Concrete Pavement for the Built Environment

Improving Safety | Managing Stormwater

Florida Concrete and Products Association

Amy Wedel, Director of Concrete Pavements

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Concrete Pavement for the Built Environment
1LU|HSW
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Course Description: This course will cover traditional concrete pavement, pervious concrete pavement and where to use each one for stormwater management. You will be introduced to cementitious materials and how to reduce the embodied carbon in concrete. It will also discus concrete's lighter color and reflectivity and its impact on lighting, temperatures and safety.

1. **Learning Objective: How to manage stormwater quality and quantity with pervious concrete pavement.**
2. **Learning Objective: Reducing urban heat island effect using concrete pavement.**
3. **Learning Objective: How concrete pavement can improve safety with improved lighting.**
4. **Learning Objective: How concrete pavement can be a part of resiliency planning in flood prone areas.**
5. **Learning Objective: How to reduce embodied carbon in concrete pavement with use of waste materials and Portland Limestone Cement.**

TOPICS COVERED

Manage Stormwater
Improving Safety
Reducing Urban Heat Islands
Improve Resiliency
Reduce Embodied Carbon

TOPICS COVERED

Manage Stormwater

Improving Safety

Reducing Urban Heat Islands

Improve Resiliency

Reduce Embodied Carbon

Pervious Concrete

Managing Stormwater

- Quantity Control
- Quality Control

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What is Pervious Concrete?

No Fines Concrete

- ~ 20% void space
- 300” to 1000” inches / hour

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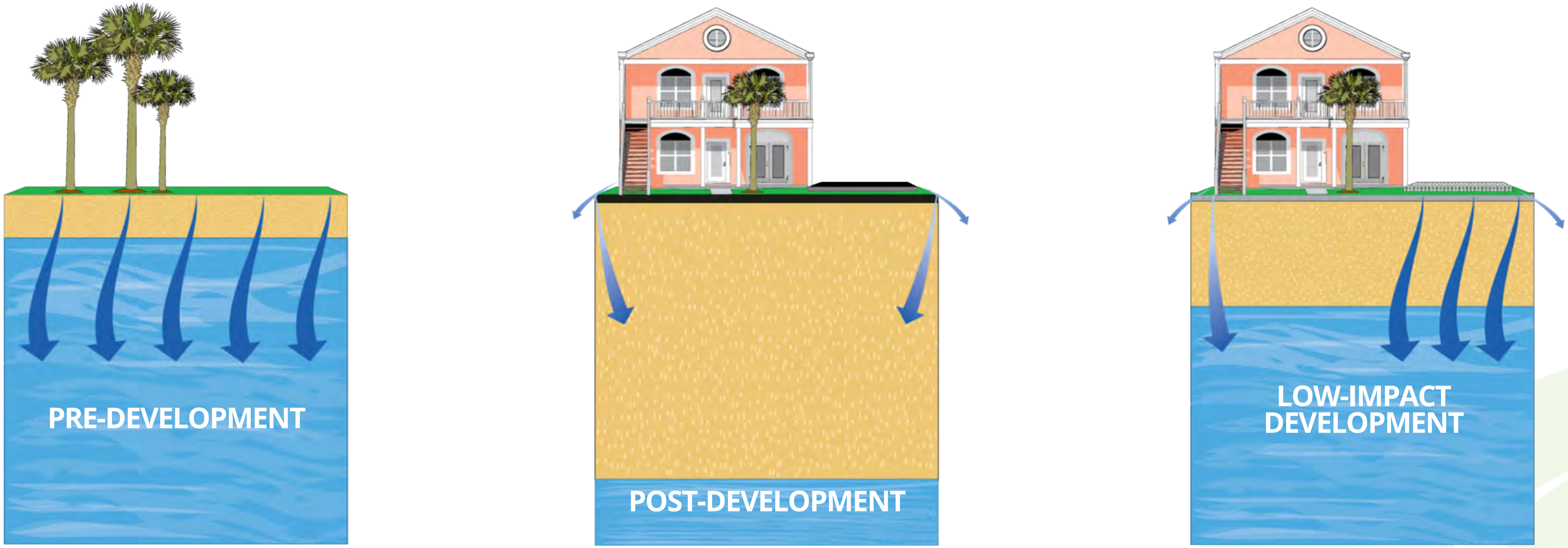
Low Impact Development



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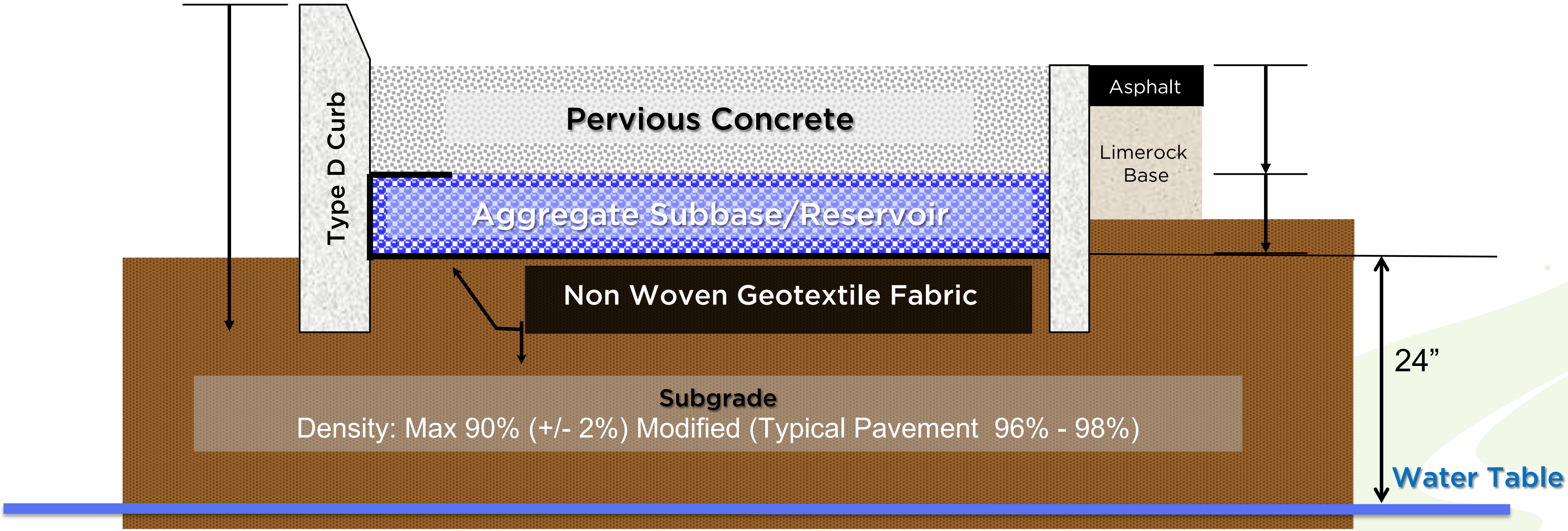
Pervious Concrete

A Stormwater Management System



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Storage Capacity

The stormwater storage capacity of a pervious concrete layer is equal to total void content multiplied by pavement thickness

Pervious Concrete — Aggregate Base

(20%) 6in. + (40%) 6 in. = 3.6 in.

