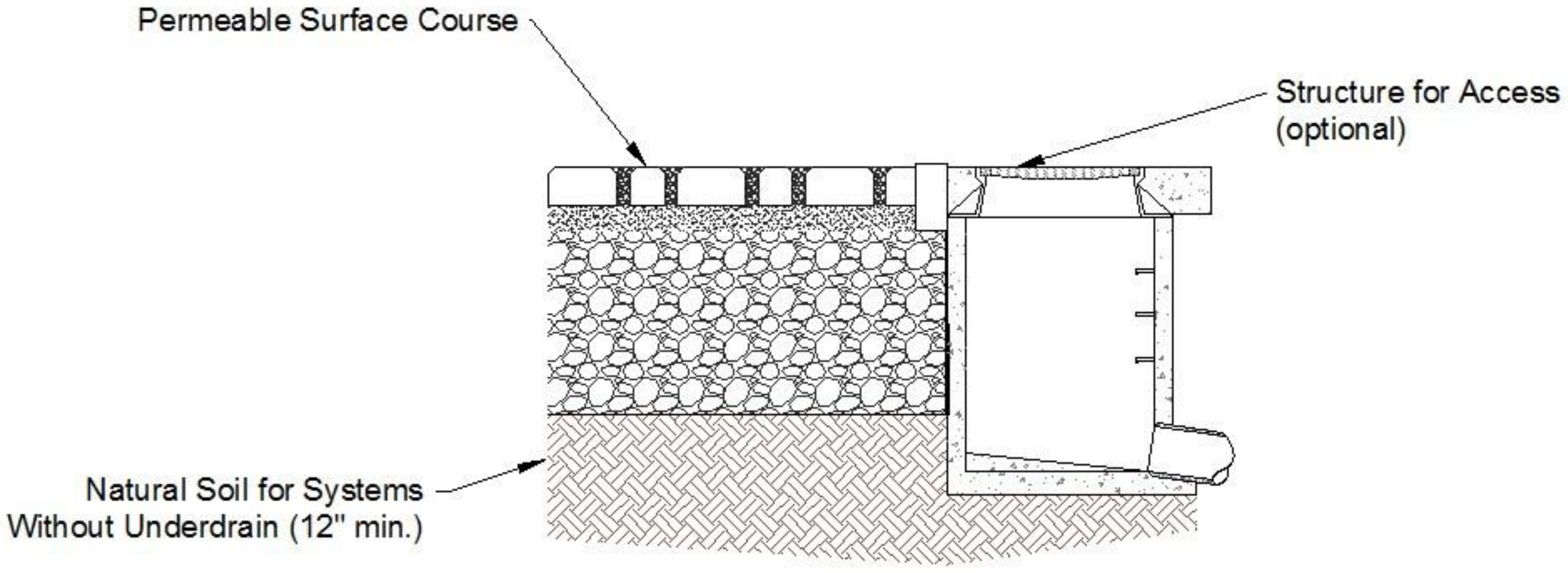
d = 3.4375 ft (depth of reservoir and sub-base/underdrain layers)

A = 33,025 ft^3 / (0.4*3.4375 ft) = 24,018 ft^2 – Typical parking place is 18’ x 9’ = 162 ft^2

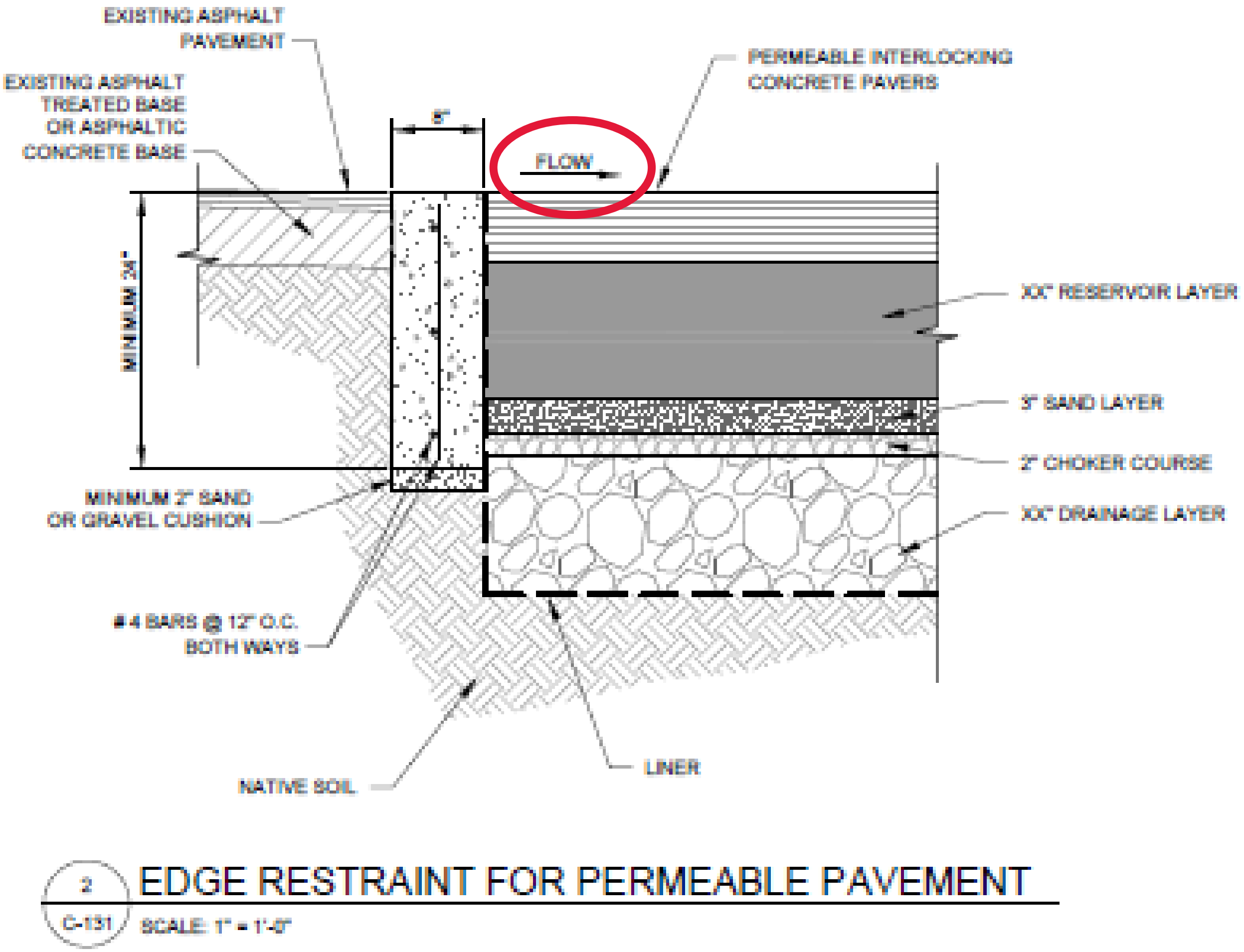
Need approximately 148 parking spots for V_{wq} required to meet 9.34” design storm.

PERMEABLE PAVEMENT | DESIGN FOR SAFE BYPASS/CONVEYANCE OF LARGE STORM

- Safely route runoff in excess of the intended design flow
- One option is to use storm drain inlets slightly above the pavement elevation
- Allow for some ponding on the surface but large flows bypass the system
- Also provides a backup if the system clogs and fails



- Downstream and conveyance systems
  - Assume permeable pavement systems are 35% impervious
  - A reduction in water quality volume requirements can be obtained
- For treatment control, design volume should be equal to the water quality volume at a minimum



EDGE RESTRAINT FOR PERMEABLE PAVEMENT

SCALE: 1" = 1'-0"

PERMEABLE PAVEMENT CONSTRUCTION SEQUENCING

PERMEABLE PAVEMENT | CONSTRUCTION SEQUENCING

PLANNING

- Construction Schedule
  - Identify milestones
    - Preparation of the Subgrade,
    - Installation of hydraulic restriction layers (if part of design),
    - Delivery of reservoir/structural layer,
    - Pavement material delivery and installation
- Prepare SWPPP plans
- Order and coordinate materials delivery and approvals
- Stockpile Materials where possible

SITE PREPARATION

- Demolition (if applicable)
- Excavation
- Infrastructure preparation (curbs, transition strip check dams, internal baffles)

PERMEABLE PAVEMENT | CONSTRUCTION SEQUENCING

IMPLEMENTATION

- Hydraulic Restriction Layers
- Drainage layer and underdrains
- Structural Layer/ Reservoir
- Overflow
- Pavement Material

PERMEABLE PAVEMENT CONSTRUCTION SEQUENCING

PLANNING

PLANNING

- Construction Schedule
  - Expect more RFIs than typical
    - Will need to prepare submittals for
      - Drainage stone
      - Liners
      - Permeable pavement materials
  - Prepare Storm Water Pollution Prevention Plans
  - Verify available materials – up to one month lead time
  - Order and stockpile materials where possible
  - Expect more Construction inspection and oversight
  - Expect it to rain!

- Washed Stone
  - No. 57
  - No. 2

Source: NCSU BAE

PERMEABLE PAVEMENT CONSTRUCTION SEQUENCING

SITE PREPARATION

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SITE PREPARATION

- Demolition (if applicable)
  - For retrofits
- Infiltration area excavation
- Infrastructure preparation
  - Curbs
  - Curb cuts
  - Transition strips
  - Pedestrian strips
  - Check dams and baffles


NOTICE
ALLEY CONSTRUCTION AND ACCESS
CLOSED
AHEAD
FROM 10/15/12 TO 12/31/12
10.16.2012 09:53


10.16.2012 09:53


10.16.2012 14:20

CONSTRUCTION SEQUENCING | SITE PREPARATION

CONSTRUCTION SEQUENCING | SITE PREPARATION

CONSTRUCTION SEQUENCING | SITE PREPARATION

Soil type/Compaction	Number of tests	Average infiltration rate (in/hr)	COV
Noncompacted sandy soils	36	13	0.4
Compacted sandy soils	39	1.4	1.3
Noncompacted and dry clayey soils	18	9.8	1.5
All other clayey soils (compacted and dry, plus all wetter conditions)	60	0.2	2.4

Infiltration Rates during Prior Tests of Disturbed Urban Soils (Pitt, Chen)

CONSTRUCTION SEQUENCING | SITE PREPARATION

- Test Actual Subgrade Infiltration Rate
  - After excavation and before installing aggregate, measure in situ infiltration rate
    - Double ring infiltrometer test
  - Determine level of compaction experienced during construction

CONSTRUCTION SEQUENCING | SITE PREPARATION

CONSTRUCTION SEQUENCING | SITE PREPARATION


CAT
CAT

- Minimize and Mitigate Compaction to Enhance Exfiltration

Source: Tyner 2009

Subgrade compaction	Minimum subgrade treatment	Specification
Low	Scarification	Loosen the top 6 to 9 inches of subgrade using the teeth of an excavator bucket (or comparable).
Low-Medium	Ripping	Using a subsoil ripper or metal bar, rip the subgrade to a depth of 9 to 12 inches, every 3 feet (on center).
High	Trenching	Excavate 1-foot-deep by 1-foot wide trenches into the subgrade, every 6 feet (on center). Fill the bottom of the trench with one-half inch of coarse sand, and top off trench with washed aggregate (No. 57 stone or comparable).

CONSTRUCTION SEQUENCING | SITE PREPARATION

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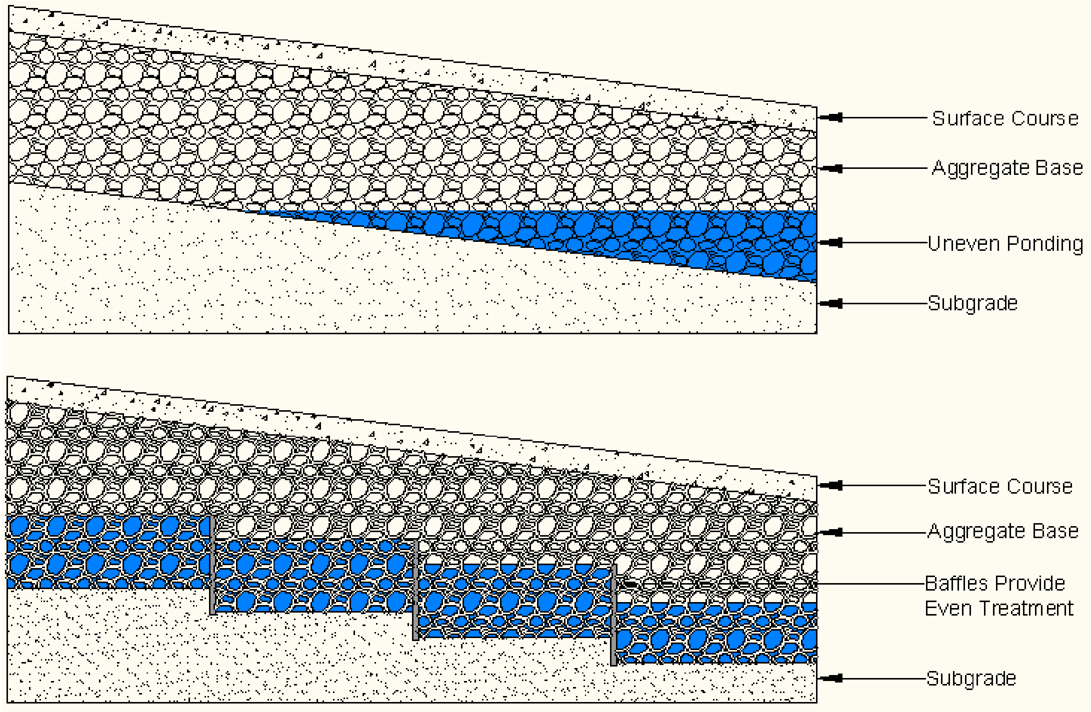
- Internal baffles/check dams



CONSTRUCTION SEQUENCING | SITE PREPARATION

Source: Tyner 2009

PERMEABLE PAVEMENT CONSTRUCTION SEQUENCING

IMPLEMENTATION

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IMPLEMENTATION

- Hydraulic Restriction Layers
- Drainage layer and underdrains
- Structural Layer/ Reservoir
- Overflow
- Pavement Material

- Hydraulic Restriction Layers
  - 30 mil PVC Liner (ASTM D-7176)
  - Concrete
  - Clay (Bentonite)

CONSTRUCTION SEQUENCING | IMPLEMENTATION

- Hydraulic Restriction Layers
  - 30 mil PVC Liner (ASTM D-7176)
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CONSTRUCTION SEQUENCING | IMPLEMENTATION