% voids — thickness — % voids — thickness

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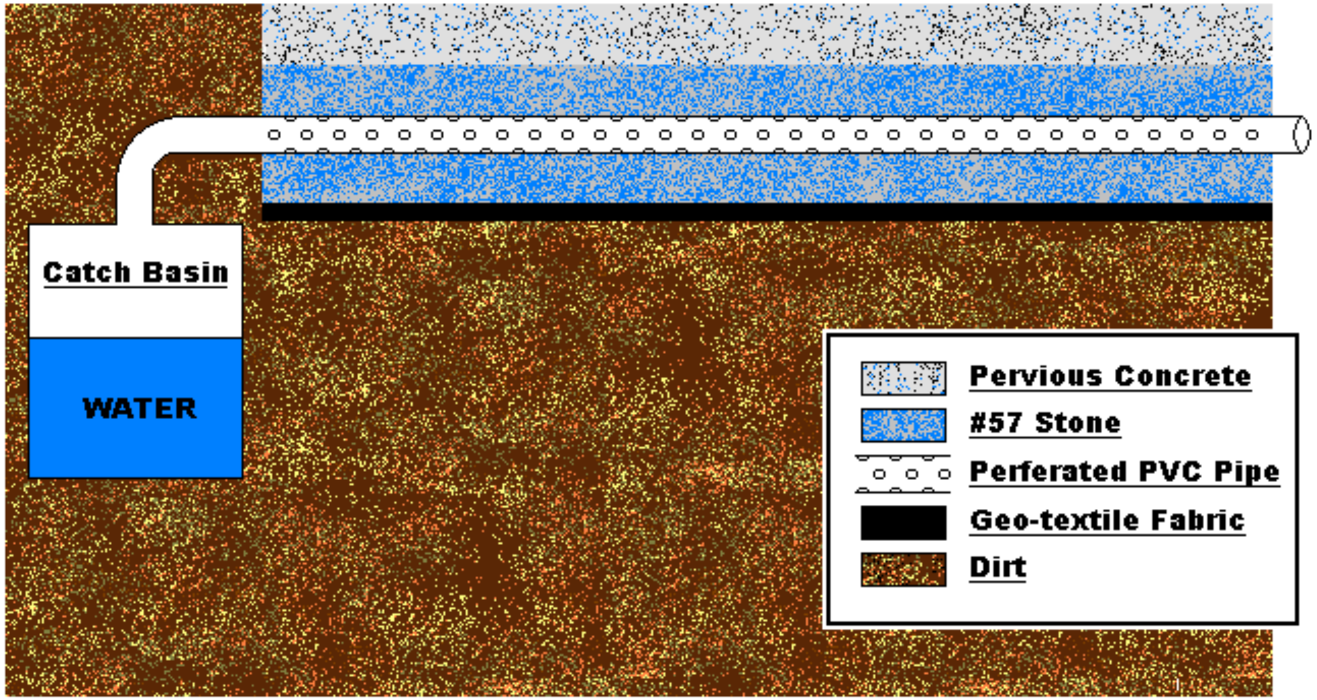
Water Collection and Use



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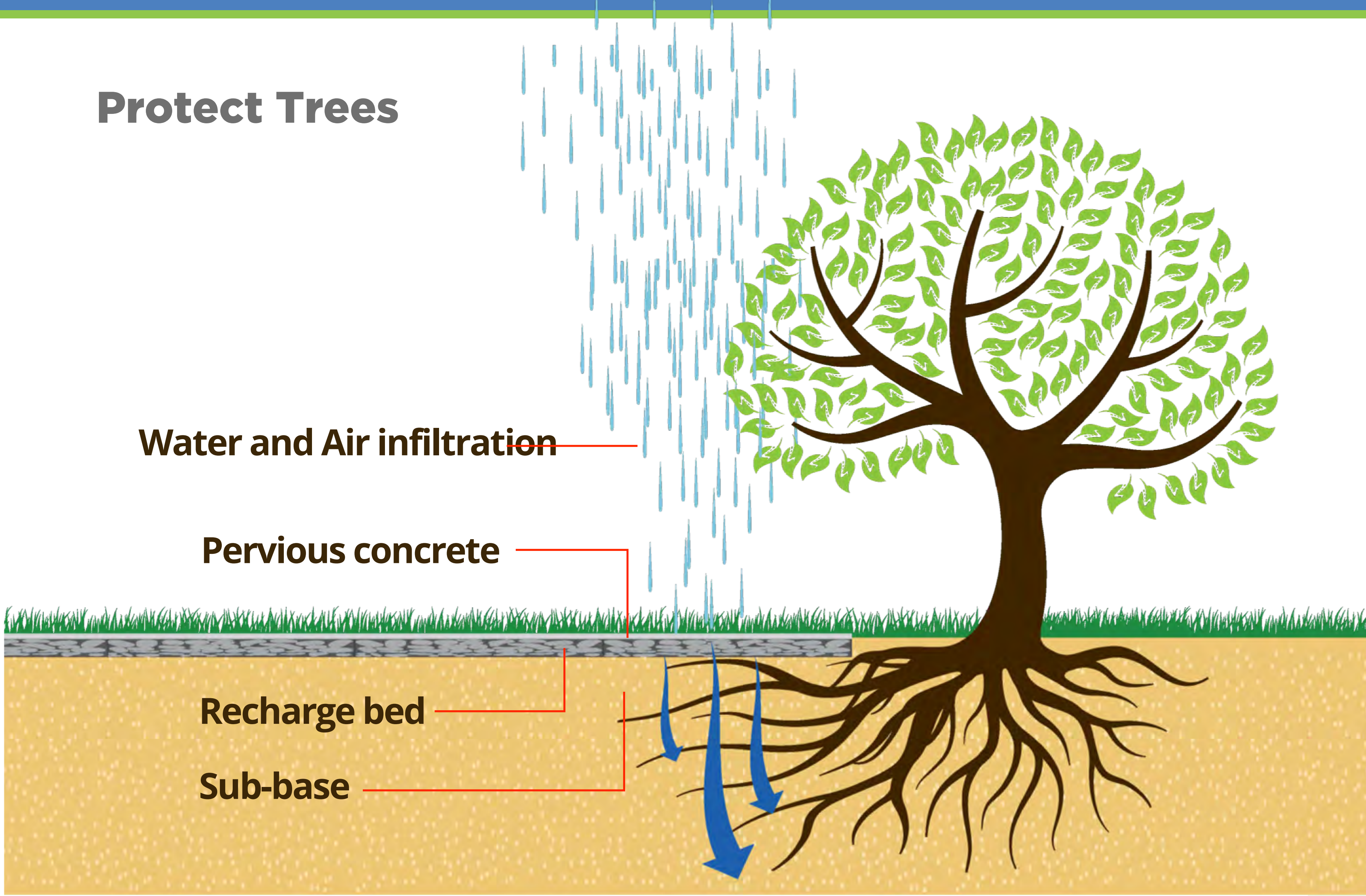
Protect Trees



Can pave within drip line

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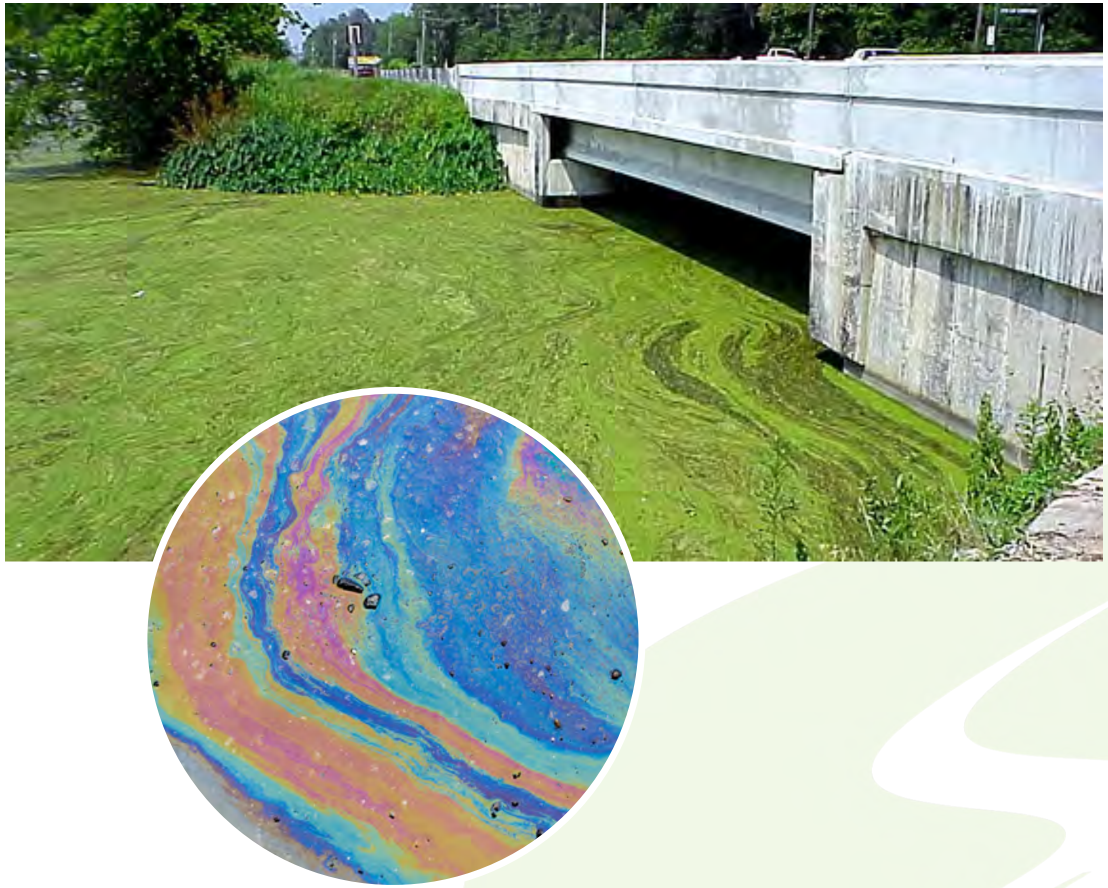
First Flush

- First 1" of rain contains contaminants
  - Oils and Greases
  - Metal
  - Sediments
  - Fertilizers
- EPA requires collection and treatment prior to release
- Pervious pavement captures first flush
- Approved by EPA as part of Stormwater Discharge
- Best Management Practice (BMP)



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Environmental Benefits of Concrete

- Percolation recharges groundwater
- Water resources are conserved
- Trees and vegetation are allowed more rainwater (less irrigation)
- Run-off to streams and lakes is reduced, (cooler & cleaner)
- Cooler surface has less impact on air temperature
- Minimizes urban heat-island effect

Economic Benefits of Pervious Concrete

Elimination of expensive retention ponds or underground storage systems

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Applications for Pervious Concrete

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Applications for Pervious Concrete

YES	NO
• Parking Lots	• Airports
• Driveways	• Basketball Courts *
• Sidewalks / Paths	• Industrial Facilities
• Residential Streets	• Gas Stations
• Roadway Base	• Areas with high water table

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Parking Lots

Palm Beach State College Loxahatchee Groves Campus

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Driveways

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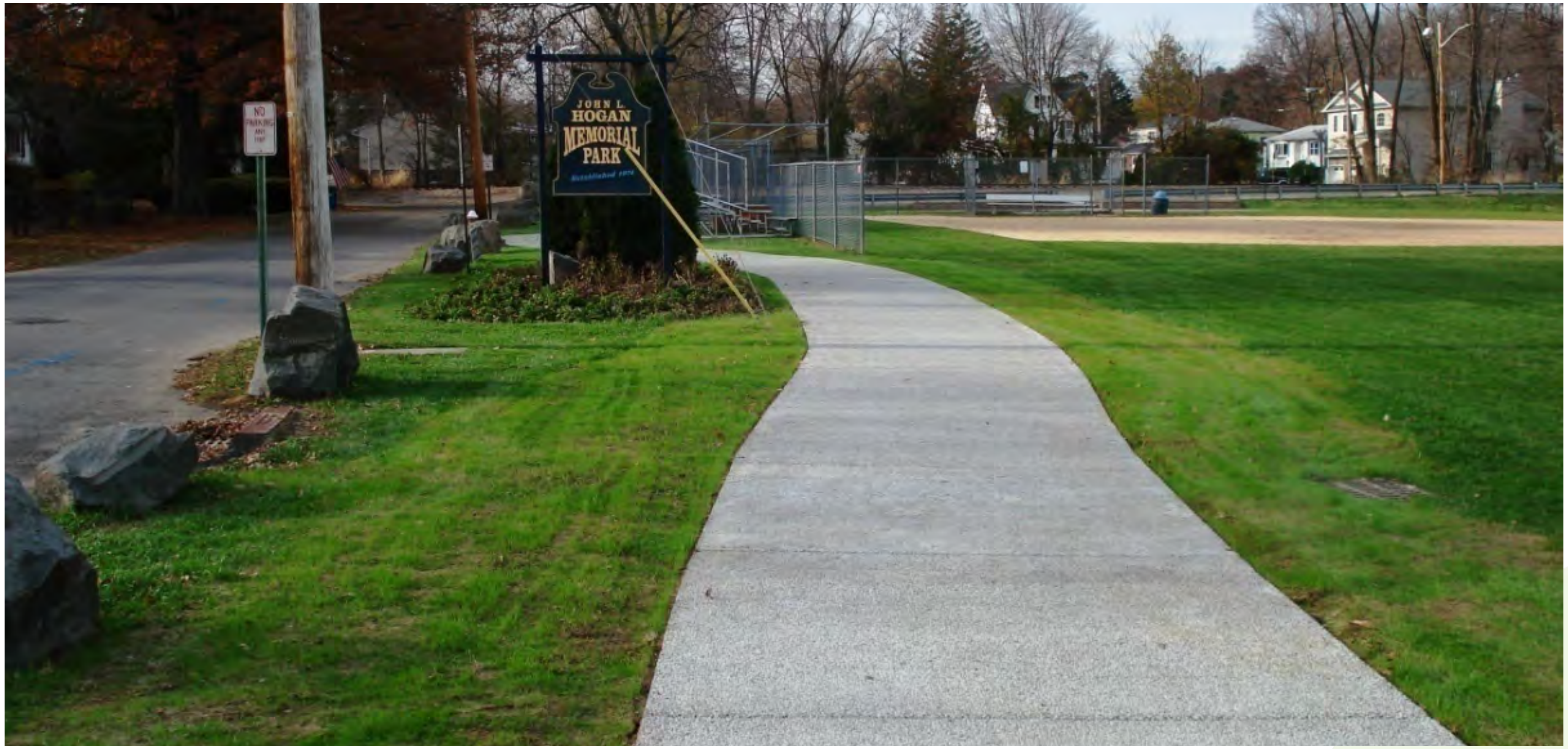
Sidewalks and Paths



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Streets and Alleys

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Pervious Concrete is NOT for Industrial facilities

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Pervious Concrete is NOT for Ball Courts

* Yes! with a cover

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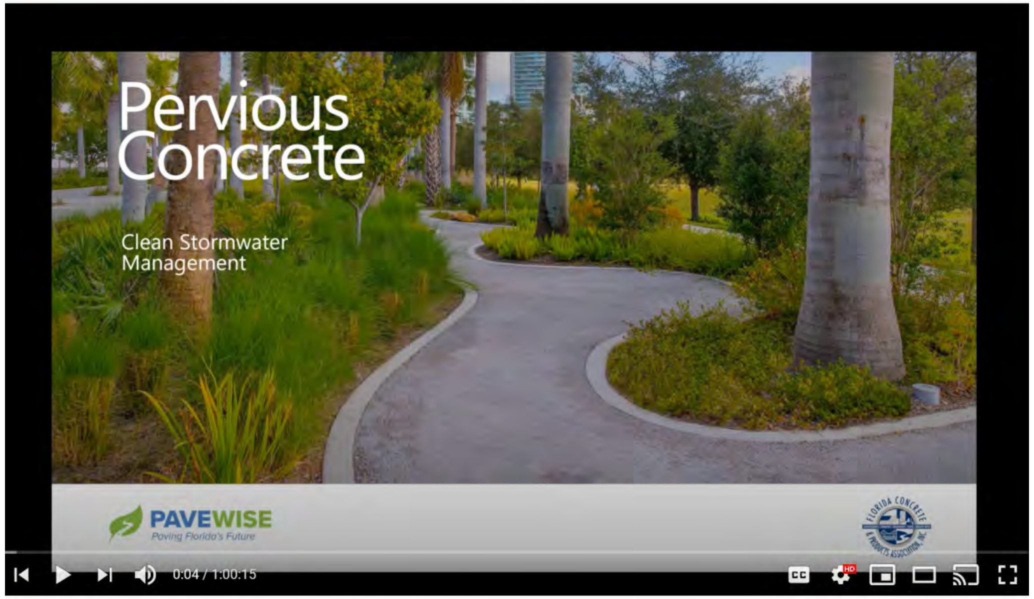
More information on Pervious Concrete