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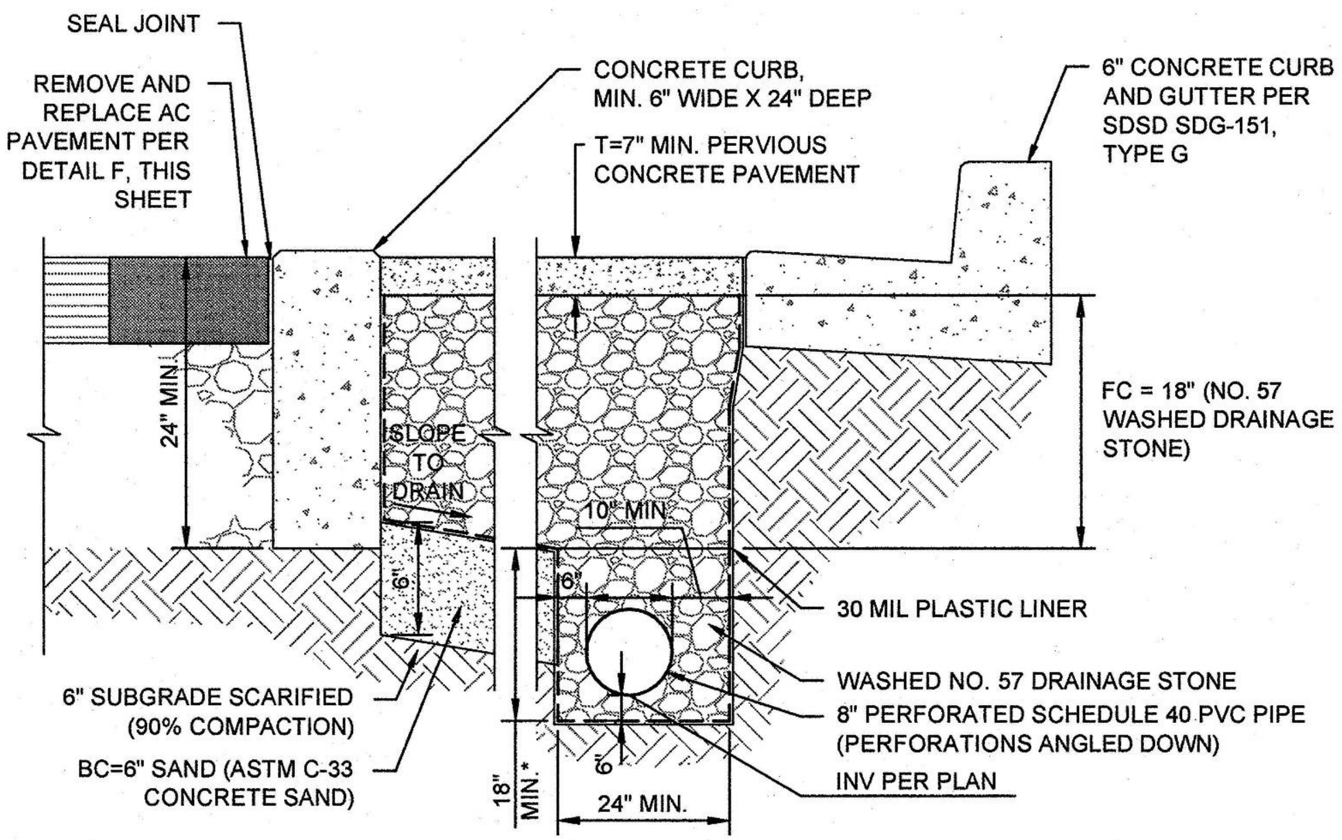
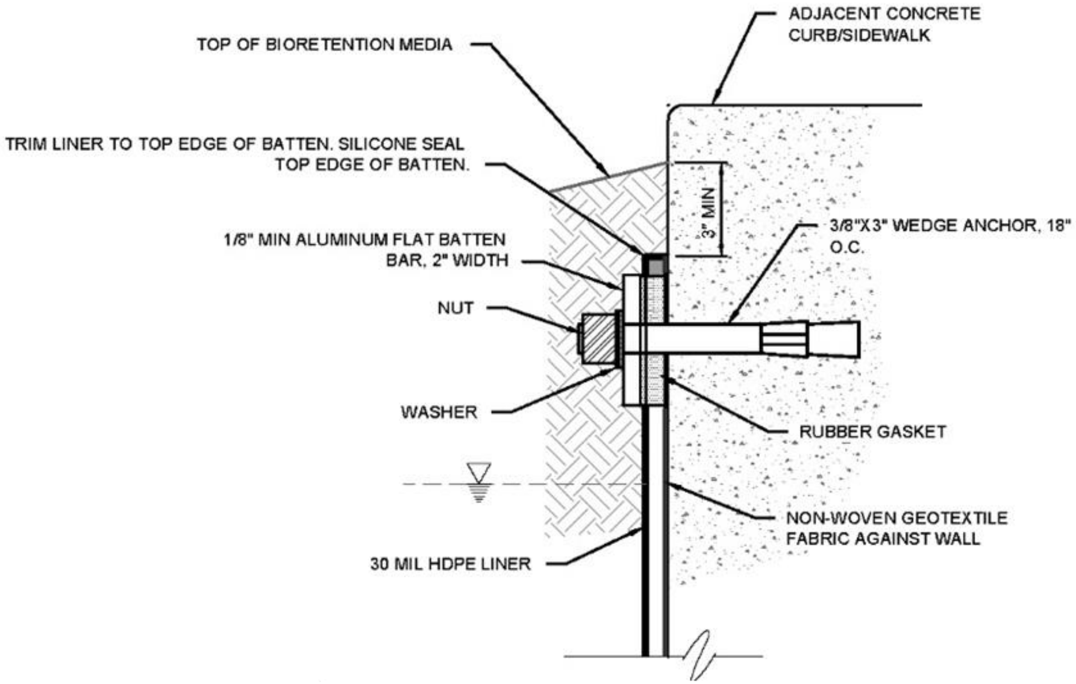


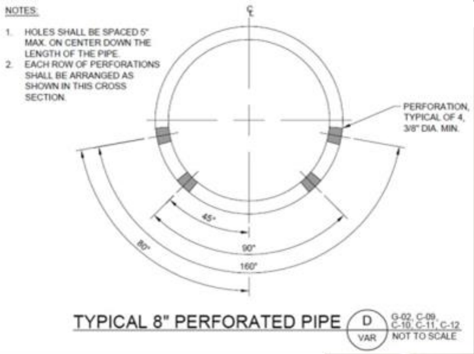
- Hydraulic Restriction Layers
  - 30 mil PVC Liner (ASTM D-7176)
  - Concrete
  - Clay (Bentonite)

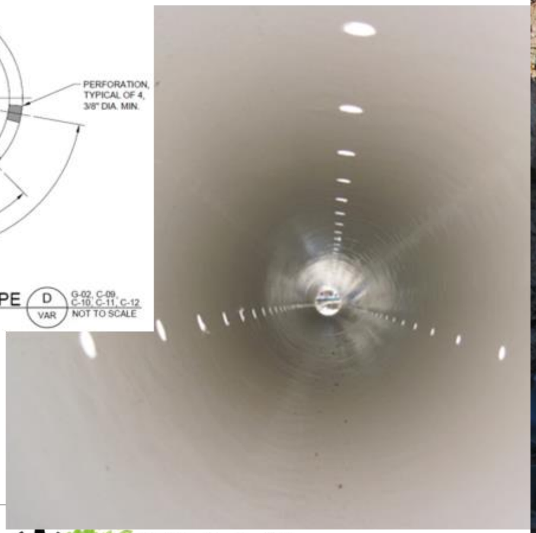
CONSTRUCTION SEQUENCING | IMPLEMENTATION

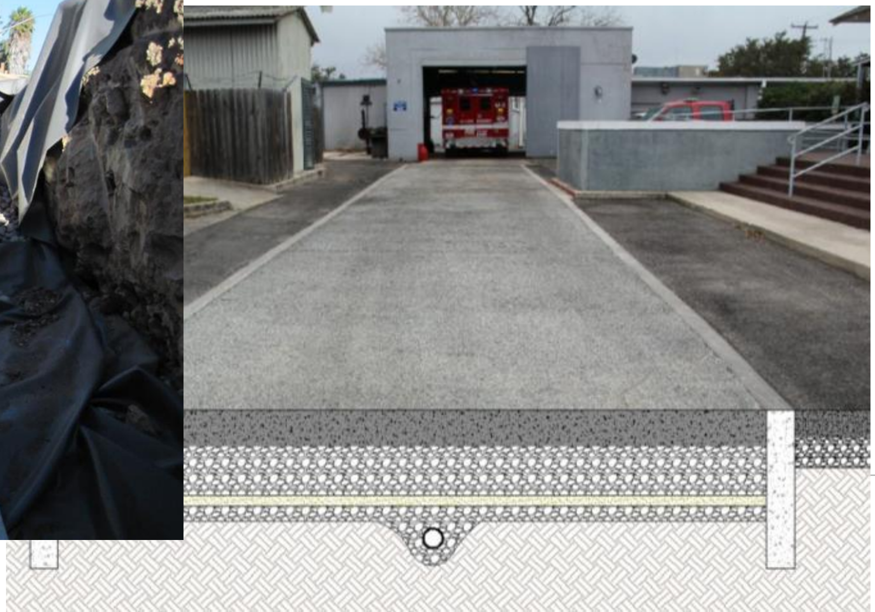


CONSTRUCTION SEQUENCING | IMPLEMENTATION

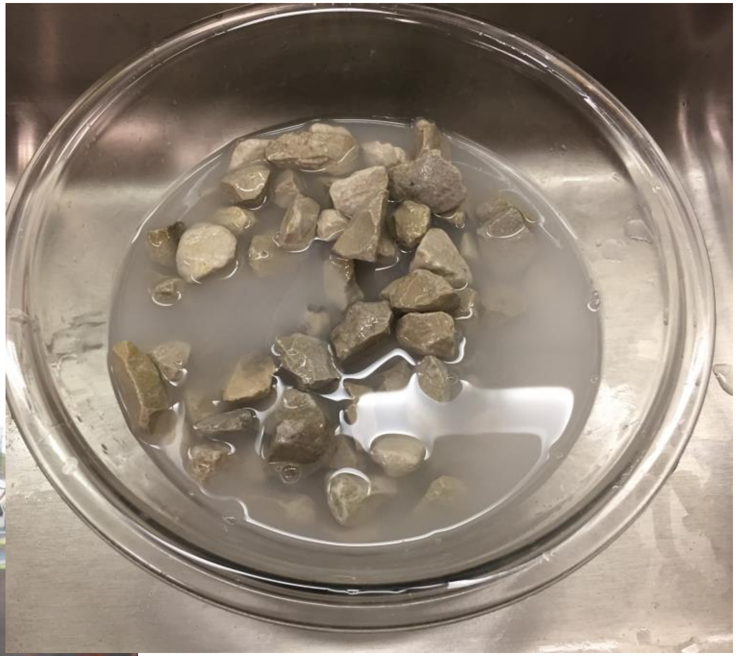
Underdrain Component	Specification
Diameter	4-inch minimum
Material	Perforated Schedule 40 PVC
Perforation Type	Slotted or round
Perforation Spacing and Placement	Max 6 inches, underdrain flow should not limit infiltration through the pavement, sand filter layer, or storage layer. *If an anaerobic zone is intended, the perforation can be placed at the top of the pipe.*
Slope	1% minimum slope toward outlet
Cleanout Access	Rigid, unperforated observation pipes with a diameter equal to the underdrain diameter every 250 to 300 feet in larger systems. The wells/cleanouts must extend 6 inches above the mulch or sod layer and be capped with a screw cap.
Outfall	Connected to a vegetated swale, daylight to a vegetated dispersion area using an effective flow dispersion device, stored for reuse, or to a stormwater drainage system.