[Florida Concrete & Products Association YouTube Channel]



https://paveahead.com/resources/

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TOPICS COVERED

Manage Stormwater

Improving Safety

Reducing Urban Heat Islands

Improve Resiliency

Reduce Embodied Carbon

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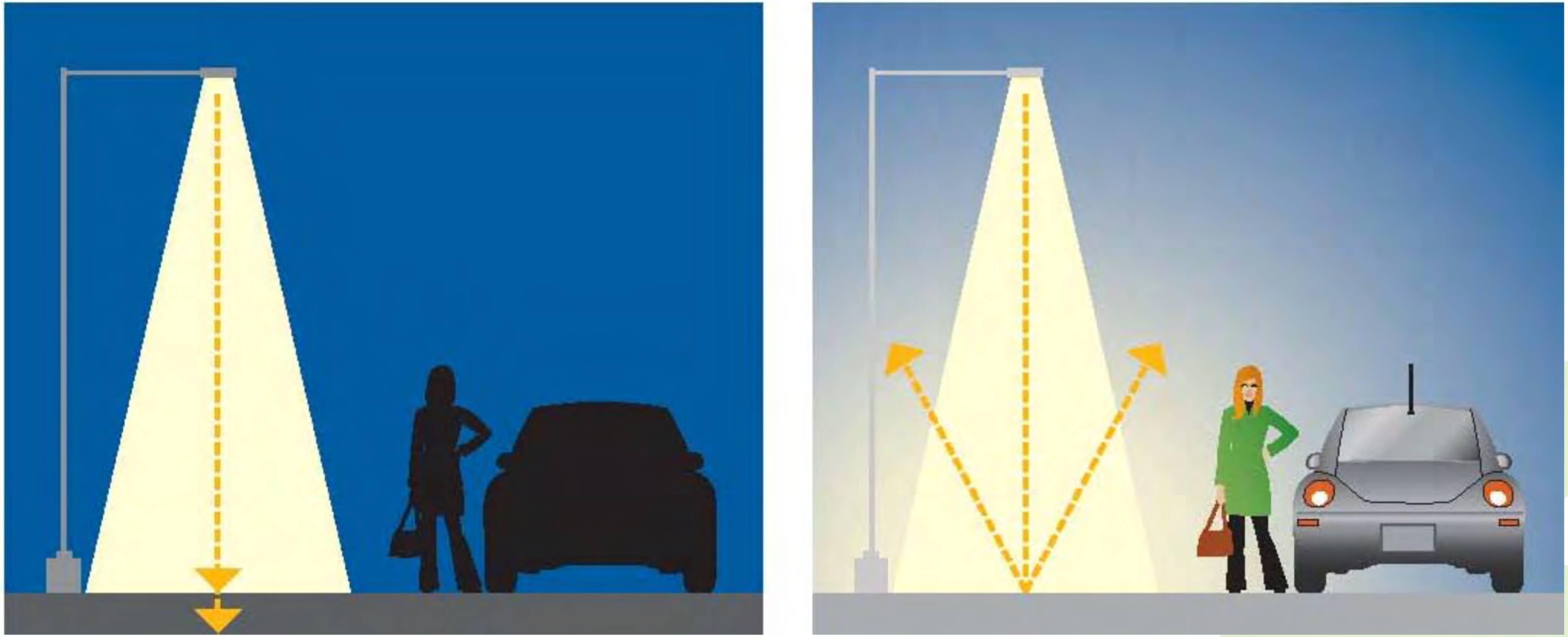
Safety

Improved visibility / reduces accidents / reduces crime



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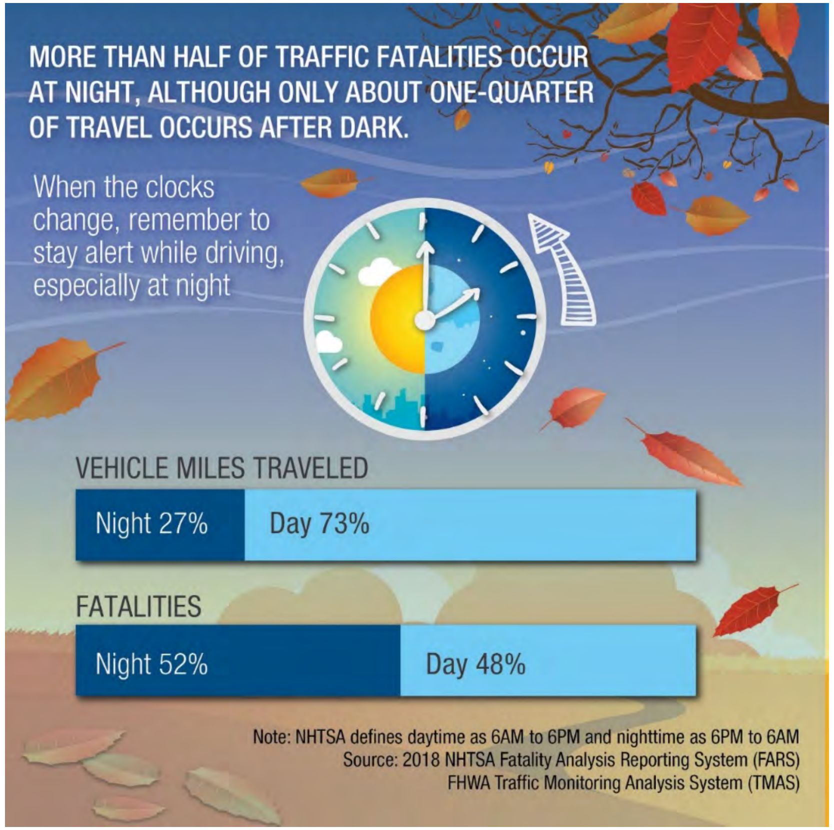
Safety

Improved visibility / reduces accidents / reduces crime



- 50% of road fatalities
- 75% of pedestrian fatalities

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Energy Savings / Brighter Pavement

Reduced lighting fixtures

Studies show 37% less lighting is needed with concrete. *SN2458PCA

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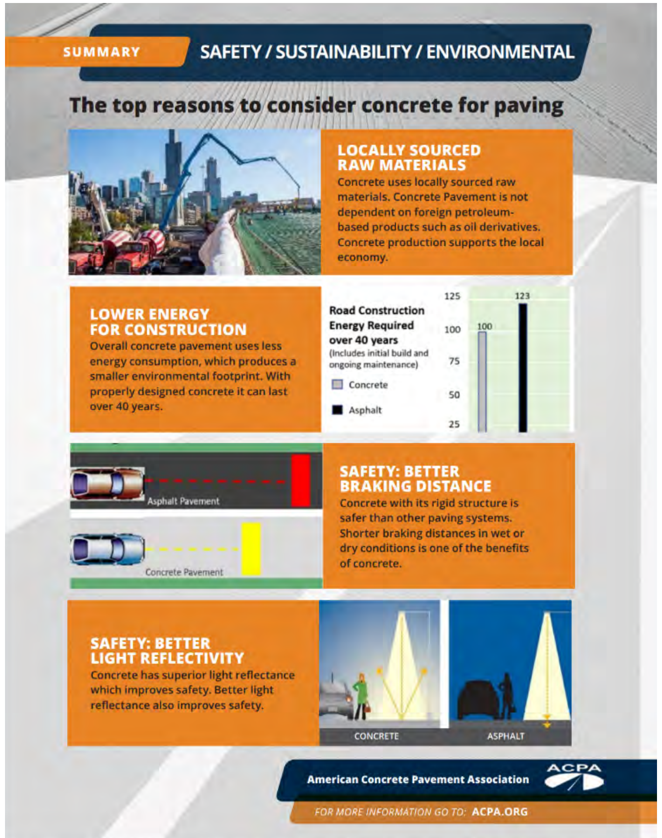
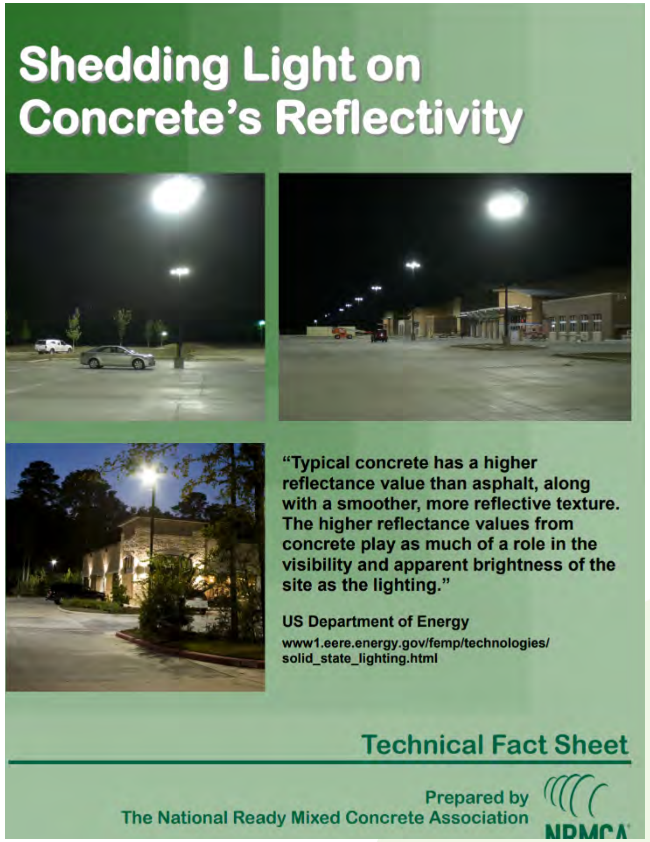
More information on Safety





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TOPICS COVERED

Manage Stormwater

Improving Safety

Reducing Urban Heat Islands

Improve Resiliency

Reduce Embodied Carbon

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Reduces Urban Heat Islands

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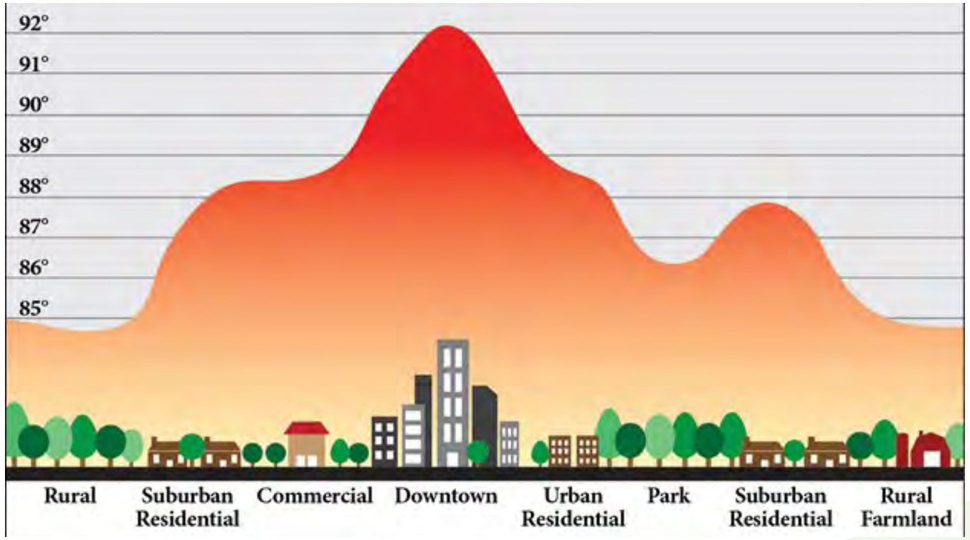
Reduce Urban Heat Islands

- Pavements 10 to 20 degrees cooler
- Reduced AC needs, context important
- Improved air quality with lower temperatures



"Reflective pavements could offset enough CO2 to remove the equivalent of around 4 million cars from the road each year" according to MIT Concrete Sustainability Hub, Mitigating Climate Change with Reflective Pavements 2020.

Urban Heat Island Ordinance

WHEREAS, hardscape management methods, such as tree planting, shading, and use of reflective paving materials, will contribute to decreasing the urban heat island effect, which can reduce the energy consumption of buildings;

TABLE INSET:

Material	Solar Reflectance
Typical new gray concrete	0.35
Typical weathered gray concrete	0.20
Typical new white concrete	0.70
Typical weathered white concrete	0.40
New asphalt	0.05
Weathered asphalt	0.10

952.5 Requirements

Sites with new construction shall be required to comply with the following:

(a) Provide any combination of the following strategies for fifty percent (50%) of the site hardscape:

(i) Shade from solar panels or roofing materials with a solar reflectance of at least 0.30.

(ii) Shade from trees within five (5) years of occupancy.

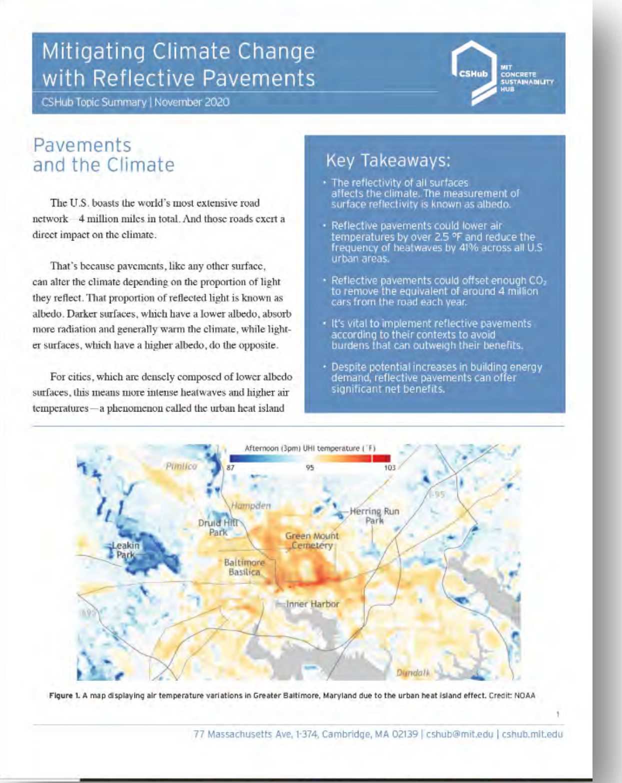
(iii) Paving materials with a solar reflectance of at least 0.30.

(iv) Pervious pavement system.

Ordinance No. 11000, Sec 952

More information on Urban Heat Islands

MIT Concrete Sustainability Hub



Mitigating Climate Change with Reflective Pavements

CSHub Topic Summary | November 2020

MIT CONCRETE SUSTAINABILITY HUB

Pavements and the Climate

The U.S. boasts the world's most extensive road network — 4 million miles in total. And those roads exert a direct impact on the climate.

That's because pavements, like any other surface, can alter the climate depending on the proportion of light they reflect. That proportion of reflected light is known as albedo. Darker surfaces, which have a lower albedo, absorb more radiation and generally warm the climate, while lighter surfaces, which have a higher albedo, do the opposite.

For cities, which are densely composed of lower albedo surfaces, this means more intense heatwaves and higher air temperatures — a phenomenon called the urban heat island

Key Takeaways:

- The reflectivity of all surfaces affects the climate. The measurement of surface reflectivity is known as albedo.
- Reflective pavements could lower air temperatures by over 2.5 °F and reduce the frequency of heatwaves by 41% across all U.S urban areas.
- Reflective pavements could offset enough CO_2 to remove the equivalent of around 4 million cars from the road each year.
- It's vital to implement reflective pavements according to their contexts to avoid burdens that can outweigh their benefits.
- Despite potential increases in building energy demand, reflective pavements can offer significant net benefits.