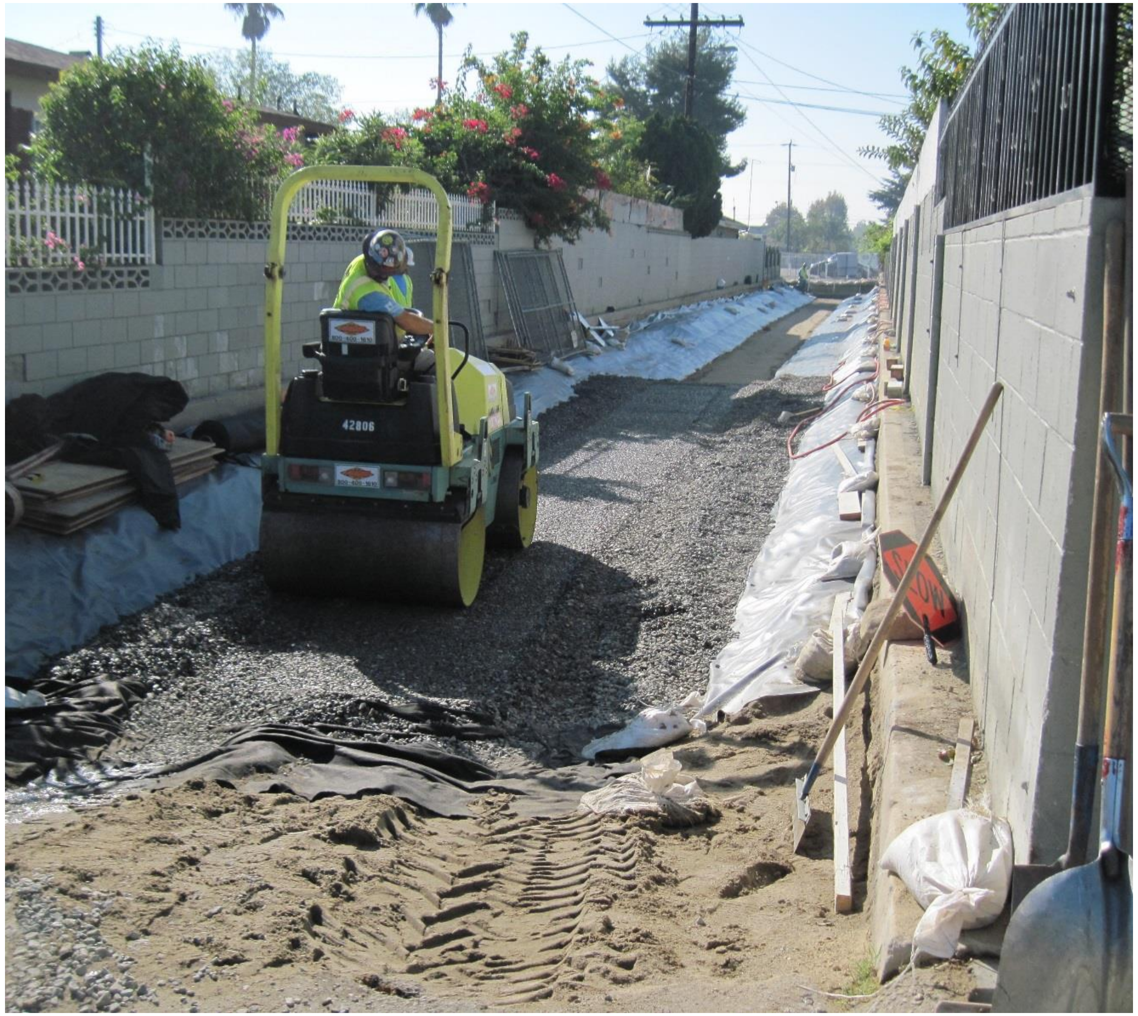


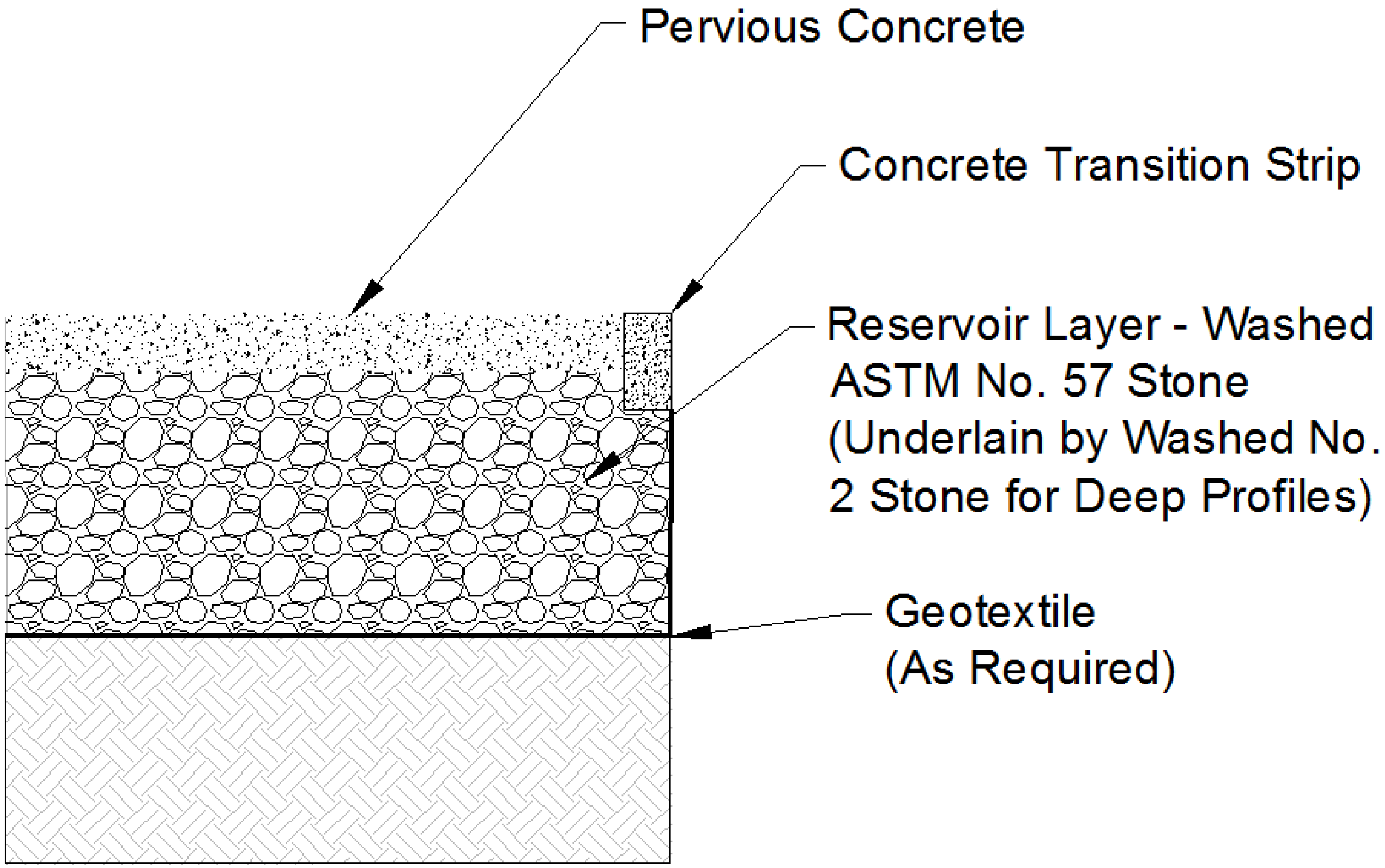
- Inspect Aggregate Upon Delivery
  - subbase courses should be thoroughly washed to prevent fines from clogging the subsoil interface or underdrains (Fassman and Blackbourne 2010)



- Note clean, freshly washed No. 2 Stone

- No 57 Structural Layer




Pervious Concrete
Concrete Transition Strip
Reservoir Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)

- Inspect the mix when delivered

- Inspect the mix when delivered

IMPLEMENTATION | PERVIOUS CONCRETE

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IMPLEMENTATION | PERVIOUS CONCRETE

IMPLEMENTATION | PERVIOUS CONCRETE

- Framed in 10 feet sections

- Strip to control compaction

- Screened and compacted

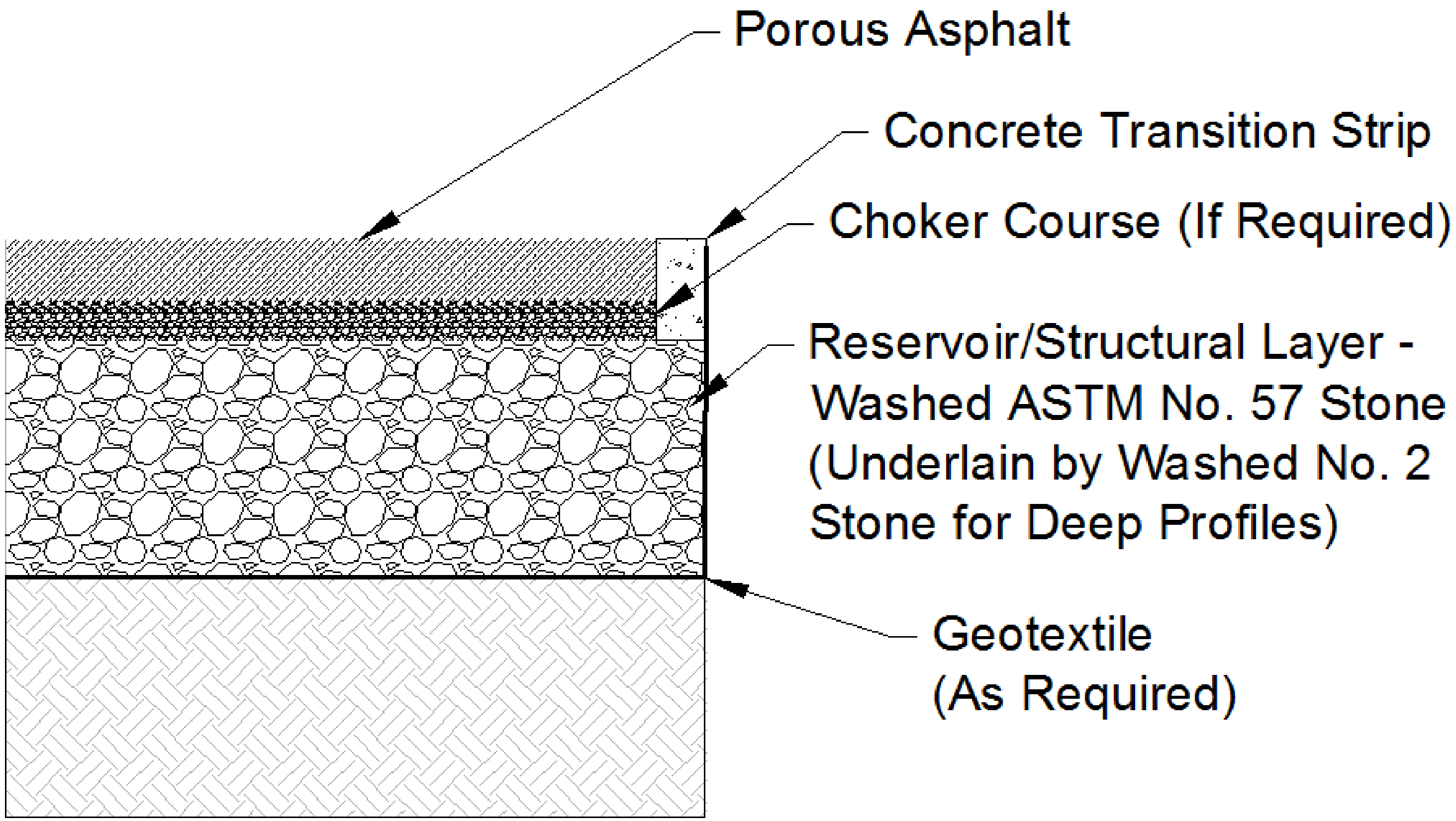
- Compacted to specified level of compaction

- Covered for 7 to 14 days to cure properly

- Transition strip

IMPLEMENTATION | PERVIOUS CONCRETE

IMPLEMENTATION | PERVIOUS CONCRETE


Porous Asphalt
Concrete Transition Strip
Choker Course (If Required)
Reservoir/Structural Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)

IMPLEMENTATION | POROUS ASPHALT

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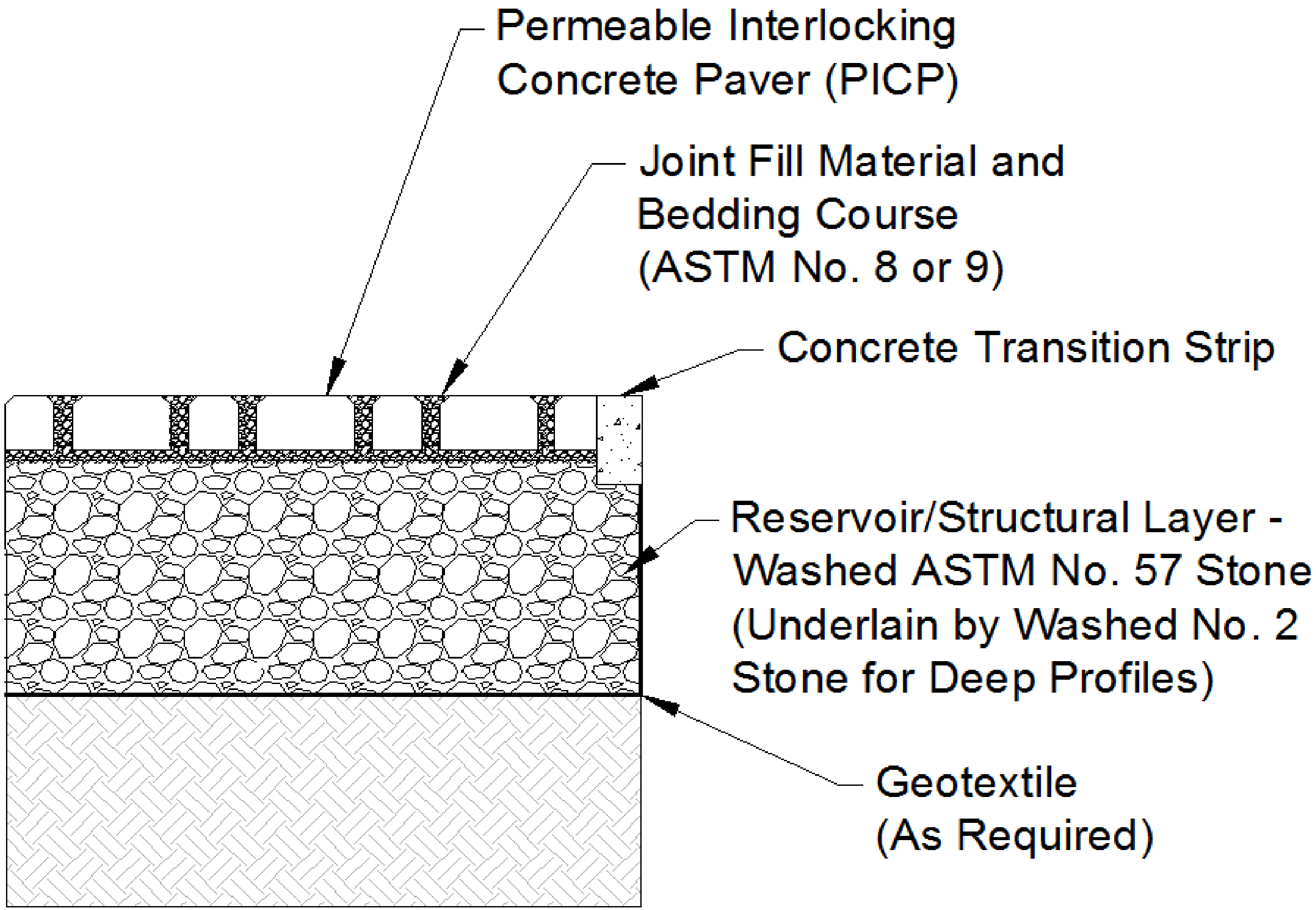

Permeable Interlocking Concrete Paver (PICP)
Joint Fill Material and Bedding Course (ASTM No. 8 or 9)
Concrete Transition Strip
Reservoir/Structural Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)

IMPLEMENTATION | PERMEABLE INTERLOCKING CONCRETE PAVERS

- Pavers placed manually

- Compacted in place

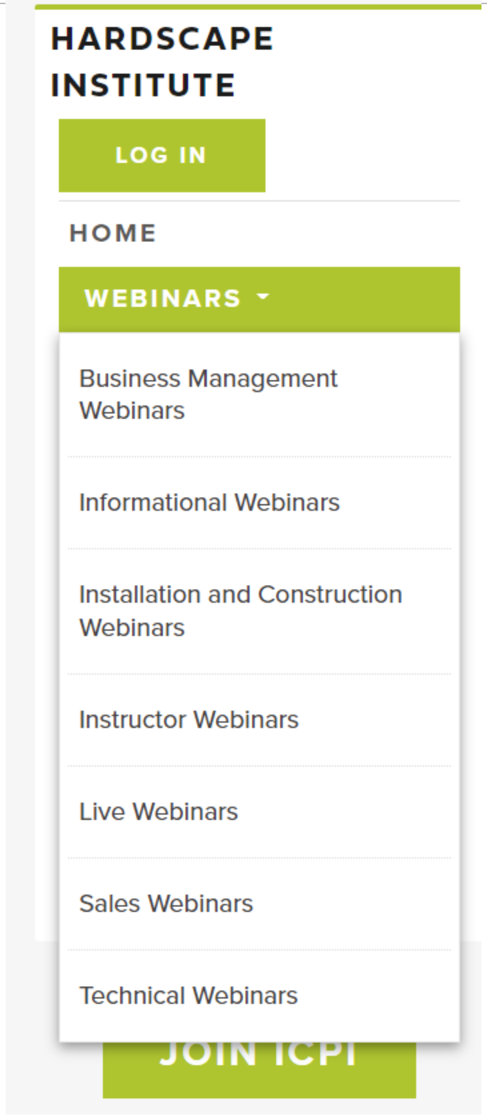
- Place fill material

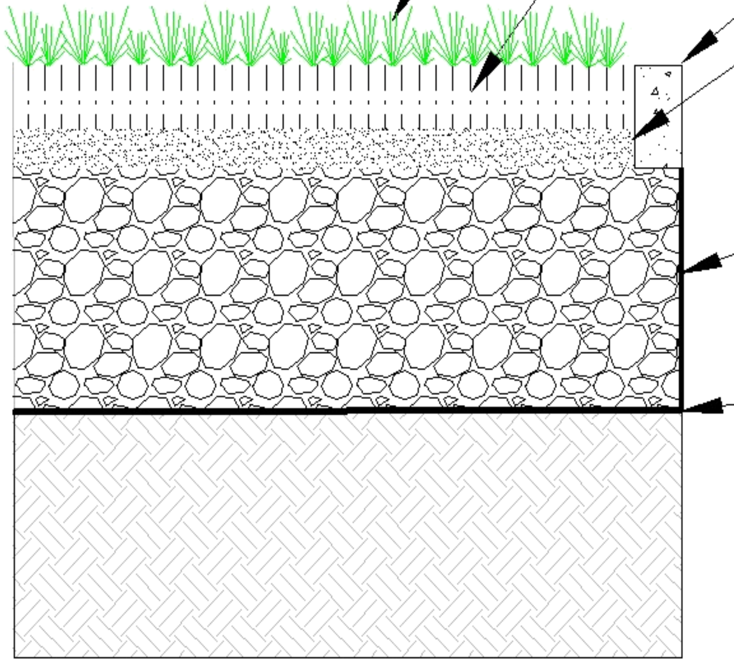
- Cut and place pavers

- A concrete transition strip prevents settling

- Edge Collapse due to structural failure.