Afternoon (3pm) UHI temperature (°F)
87 95 103
Pimlico
Hampden
Druid Hill Park
Herring Run Park
Green Mount Cemetery
Leakin Park
Baltimore Basilica
Inner Harbor
Dundalk

Figure 1. A map displaying air temperature variations in Greater Baltimore, Maryland due to the urban heat island effect. Credit: NOAA

1

77 Massachusetts Ave, 1-374, Cambridge, MA 02139 | cshub@mit.edu | cshub.mit.edu

TOPICS COVERED

Manage Stormwater

Improving Safety

Reducing Urban Heat Islands

Improve Resiliency

Reduce Embodied Carbon

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Pavement Resiliency

- How are pavements impacted by flooding events?
- How can we make pavements more resilient to flooding?

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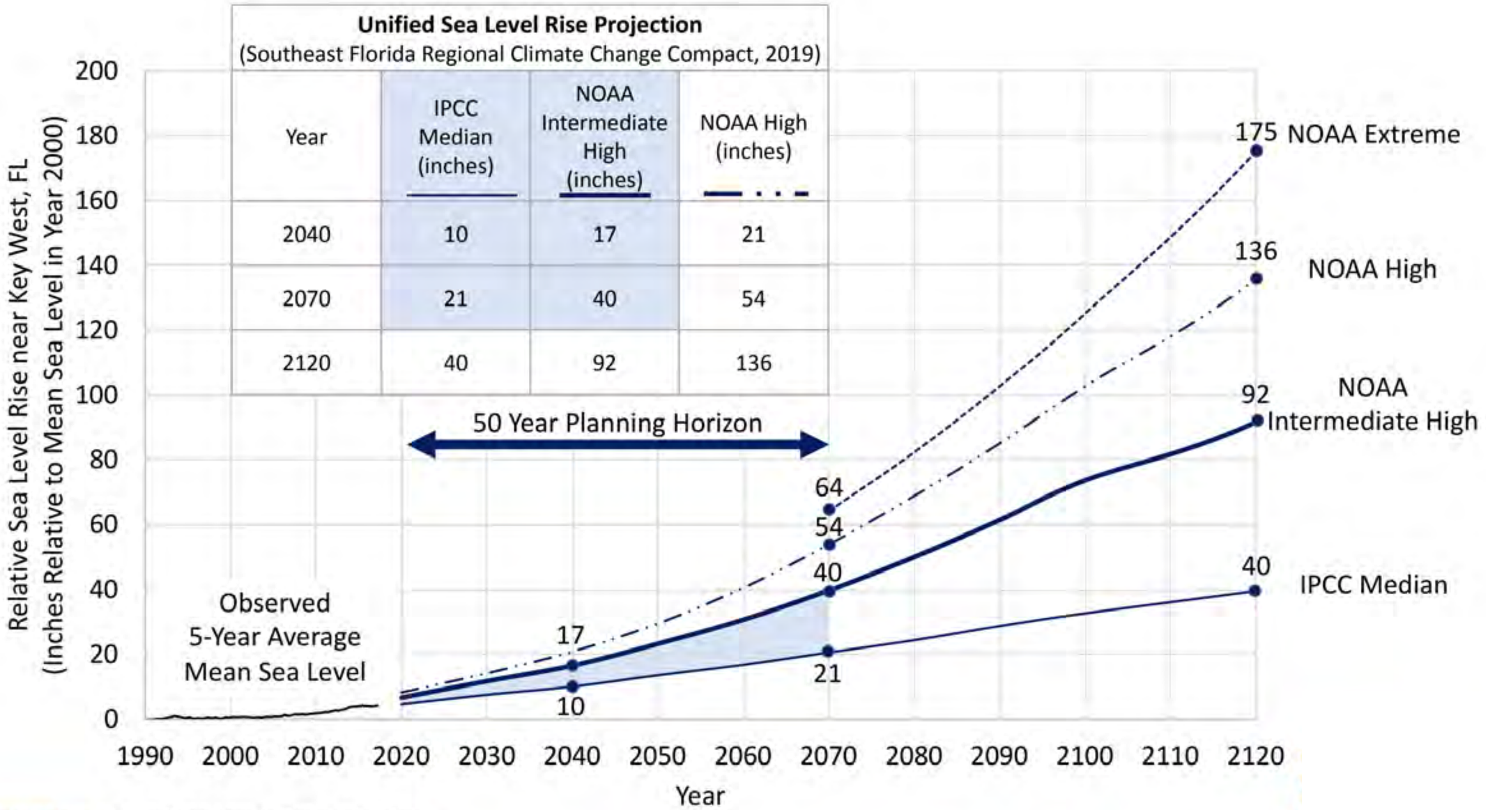
Unified Sea Level Rise Projection



Year	IPCC Median (inches)	NOAA Intermediate High (inches)	NOAA High (inches)
2040	10	17	21
2070	21	40	54
2120	40	92	136

FIGURE 1: Unified Sea Level Rise Projection

These projections start from zero in year 2000 and are referenced to mean sea level at the Key West tide gauge. Based on the 5-year average of mean sea level, approximately 3.9 inches of sea level rise has occurred from 2000 to 2017 (see historic sea level section of guidance document). The projection includes global curves adapted for regional application: the median of the IPCC AR5 RCP 8.5 scenario (Growing Emissions Scenario) as the lowest boundary (solid thin curve), the NOAA Intermediate High curve as the upper boundary for short-term use until 2070 (solid thick line), the NOAA High curve as the upper boundary for medium and long-term use (dash dot curve). The shaded zone between the IPCC AR5 RCP 8.5 median curve and the NOAA Intermediate High is recommended to be generally applied to most projects within a short-term planning horizon. Beyond 2070, the adaptability, interdependencies, and costs of the infrastructure should be weighed to select a projection value between the IPCC Median and the NOAA High curves. The NOAA Extreme curve (dash curve) brackets the published upper range of possible sea level rise under an accelerated ice melt scenario. Emissions reductions could reduce the rate of sea level rise significantly

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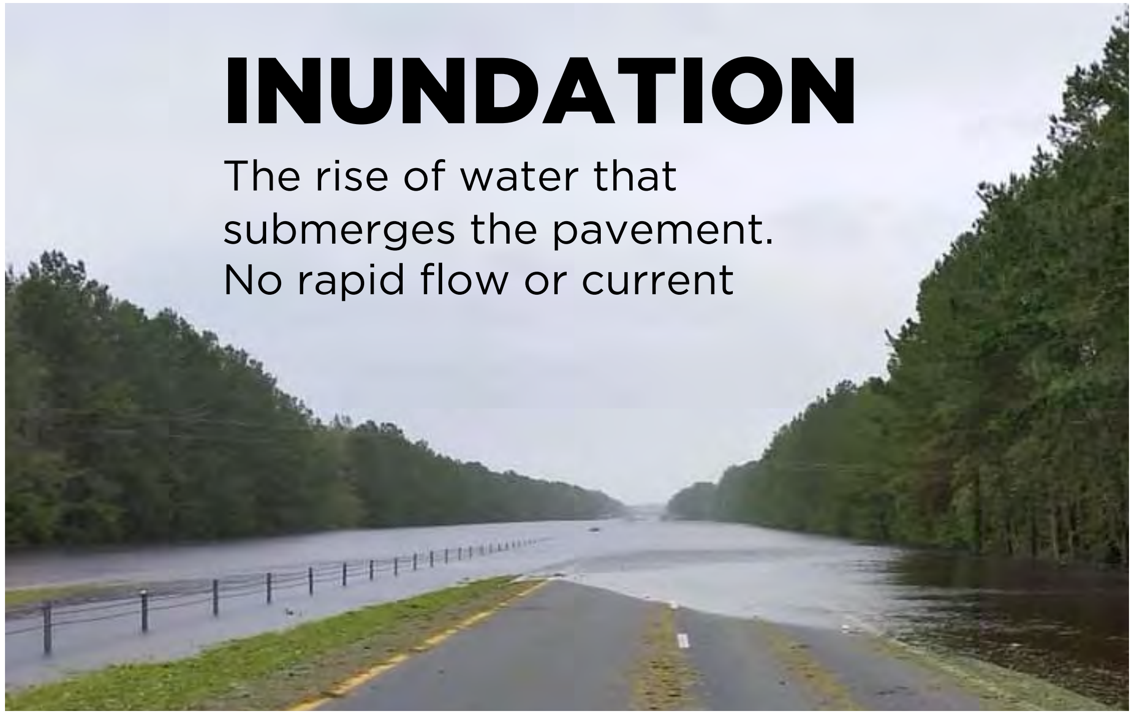
Increased Flooding is impacting our Pavement Structures

Need to distinguish between Inundation and Washout Impacts



Pavement type does have an impact

Pavement type has little impact

Need for Creating Flood Resistant Infrastructure

This recent PEW article recognized the need to make our infrastructure “Flood Ready”

- Existing policies fall short
- Costs due to flooding are increasing, and will likely continue to increase
  - Rebuild the same asset multiple times
  - Higher population density / more damage
- Flood-ready investments are cost-effective


A fact sheet from THE PEW CHARITABLE TRUSTS | April 2019

Federally Funded Infrastructure Must Be Flood Ready

Incorporating future flood risk into projects would reduce losses, recovery costs

Overview

Flooding is the most common[1] and costly[2] natural disaster in the United States, causing more than $830 billion in estimated losses since 2000.[3] In addition to private property damage, deluges from hurricanes and other storms have washed out roads and bridges and flooded schools, hospitals, and utilities.

Much of this infrastructure is vulnerable to flooding because it’s decades old and in poor condition, reflected by a failing grade by the American Society of Civil Engineers in its 2017 report card.[4] And as floods have become more frequent and intense, exposing more areas to a deluge, federal policies haven’t evolved to address this growing threat. As Congress considers new investments in infrastructure, it must account for present and future risk to ensure that every dollar spent makes communities more resilient in the face of increasingly costly storms.

Did not specifically touch on the WAYS to increase the resilience of pavements and roadway infrastructure

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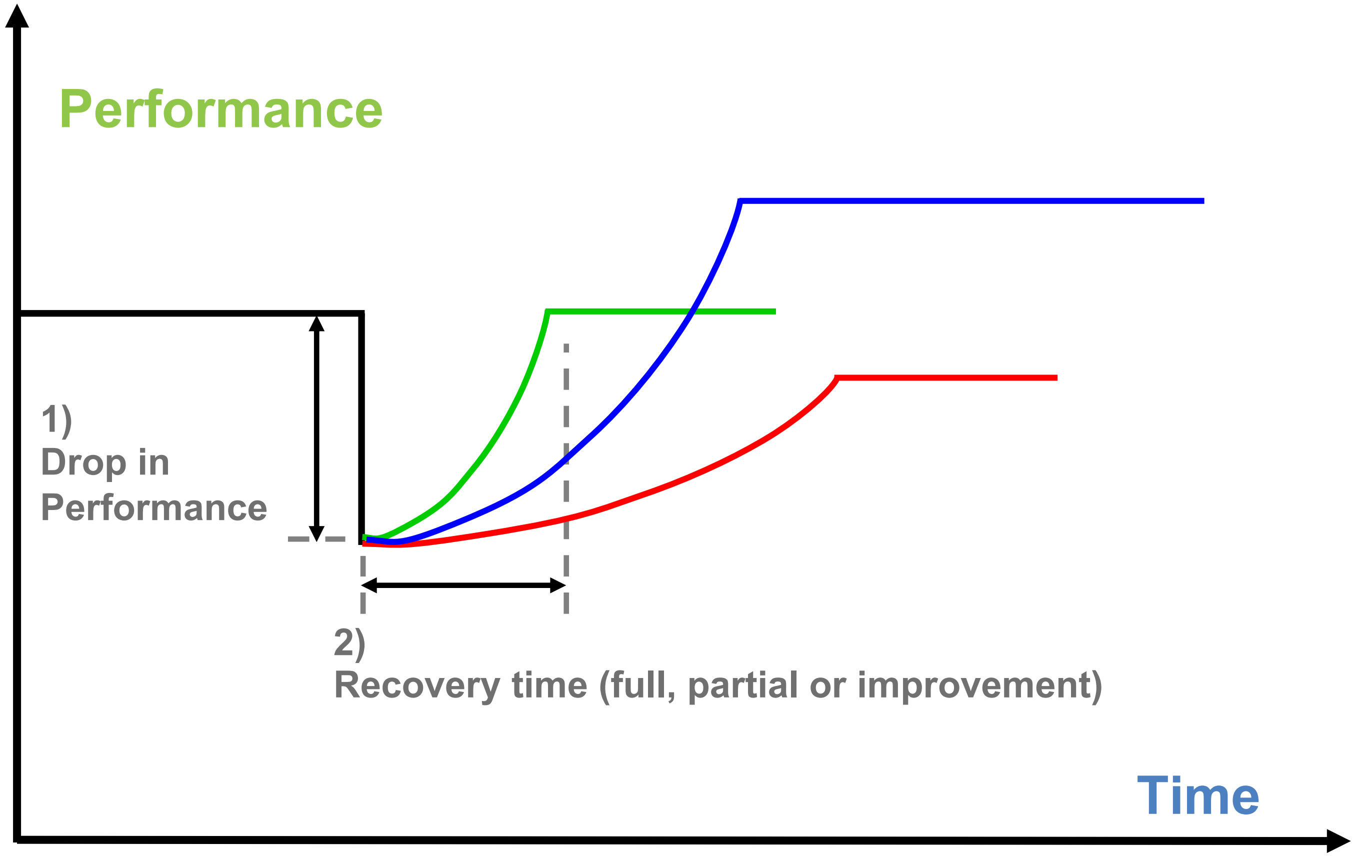
Introduction to Pavement Resiliency

The ability … to resist, absorb, accommodate, & recover … in a timely and efficient manner[1]



Green is more resilient than Red

- faster recovery time
- Higher level of service

Blue is a hardened [2] system as it has a higher final performance level

Pavement Resilience with respect to an event (eg. Flooding) is characterized by two parameters:

1. **Drop in performance, induced by the event (eg. reduced ability to carry load).**
2. **Recovery time to reinstate or improve performance.**

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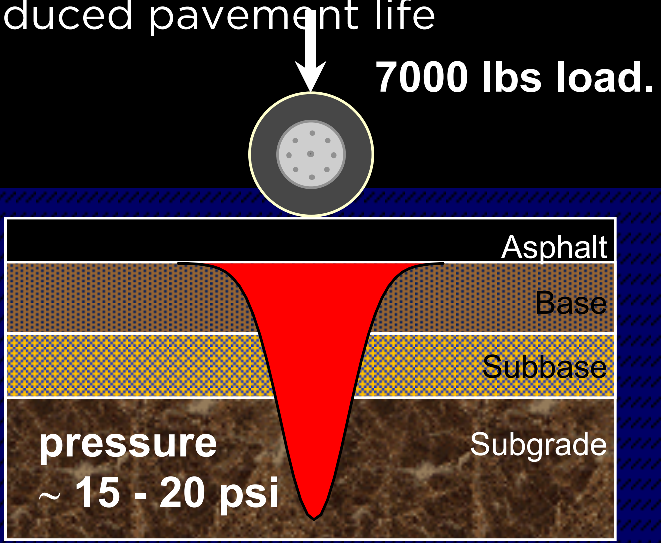
UN-International Strategy for Disaster Reduction
Hardening Infrastructure – Elevating, upgrading, relocating assets, flood walls, berms and levees, etc.