- These systems should be installed by a qualified professional
  - The only exception is very small backyard patios where BMP failure will not be hazardous to human health
  - A list of professionals qualified in permeable paver installation is available through the Interlocking Concrete Pavement Institute (ICPI)
  - \- www.icpi.org
  - More information on pervious concrete is available through the Texas Aggregates and Concrete Association (TACA)
  - \- www.tx-taca.org




Appropriate Vegetation
or Gravel
Plastic Grid Paver
Concrete Transition Strip
Bedding Layer
(Gravel or Sand)
Reservoir/Structural Layer
(Washed ASTM No. 57 Stone)
Geotextile
(As Required)

IMPLEMENTATION | PLASTIC GRID / TURF PAVERS

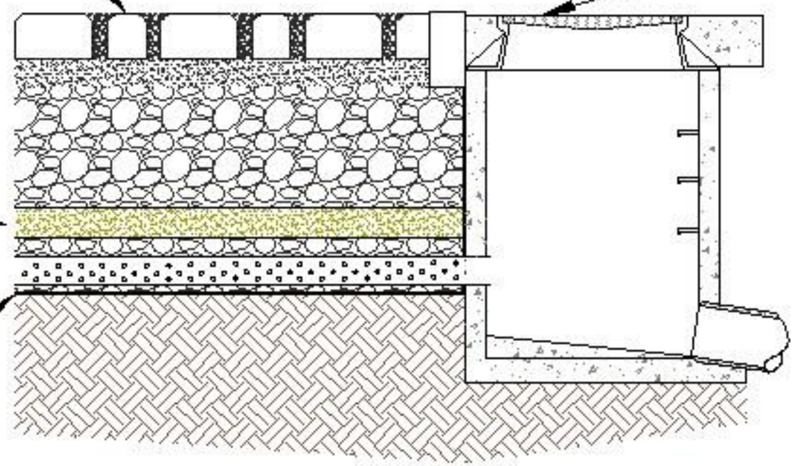
IMPLEMENTATION | PLASTIC GRID / TURF PAVERS

IMPLEMENTATION | PLASTIC GRID / TURF PAVERS

IMPLEMENTATION | PLASTIC GRID / TURF PAVERS

IMPLEMENTATION | PLASTIC GRID / TURF PAVERS

- Min. of 4 inches of ASTM C-33 washed sand above the aggregate of the underdrain drainage layer (Barrett 2005)
- Enhance water quality



- Observation Wells
  - Monitor the drawdown rate
  - Perforated PVC pipe (4-inch diameter or greater)
  - Sealed with watertight caps

INSPECTION AND MAINTENANCE OF PERMEABLE PAVEMENT

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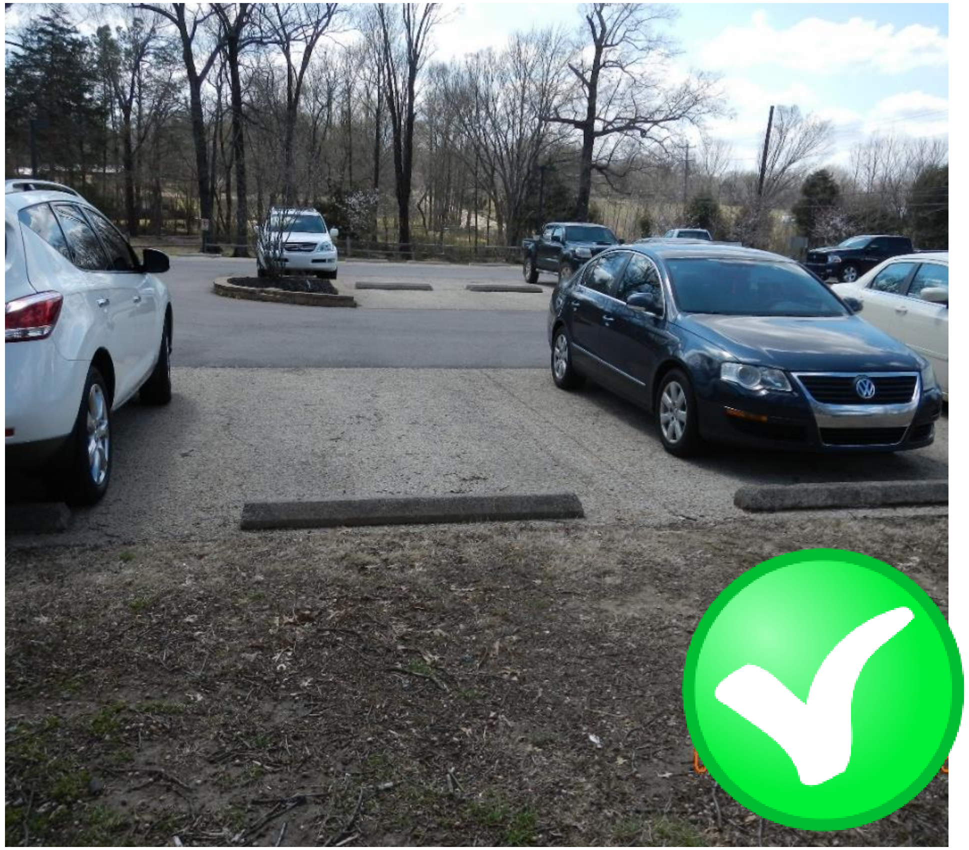
PERMEABLE PAVEMENT 'EDGE'

- Landscape along edge should slope away from pavement



SURROUNDING LANDSCAPE MAINTENANCE

- Maintain good vegetative cover on all surrounding landscape
- Blow leaves and grass off pavement before they can decompose or be ground into the permeable pavement
- Blow grass discharge from mowers away from permeable pavement
- Avoid spillage of dumpster juice and oil leaks if possible

GRASS CLIPPINGS

- What to do here?
- Can the debris be blown off?
- Use of vegetation other than turf grass or inorganic mulch would be a better choice

- The enemy of permeable pavement:

  Sediment and organic matter….

PERMEABLE CONCRETE

- Open and Permeable
- Clogged

- Look for signs that water is flowing over the surface instead of through the pavement

- Look for signs of water ponding on the surface instead of infiltrating through the pavement

STANDARD CLOGGING RULE OF THUMB

- If only 10-20% of surface is clogged the total system should be working fine (Resilience built in!)
- Street sweeping is optional unless a test shows significant clogging

MAINTENANCE SCHEDULE

Table 24.1 Typical Maintenance Activities for Modular Porous Paver Systems

Activity	Schedule
• Ensure that the porous paver surface is free of extraneous sediment. • Check to make sure that the system dewaters between storms.	Monthly
• Clear debris from contributing area and porous paver surface. • Stabilize and mow contributing adjacent areas and remove clippings.	As needed, based on inspection
• Vacuum sweep porous paver surface to keep free of sediment.	Typically three to four times a year
• Inspect the surface for deterioration or spalling.	Annually
• Totally rehabilitate the porous paver system, including the top and base course.	Upon failure

MAINTENANCE SCHEDULE

Table 25.1 Typical Maintenance Activities for Porous Concrete Systems

Activity	Schedule
• Initial inspection	Monthly for three months after installation
• Ensure that the porous paver surface is free of sediment	Monthly
• Ensure that the contributing and adjacent area is stabilized and mowed, with clippings removed	As needed, based on inspection
• Vacuum sweep porous concrete surface followed by high pressure hosing to keep pores free of sediment	Four times a year
• Inspect the surface for deterioration or spalling • Check to make sure that the system dewaters between storms	Annually
• Spot clogging can be handled by drilling half-inch holes through the pavement every few feet • Rehabilitation of the porous concrete system, including the top and base course as needed	Upon failure

INSPECTION AND MAINTENANCE OF PERMEABLE PAVEMENT

HOW TO TEST INFILTRATION

- How to test infiltration...

SIMPLE INFILTRATION TEST

- Performed in under 5 minutes by individual
- Easily-furnished and cheap materials
- Shallow head conditions…
  - Better predict actual infiltration during rainfall
  - Reduce lateral seepage
- Simple!

STEP 1: CONSTRUCT THE DEVICE

- Materials:
  - One 8-foot piece of unwarped 2”x4” lumber
  - Screws and drill
  - 80 oz. plumber’s putty (approx.)
  - 5 gallon bucket of water
  - Stopwatch or timepiece
- Cut 2x4 into four sections and screw together into rectangular frame

STEP 2: APPLY PLUMBER'S PUTTY AND PLACE

- Apply 1" bead of plumber's putty to the frame (or inside)
- Place frame in area to be tested and apply gentle pressure to seal

STEP 3: RAPIDLY ADD 5 GAL. WATER & TIME

- Apply weight to frame to maintain seal
- Quickly pour contents of one 5-gal bucket and begin timing
- Record time for all standing water to infiltrate joints/voids

STEP 4: ASSESS PERFORMANCE & PRESCRIBE MAINTENANCE

Drawdown Time	Hydraulic Condition
< 30 seconds	Newly Installed / Recently Maintained
30-90 seconds	Acceptable – Continue Preventative Maintenance. Consider Regen Air S.S.?
90-300 seconds	Partially Clogged – Regen Air Street Sweeper NEEDED
> 300 seconds	Clogged – Vac Truck Time?

INSPECTION AND MAINTENANCE OF PERMEABLE PAVEMENT

WHAT TO DO IF SYSTEM IS CLOGGED?

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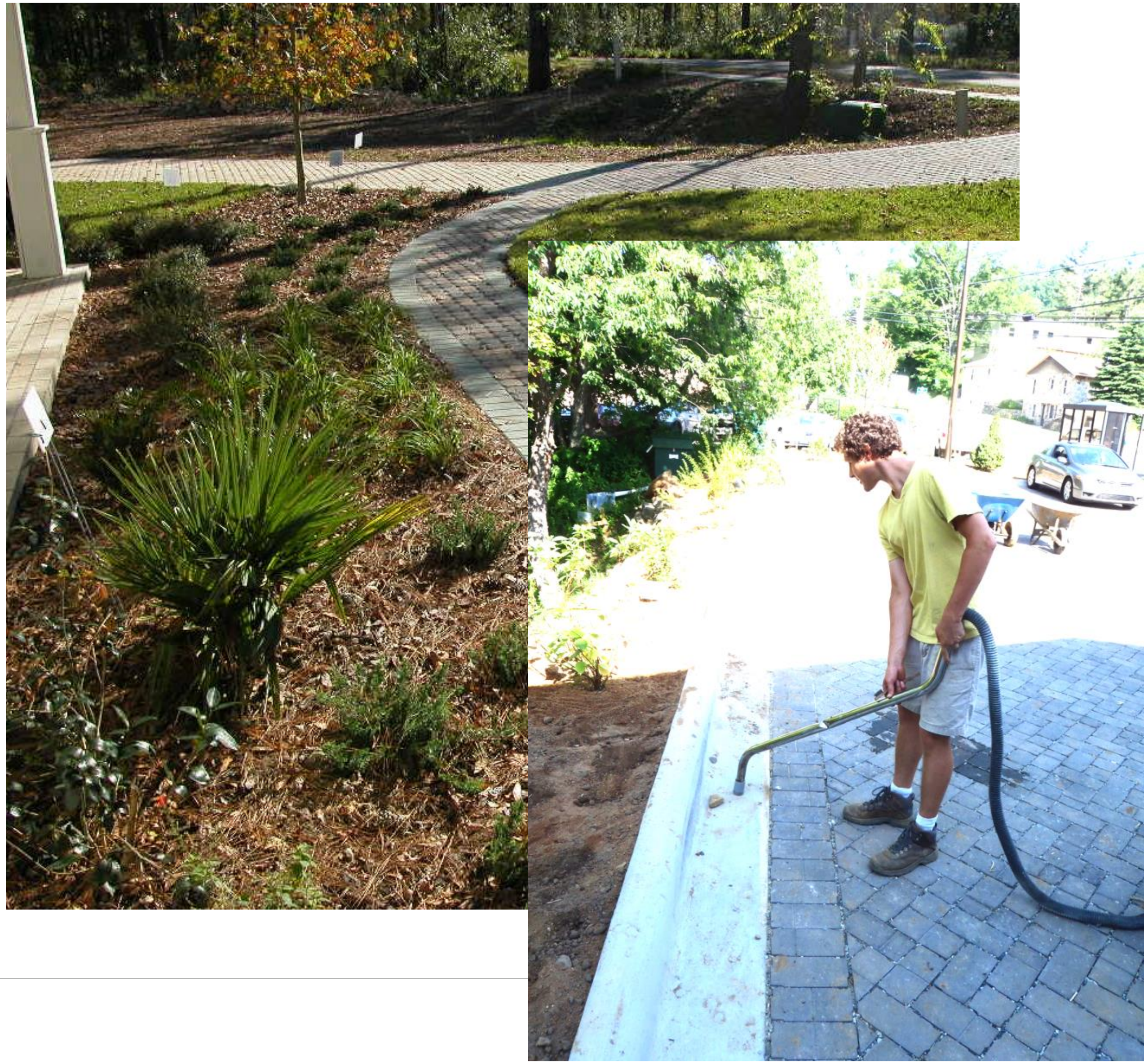
SMALL- SCALE OPTIONS

- Possible to maintain with a good leaf blower and a shop vac if performed regularly



STREET SWEEPERS TO VACUUM TRUCKS

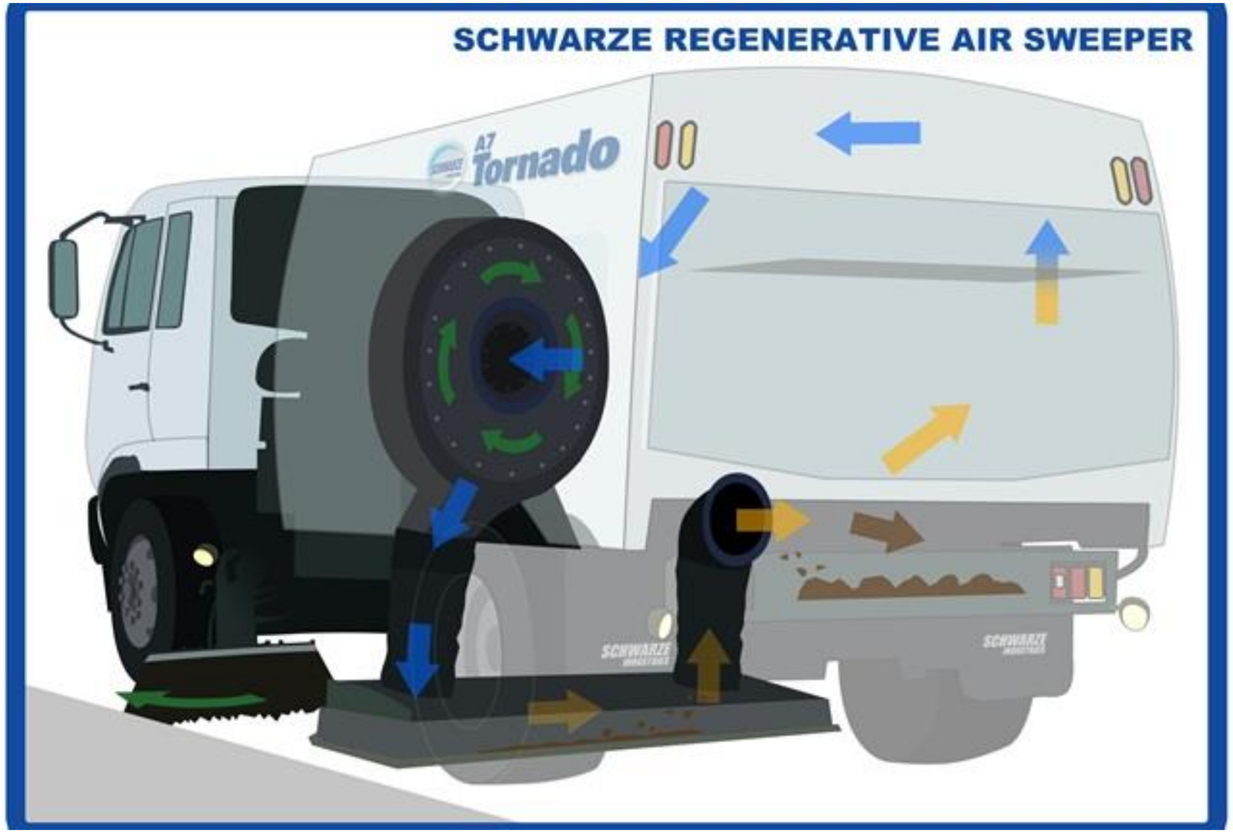
- Different Types of Sweepers for Different Types of Permeable Pavements:
- Mechanical Sweeper vs. Regenerative Air Sweeper vs. Vacuum Sweeper

MECHANICAL STREET SWEEPERS

- Mechanical or Broom Sweeper components:
  - broom to conveyor to hopper
- Do a good job of stirring up top of sand layer
- Good for concrete grid pavers (CGP)
  - bristle penetration is not enough for other types of permeable pavement

REGENERATIVE AIR STREET SWEEPERS

- Regenerative Air Street Sweepers pick up debris by vacuum and blasted air
- Good for preventative maintenance for:
  - PICP
  - Pervious Concrete
  - Pervious Asphalt
- May not work for Restorative Maintenance



VACUUM STREET SWEEPERS

- Vacuum Sweepers pick up debris by vacuum
- The most powerful street sweeper
- Must be careful not to ‘over’ vacuum the fill material between pavers – can destabilize them
- Use for restorative maintenance if clogging is not too deep….

VACUUM STREET SWEEPERS

OIL AND GREASE DEPOSITS

- How to clean?

- Add Stain Remover…

  let it soak, then pressure wash…

WHAT ABOUT PRESSURE WASHING?

- "Both sand and clay caused measurable clogging that was not reversible by pressure washing."
- From Coughlin et al. Journal of Hydrologic Engineering, 2012

QUESTIONS?

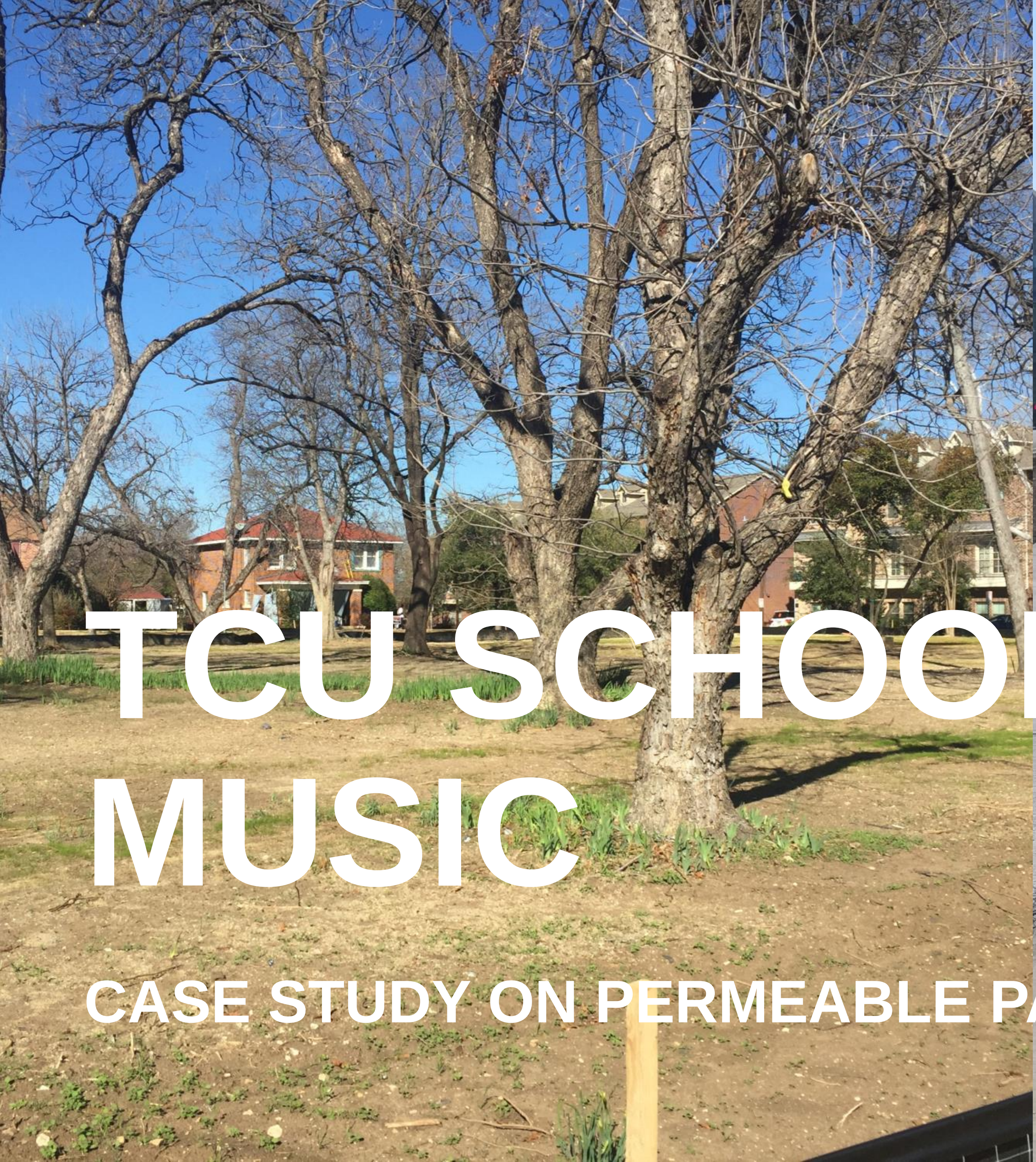
CASE STUDIES

CASE STUDIES

TCU

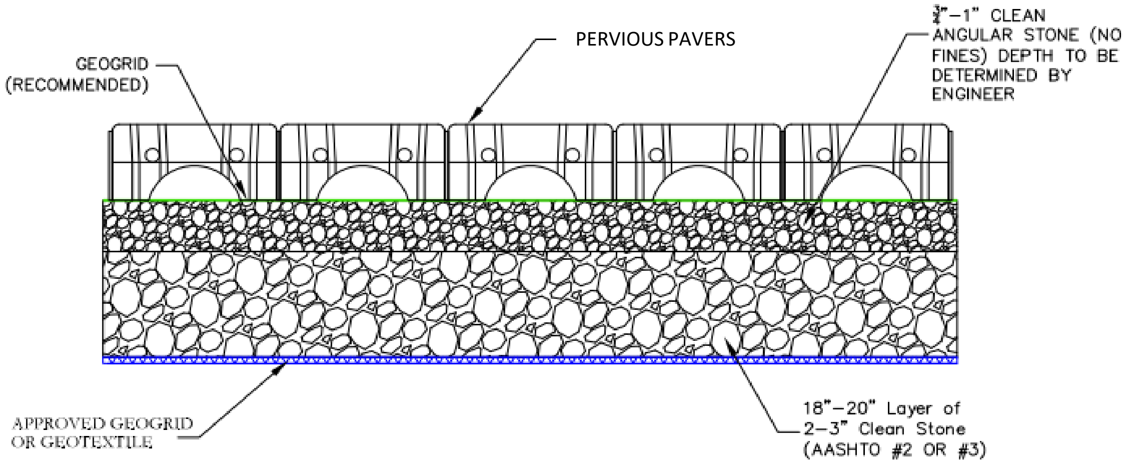
TCU SCHOOL OF MUSIC

CASE STUDY ON PERMEABLE PAVEMENT

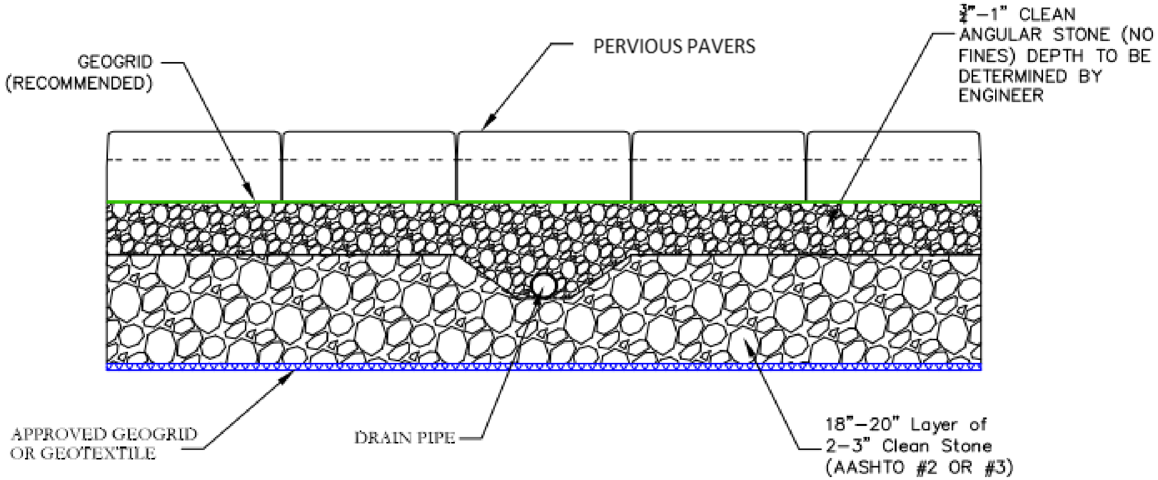


PERMEABLE PAVERS SCHEMATIC

- Pavers allow for an average curve number of 30 (similar to that of fair grade grasses)
- Infiltration rates of up to 4,000 in/hr



CROSS–SECTION
END VIEW



CROSS–SECTION
SIDE VIEW

PROJECT AREA – PRE-PROJECT

PROJECT AREA – POST PROJECT

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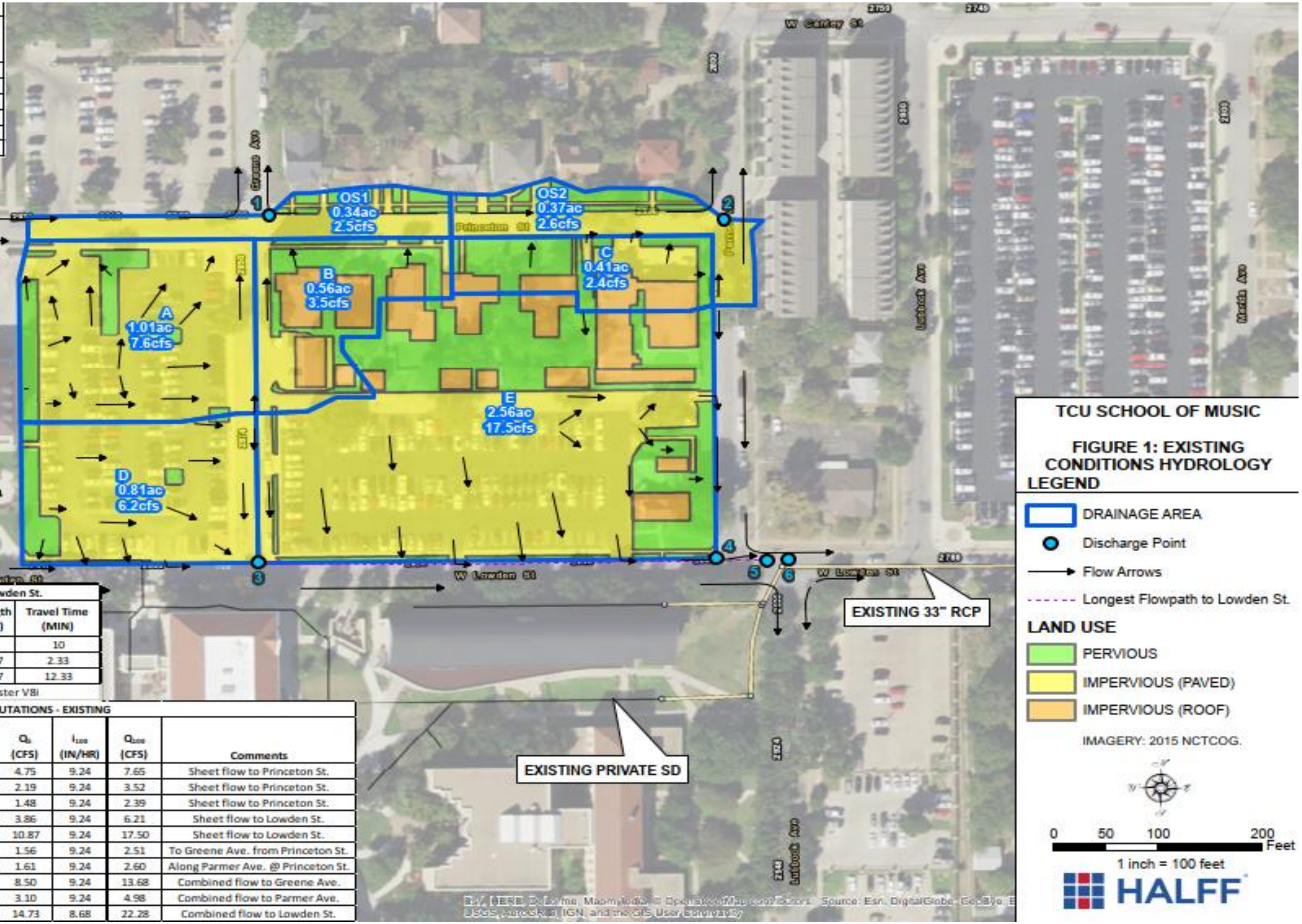
EXISTING CONDITIONS DISCHARGE POINTS SUMMARY			
DISCHARGE POINT ID	CONTRIBUTING DRAINAGE AREAS	Q100 (CFS)	Comments
1	A,B,OS1	13.68	Combined flow to Greene Ave.
2	C,OS2	4.98	Combined flow to Parmer Ave.
3	D	6.21	Sheet flow to Lowden St.
4	E	17.50	Sheet flow to Lowden St.
5	-	-	-
6	D,E	22.28	Combined flow to Lowden St.



TCU SCHOOL OF MUSIC

FIGURE 1: EXISTING CONDITIONS HYDROLOGY

Time of Concentration Calculation for Drainage Area to Lowden St.				
Segment Type	Gutter Slope (FT/FT)	V[1] (FT/S)	Length (FT)	Travel Time (MIN)
Time to Discharge Point 3 (Minimum Tc)				10
Gutter Flow	0.0082	3.48	487	2.33
TOTAL:		-	487	12.33

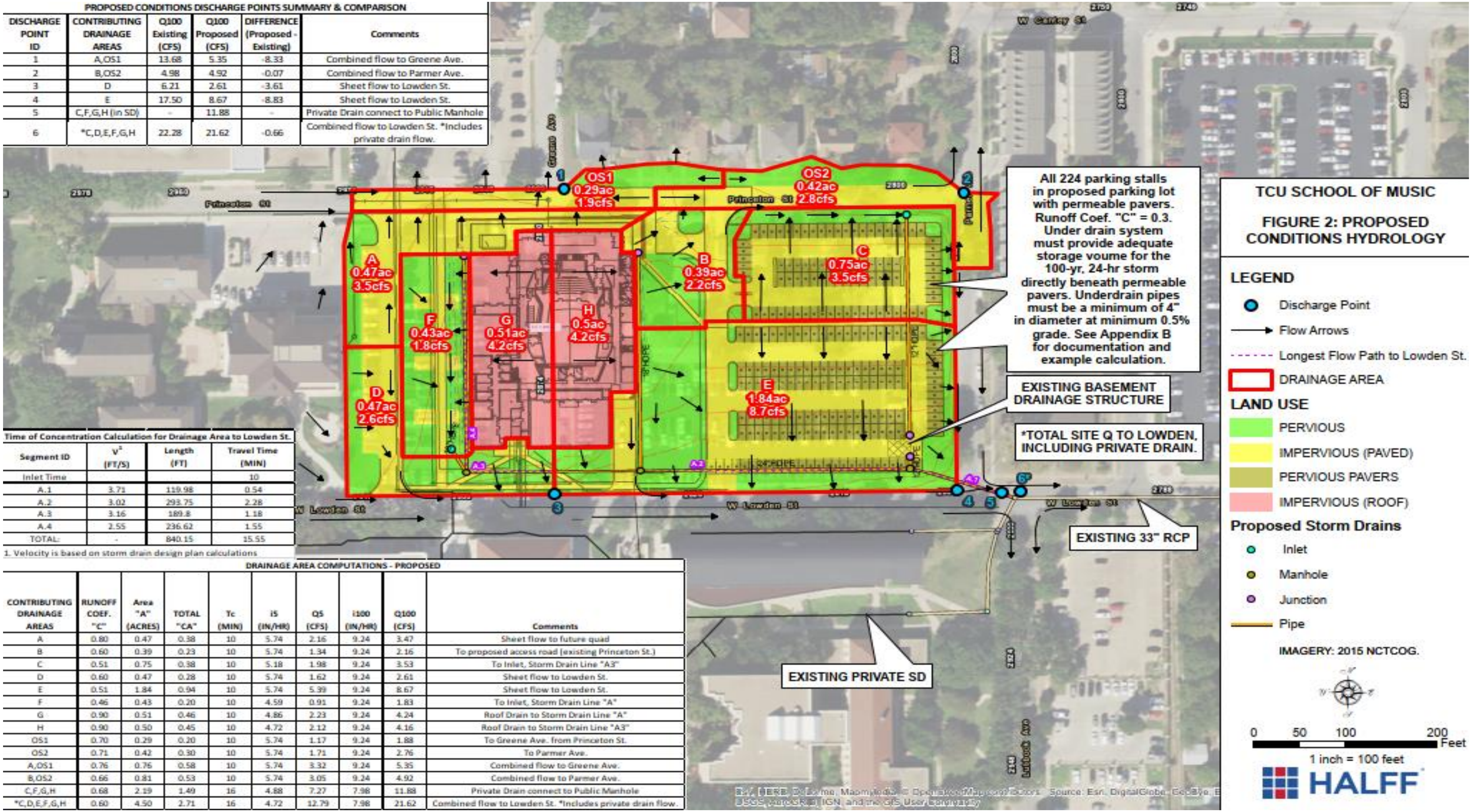
1. Velocity is based on Manning's Equation calculation using Flowmaster V8i

DRAINAGE AREA COMPUTATIONS - EXISTING

CONTRIBUTING DRAINAGE AREAS	RUNOFF COEF. "C"	Area "A" (ACRES)	TOTAL "CA"	T_c (MIN)	i_5 (IN/HR)	Q_5 (CFS)	i_{100} (IN/HR)	Q_{100} (CFS)	Comments
A	0.82	1.01	0.83	10	5.74	4.75	9.24	7.65	Sheet flow to Princeton St.
B	0.68	0.56	0.38	10	5.74	2.19	9.24	3.52	Sheet flow to Princeton St.
C	0.63	0.41	0.26	10	5.74	1.48	9.24	2.39	Sheet flow to Princeton St.
D	0.83	0.81	0.67	10	5.74	3.86	9.24	6.21	Sheet flow to Lowden St.
E	0.74	2.56	1.89	10	5.74	10.87	9.24	17.50	Sheet flow to Lowden St.
OS1	0.80	0.34	0.27	10	5.74	1.56	9.24	2.51	To Greene Ave. from Princeton St.
OS2	0.76	0.37	0.28	10	5.74	1.61	9.24	2.60	Along Parmer Ave. @ Princeton St.
A,B,OS1	0.78	1.91	1.48	10	5.74	8.50	9.24	13.68	Combined flow to Greene Ave.
C,OS2	0.69	0.78	0.54	10	5.74	3.10	9.24	4.98	Combined flow to Parmer Ave.
D,E	0.76	3.37	2.57	12	5.74	14.73	8.68	22.28	Combined flow to Lowden St.

PROPOSED CONDITIONS DISCHARGE POINTS SUMMARY & COMPARISON

DISCHARGE POINT ID	CONTRIBUTING DRAINAGE AREAS	Q100 Existing (CFS)	Q100 Proposed (CFS)	DIFFERENCE (Proposed - Existing)	Comments
1	A,OS1	13.68	5.35	-8.33	Combined flow to Greene Ave.
2	B,OS2	4.98	4.92	-0.07	Combined flow to Parmer Ave.
3	D	6.21	2.61	-3.61	Sheet flow to Lowden St.
4	E	17.50	8.67	-8.83	Sheet flow to Lowden St.
5	C,F,G,H (in SD)	-	11.88	-	Private Drain connect to Public Manhole
6	*C,D,E,F,G,H	22.28	21.62	-0.66	Combined flow to Lowden St. *Includes private drain flow.



Time of Concentration Calculation for Drainage Area to Lowden St.

Segment ID	V[1] (FT/S)	Length (FT)	Travel Time (MIN)
Inlet Time			10
A.1	3.71	119.98	0.54
A.2	3.02	293.75	2.28
A.3	3.16	189.8	1.18
A.4	2.55	236.62	1.55
TOTAL:	-	840.15	15.55

1. Velocity is based on storm drain design plan calculations

DRAINAGE AREA COMPUTATIONS - PROPOSED

CONTRIBUTING DRAINAGE AREAS	RUNOFF COEF. "C"	Area "A" (ACRES)	TOTAL "CA"	Tc (MIN)	i5 (IN/HR)	Q5 (CFS)	i100 (IN/HR)	Q100 (CFS)	Comments
A	0.80	0.47	0.38	10	5.74	2.16	9.24	3.47	Sheet flow to future quad
B	0.60	0.39	0.23	10	5.74	1.34	9.24	2.16	To proposed access road (existing Princeton St.)
C	0.51	0.75	0.38	10	5.18	1.98	9.24	3.53	To Inlet, Storm Drain Line "A3"
D	0.60	0.47	0.28	10	5.74	1.62	9.24	2.61	Sheet flow to Lowden St.
E	0.51	1.84	0.94	10	5.74	5.39	9.24	8.67	Sheet flow to Lowden St.
F	0.46	0.43	0.20	10	4.59	0.91	9.24	1.83	To Inlet, Storm Drain Line "A"
G	0.90	0.51	0.46	10	4.86	2.23	9.24	4.24	Roof Drain to Storm Drain Line "A"
H	0.90	0.50	0.45	10	4.72	2.12	9.24	4.16	Roof Drain to Storm Drain Line "A3"
OS1	0.70	0.29	0.20	10	5.74	1.17	9.24	1.88	To Greene Ave. from Princeton St.
OS2	0.71	0.42	0.30	10	5.74	1.71	9.24	2.76	To Parmer Ave.
A,OS1	0.76	0.76	0.58	10	5.74	3.32	9.24	5.35	Combined flow to Greene Ave.
B,OS2	0.66	0.81	0.53	10	5.74	3.05	9.24	4.92	Combined flow to Parmer Ave.
C,F,G,H	0.68	2.19	1.49	16	4.88	7.27	7.98	11.88	Private Drain connect to Public Manhole
*C,D,E,F,G,H	0.60	4.50	2.71	16	4.72	12.79	7.98	21.62	Combined flow to Lowden St. *Includes private drain flow.

DISCHARGE COMPARISON

- The overall site runoff will be reduced from 42 cfs to 35 cfs, a reduction of 7 cfs

PROPOSED CONDITIONS DISCHARGE POINTS SUMMARY & COMPARISON					
DISCHARGE POINT ID	CONTRIBUTING DRAINAGE AREAS	Q100 Existing (CFS)	Q100 Proposed (CFS)	DIFFERENCE (Proposed - Existing)	Comments
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CASE STUDIES

SAN ANTONIO RIVER AUTHORITY HEADQUARTERS

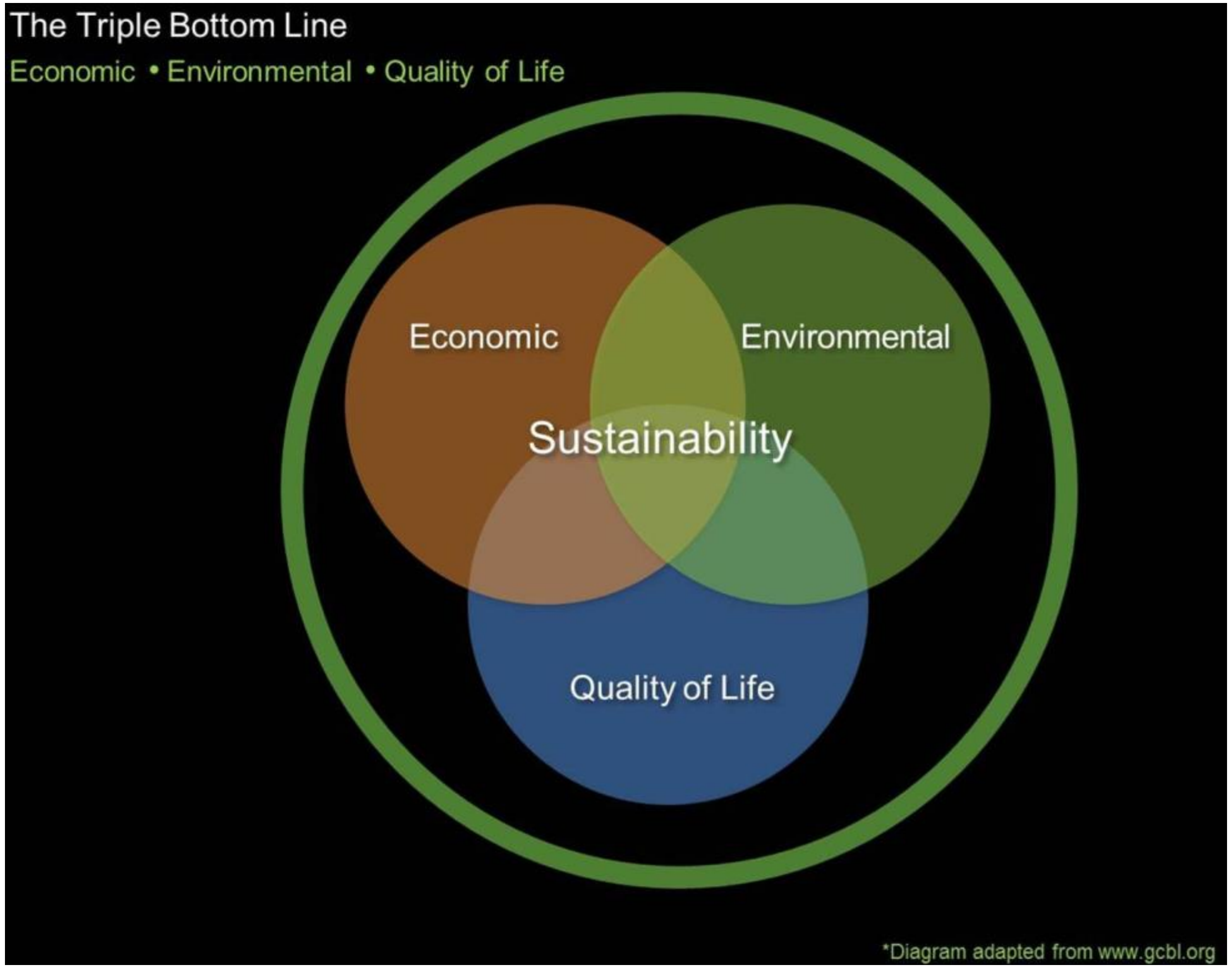

SAN ANTONIO RIVER AUTHORITY HEADQUARTERS RETROFIT
CASE STUDY ON PERMEABLE PAVEMENT AND SITE DESIGN

EXISTING SITE CONSIDERATIONS

- Grading
- Landscaping
- Downspouts
- Utilities
- Parking
- Maintenance

TRIPLE BOTTOM LINE ANALYSIS

- Environmental
  - Pounds of sediment and nutrient removed (modeling analysis required)
  - Increased groundwater recharge
  - Stormwater Infrastructure
- Economic
  - Full life cycle costs
  - Stormwater treatment benefits
  - Irrigation and maintenance costs reduced
- Quality of Life
  - Increased habitat for pollinators
  - Healthier trees
  - Cleaner river



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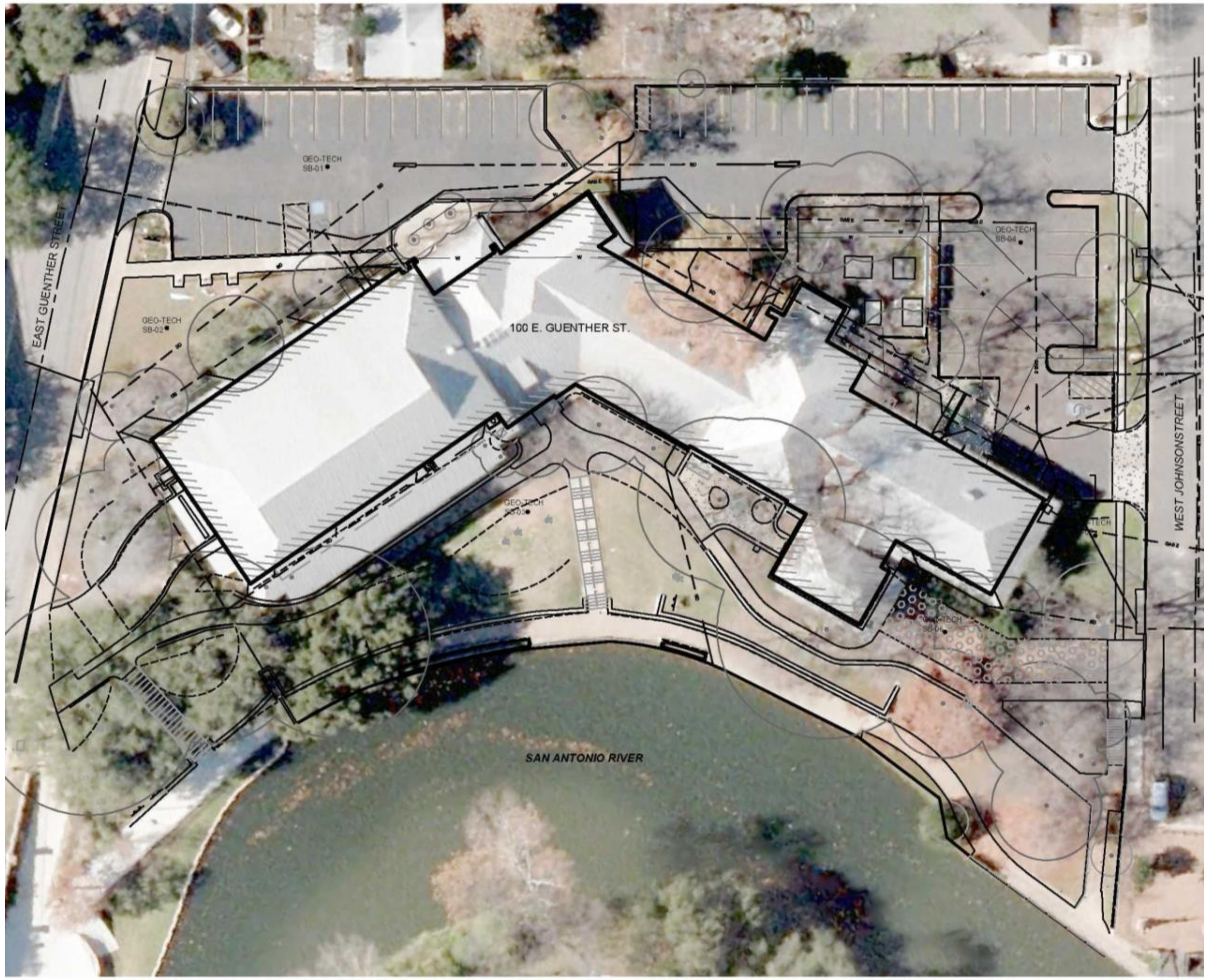
EXISTING SITE LAYOUT



Parking Areas – 23,750 square ft.

Building Footprint – 24,350 square ft.

Sidewalks, Driveways, Fire lane – 7,625 square feet

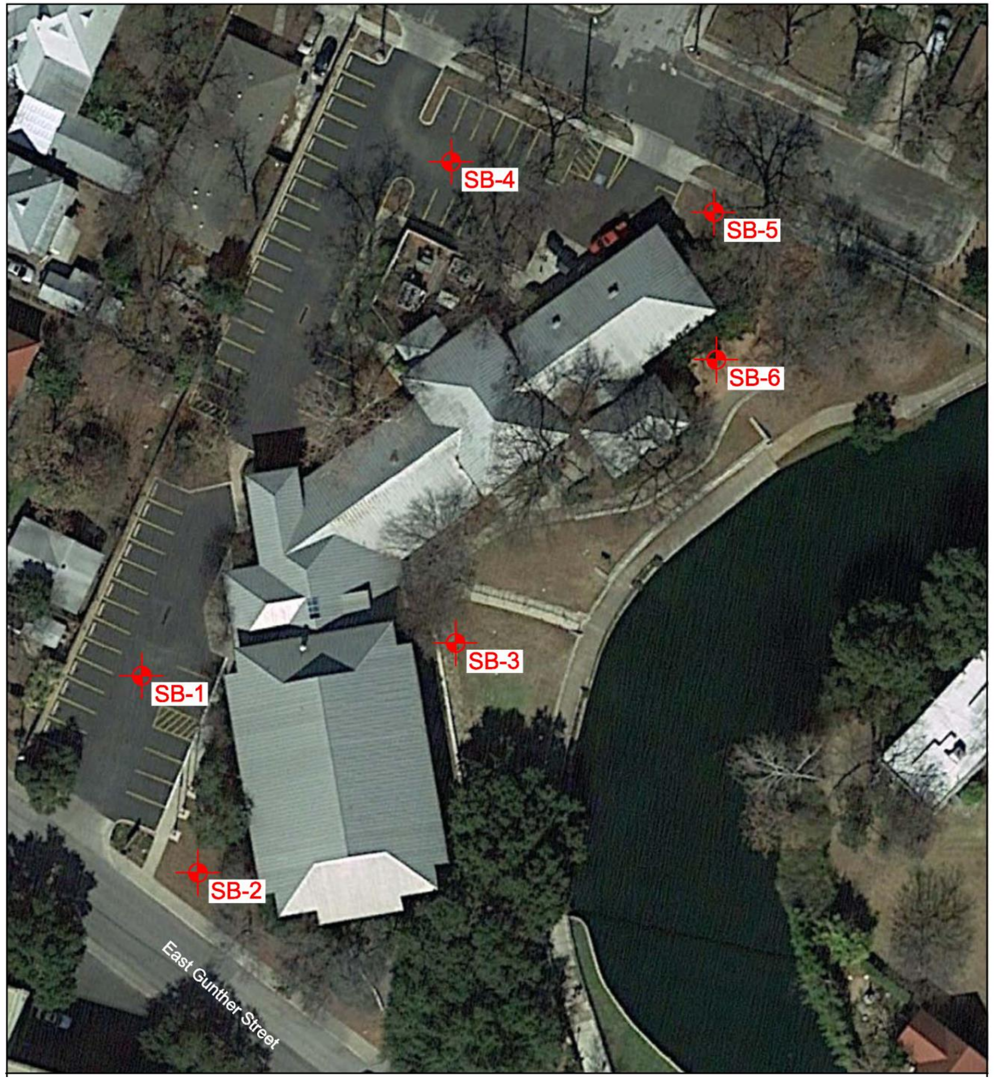
Flows – 6.5 – 7.5 cfs for 2 – 5 Year storms

Constituents – Bacteria, Sediment, PAHs

Volumes – Annual volume of ~1 Million Gallons

Soils – Fill Clayey Gravels/Sands underlain by Fat Clay

SITE LAYOUT



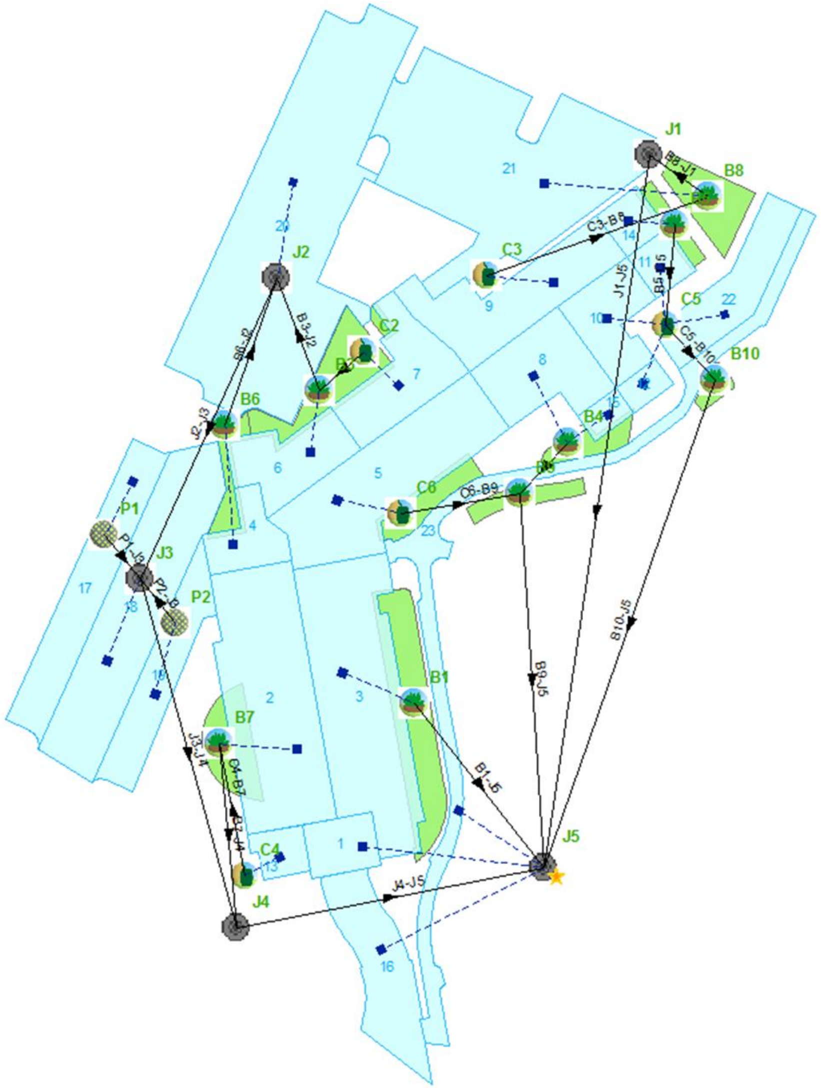
SB-2

LOCATION See Exhibit A-2
Latitude: 29.412747° Longitude: -98.496821°

DEPTH	Description	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
	FILL-SANDY LEAN CLAY with GRAVEL (CL); dark brown, brown and tan				4.5 (HP)	6	41-16-25	59
					29-14-33 N=47	7		
4.0	**FILL-CLAYEY GRAVEL (GC)**; tan	5			7-12-10 N=22	9	42-18-24	49
					8-13-18 N=31	10		
		10			4-3-3 N=6	8		30
13.0	**SANDY FAT CLAY (CH)**; dark brown, with roots and organics				4-2-4 N=6	18		

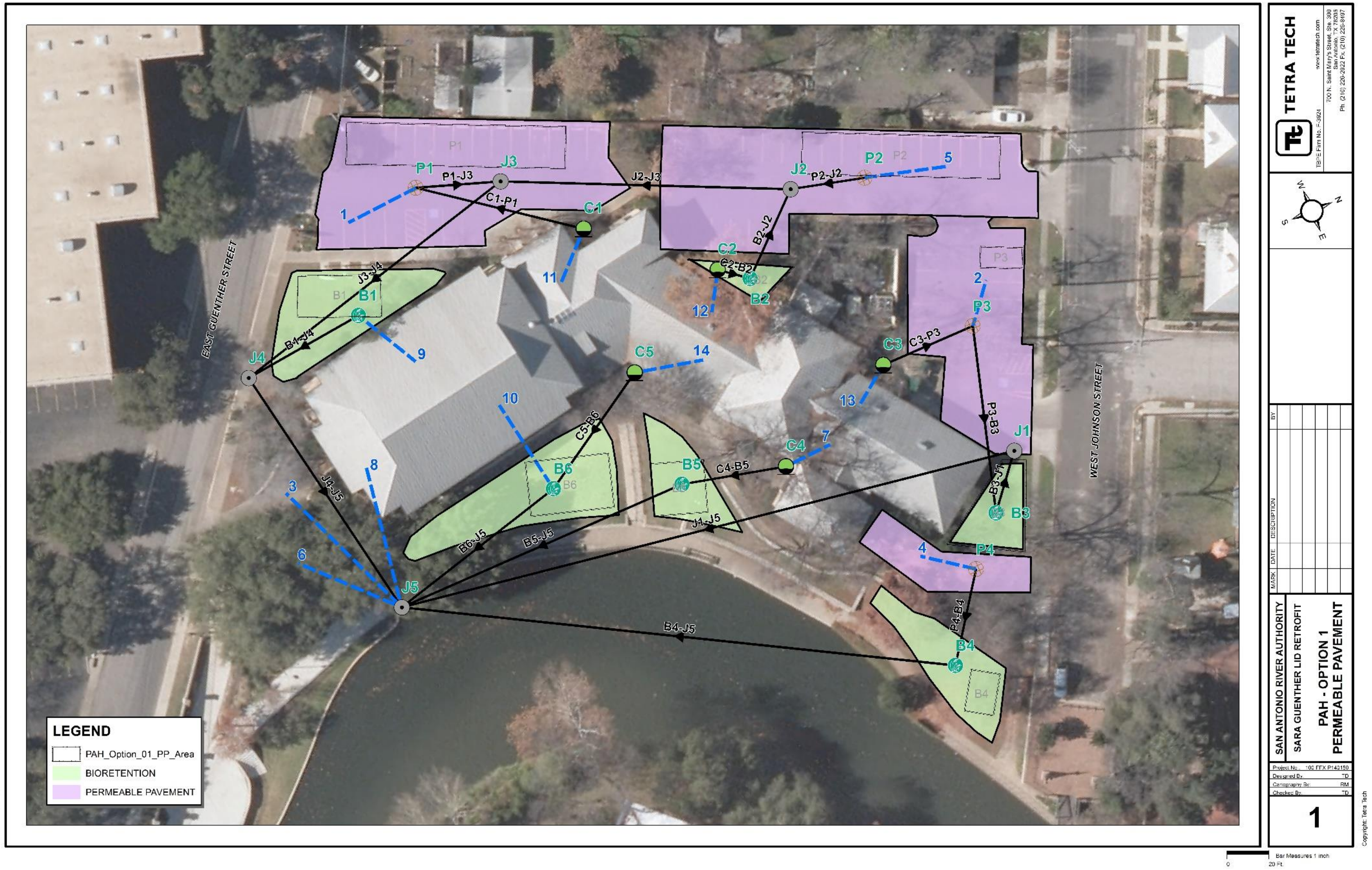
MODELING

- SUSTAIN Evaluation
- Potential BMPs
  - Vegetated Swales/Filter Strips
  - Storage
  - Stormwater Wetlands
  - **Permeable Pavement**
  - Sand Filter
  - Bioretention/Bioswale
  - Green Roofs
  - Planter Boxes



SCENARIO 1 - OPTIMIZED FOR BACTERIA USING PERMEABLE PAVING

SCENARIO 3 – OPTIMIZED FOR PAHS USING PERMEABLE PAVEMENT



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SCENARIO 4 – OPTIMIZED FOR VOLUME – NO TREATMENT OF PARKING AREAS 1 AND 2

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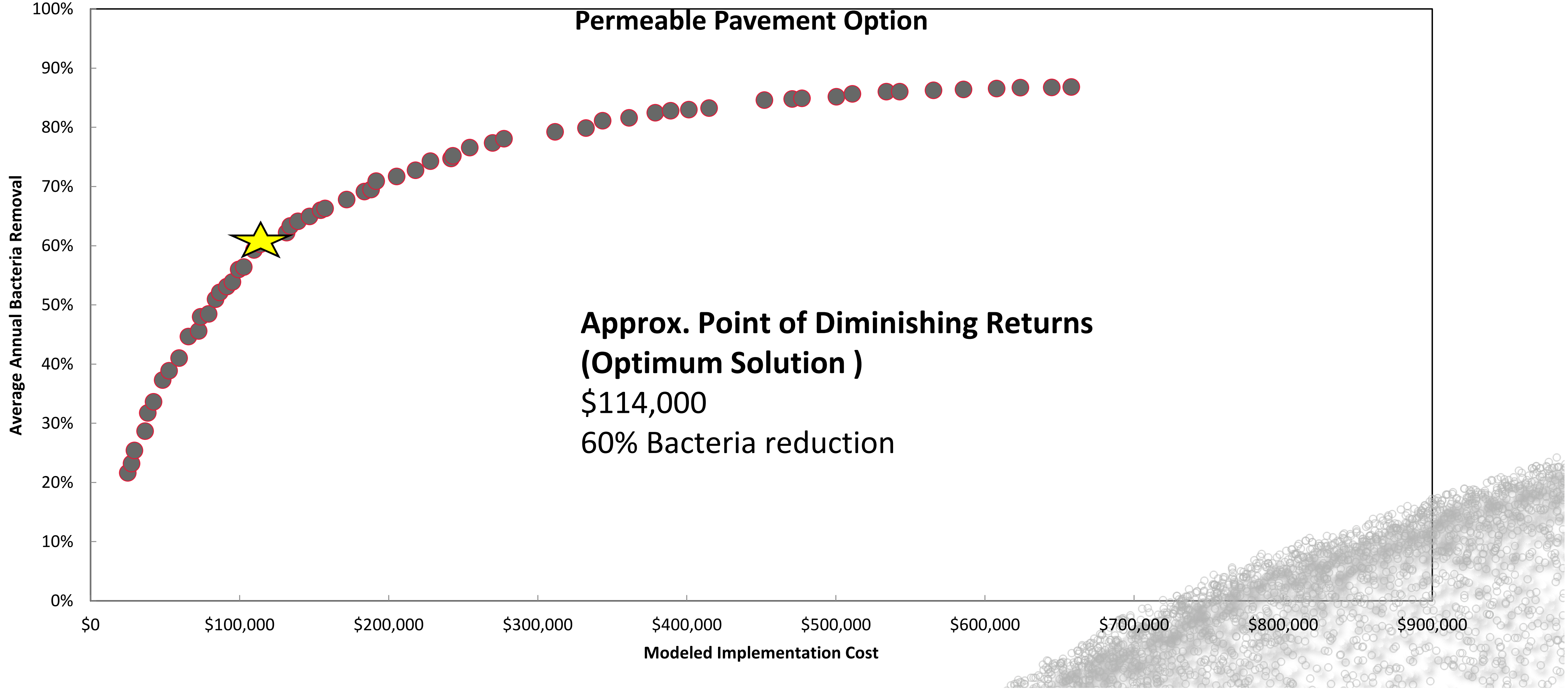
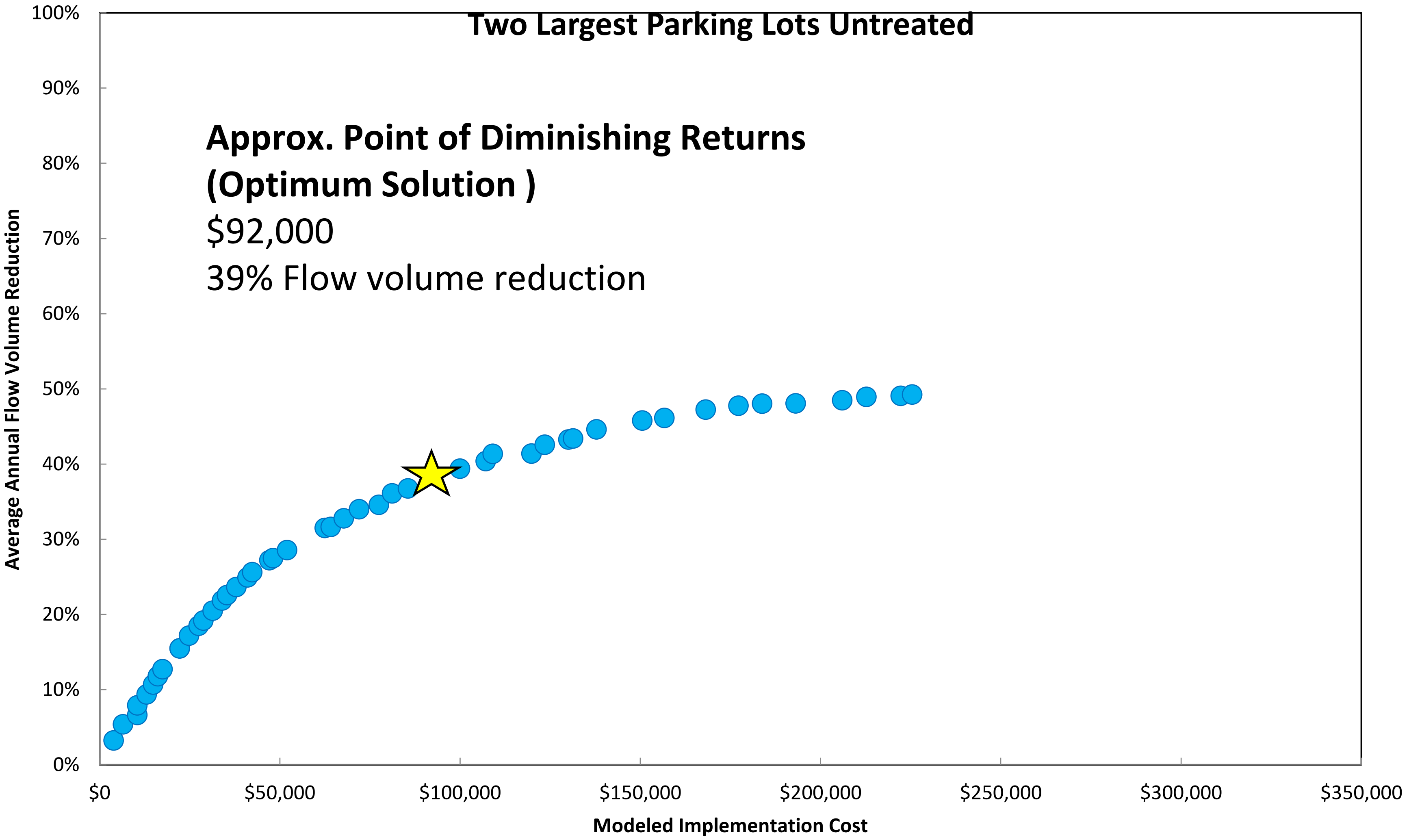


Permeable Pavement Option
Average Annual Bacteria Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
$0
$100,000
$200,000
$300,000
$400,000
$500,000
$600,000
$700,000
$800,000
$900,000
Modeled Implementation Cost
Approx. Point of Diminishing Returns
(Optimum Solution)
$114,000
60% Bacteria reduction



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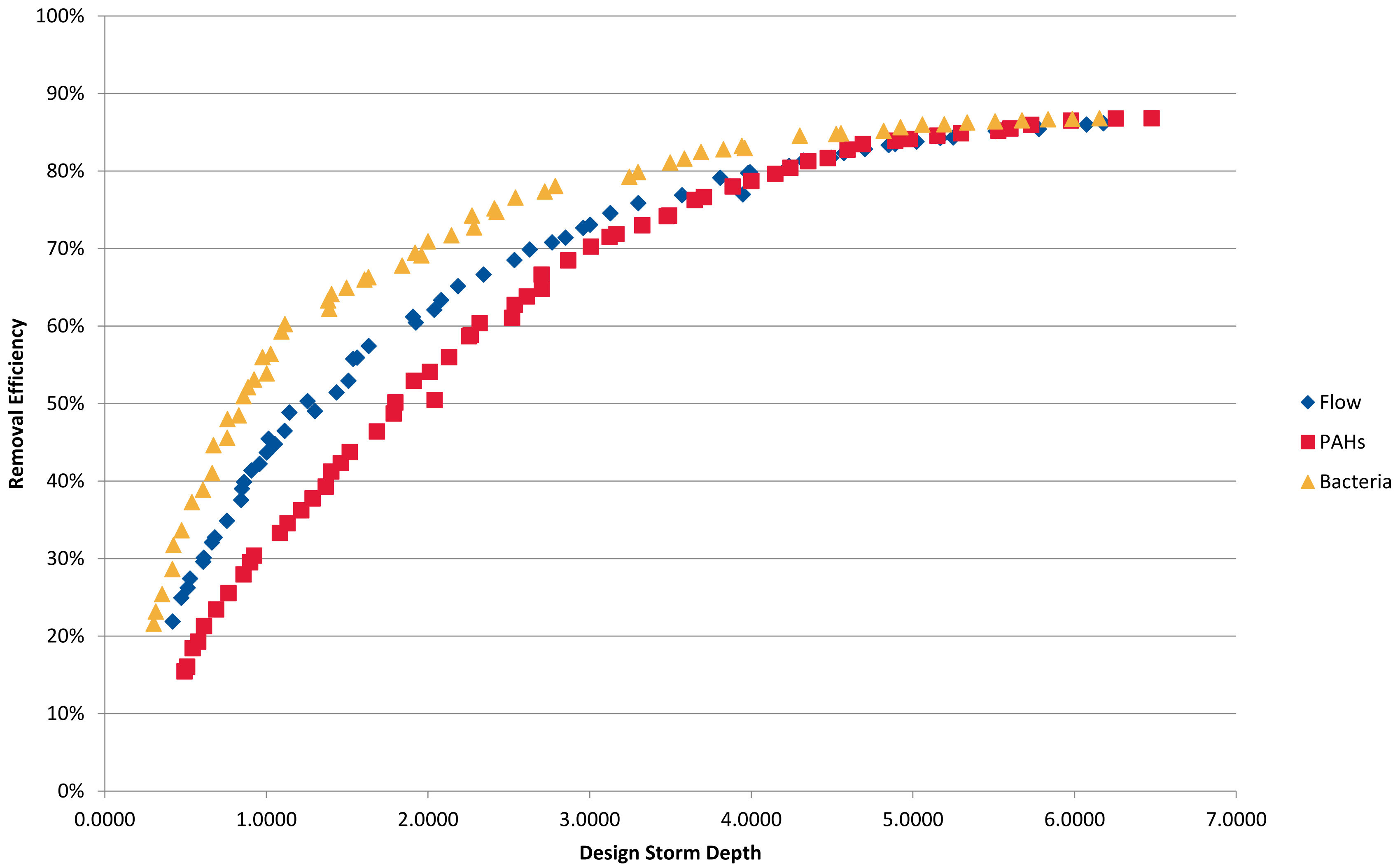
COMPARE THE RESULTS FOR DIFFERENT CONSTITUENTS OF CONCERN



COMPARISON OF OPTIMUM SCENARIOS

	Bacteria	PAH	Flow
Permeable Pavement	$114,000 60% 1.11 in.	$295,000 70% 3.01 in	$247,000 70% 2.62 in.
Sand Filter	$86,000 60% 1.09 in	$201,000 71% 2.54 in.	$93,000 39% 1.18 in
Untreated Parking	$59,000 39% 0.71 in	$141,000 46% 1.65 in	$92,000 39% 1.18 in

BENEFITS

Economic Factors					
Life Cycle Costs		LID BMP Cost		*Increased Property Value*	$374,004
Traditional Infrastructure	$ 52,723	Permeable Pavement	$105,273		
Traditional Landscaping	$134,819	Bioretention Areas and Cisterns	$334,645	*Reduced Irrigation Cost*	$37,695
Total Cost	**$187,542**	Total Cost	**$439,919**	Includes Averted Maint.	
				Energy Savings	$14,307
Quality of Life Factors					
				Improved Air Quality	$4,036
				Increased Amenity Value	$0
Environmental Benefits				*Pounds of Sediment Removed*	$209
				Storm water infrastructure capacity	$200,649
				Total	$630,900
Increased Cost of LID			**$252,376**		
Net Benefit of LID					$378,524

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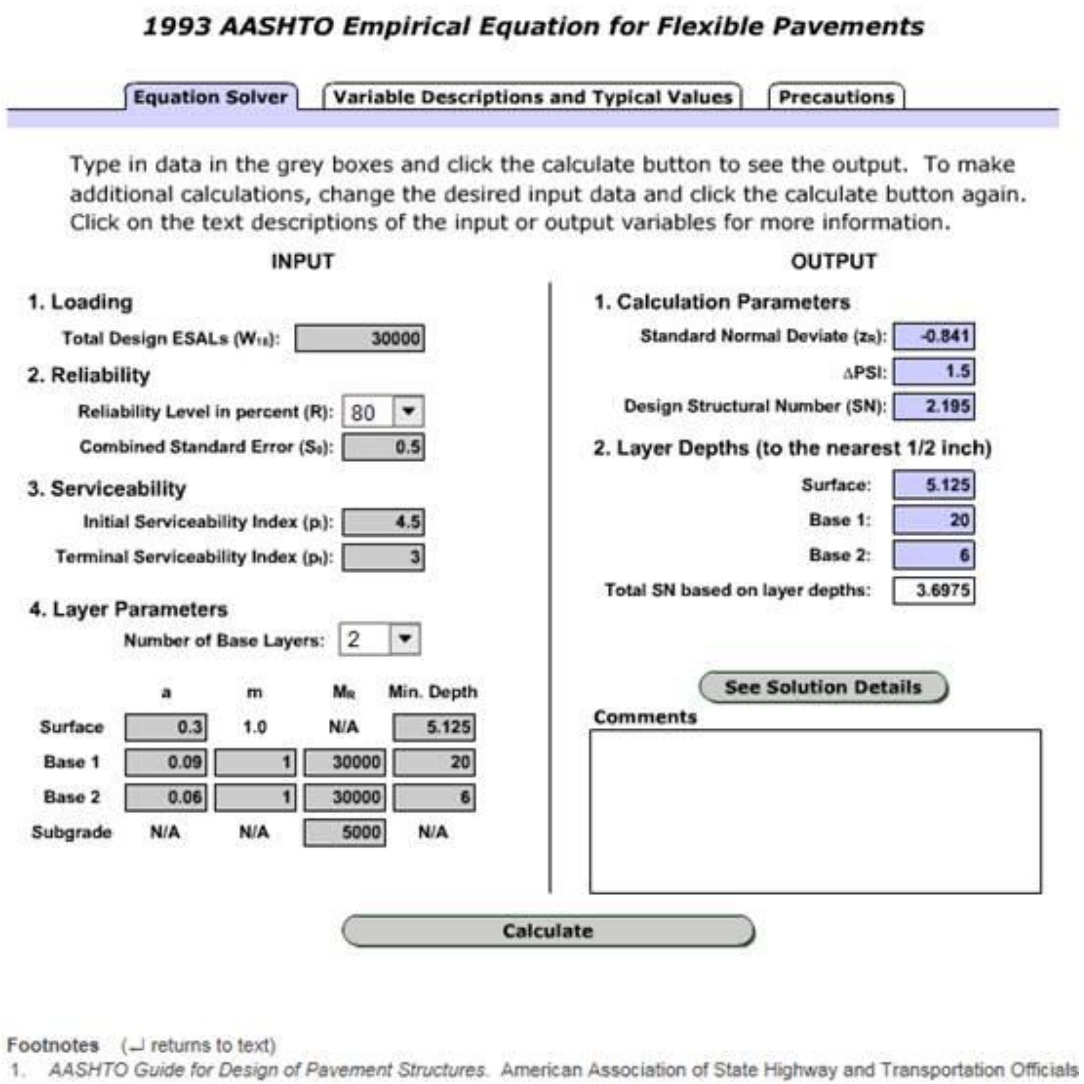
VISUALIZING THE PLAN

SITE DESIGN



STORAGE DEPTH CONTROLS PAVEMENT STRENGTH

Water Quality Design Depth of base layer ~ 6 inches

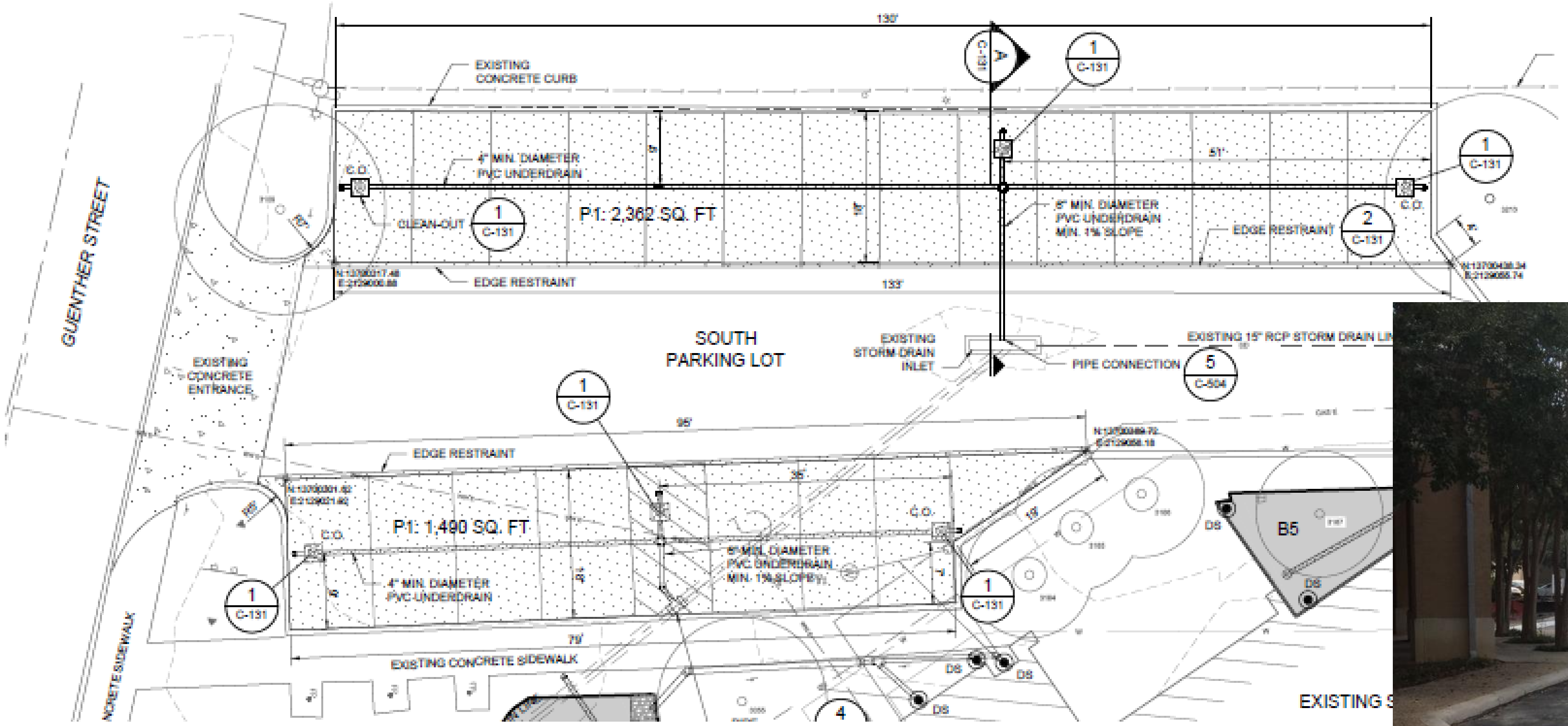
Minimum Depth for paver support per ICPI = 9 inches

Pavement Structural Design required 23 inches

100-yr storm capture volume required 26 inches.

Per the TechBrief FHWA-HIF-15-007 (Jan 2015) titled “Permeable Interlocking Concrete Pavement”, PICP structural design adopts the AASHTO 1993 design procedure for flexible pavements.

CONSTRUCTION PLANS AND RESULTS



QUESTIONS?

QUESTIONS?