Flooding Causes the Subgrade to become Supersaturated

Moisture infiltrates base, pushes the subgrade particles apart and weakens the system

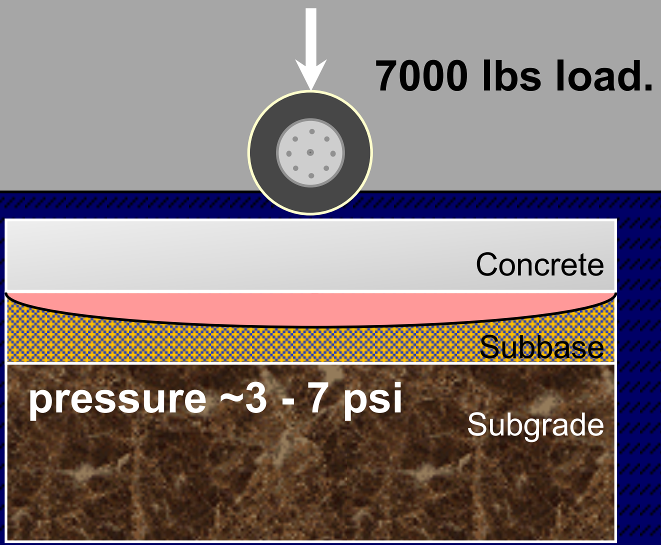
Asphalt Pavements are Flexible

- Lowered subgrade strength & reduced modulus
  - Reduced load carrying capacity
  - Takes ~1 year to regain strength
- Loading during this times accelerates pavement damage / deterioration
  - Reduced pavement life



Concrete Pavements are Rigid

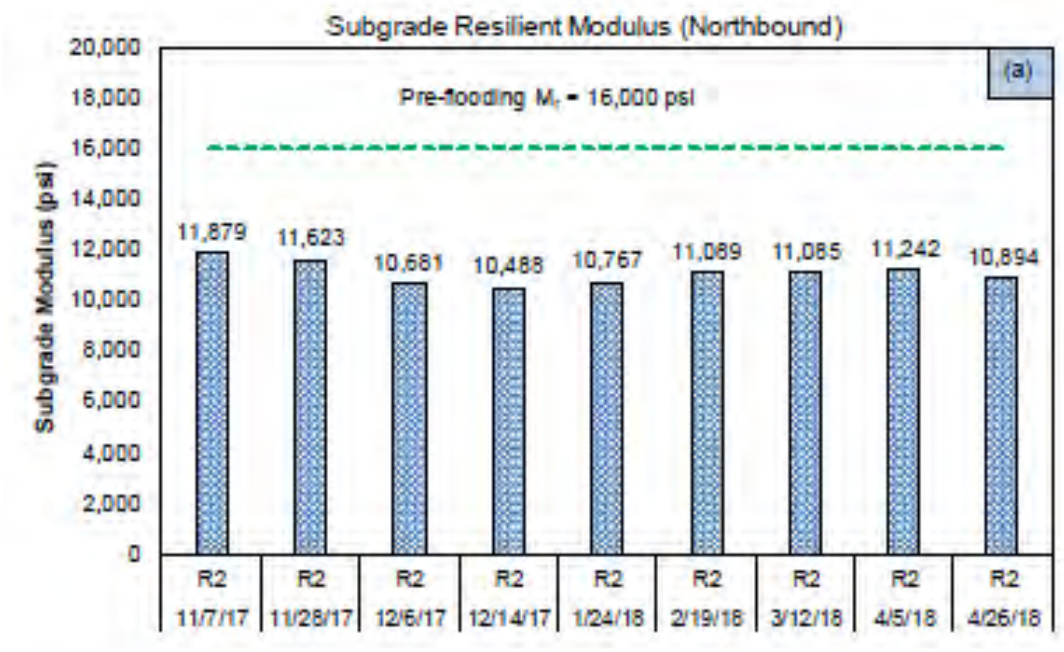
- Maintains high level of strength / stiffness
- Subgrade is weak, but still uniform
- Spreading of the load means subgrade is not overstressed
- Little impact on the serviceability / life

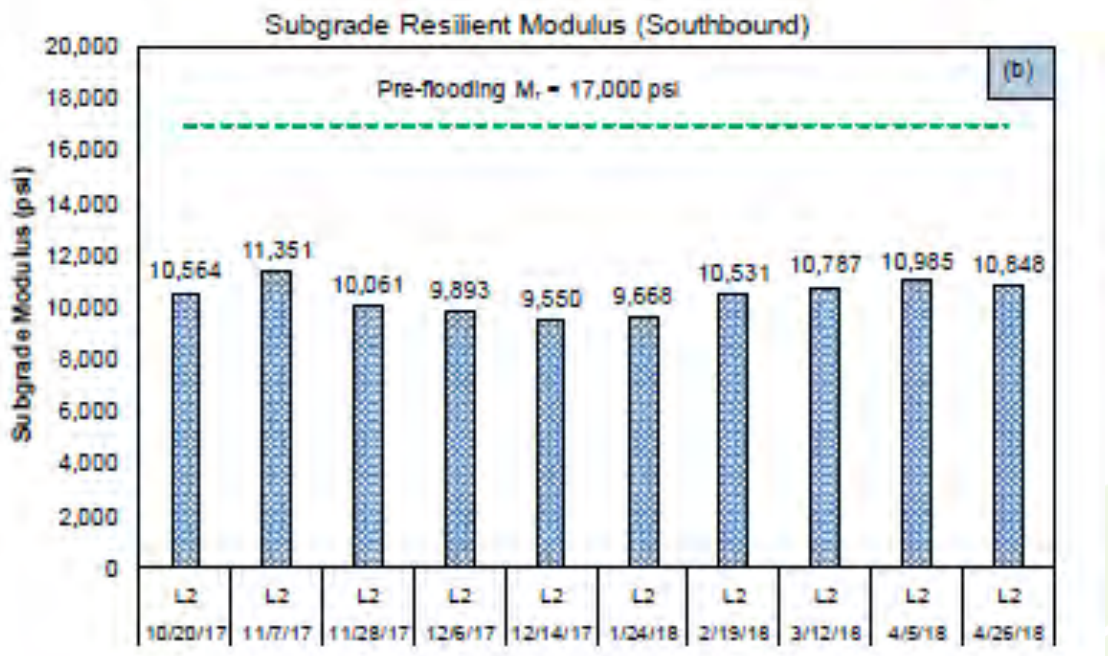


Flooding does not impact the concrete's load carrying capacity to the same degree as asphalt's.

Long Term Latent effects of Flooding

After the flood waters recede, the pavements are structurally vulnerable





Research Findings Indicate it takes up to a year for the subgrade to recover

For this case, this strength loss is a 40 to 60% reduction load carrying capacity and about 3 years of life

Sources:

1. Decision Support Criteria for Flood Inundated Roadways: A Case Study, A. Gundla, Ph.D., E. Offei, Ph.D. G. Wang, Ph.D., P.E. C.Holzschuher, P.E. and B>Choubane, Ph.D., P.E., Presented at the 2020 TRB Annual Mtg
2. Western Iowa Missouri River Flooding— Geo-Infrastructure Damage Assessment, Repair, and Mitigation Strategies; Center for Earthworks Engineering Research, Iowa State University, Report No. IHRB Project TR-638

US 441 in Alachua County, Florida between MP 7.960 to MP 9.680

Two Types of Damage

To have resilient system requires the pavement be able to withstand both

Impact Types / Timing

Primary Impacts –alters the pavement structural or functional capabilities

Secondary Impacts –Impacts due to recovery activities

- Rescue and Emergency response during the disaster
- Recovery activities (clean up and rebuilding) after the disaster

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RELIEF AND RESCUE EFFORTS WILL TAKE PLACE

Loading weakened Pavements will shorten their lives

Hurricane Michael 2018, 2 million ready-to-eat meals
1 million gallons of water and
40,000 10-pound bags of ice

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Debris Removal

Capacity = 10 to 17 cubic yards
1M CY ~ 65,000 Dump Trucks

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Roads designed for small town traffic

additional 150,000 trucks under weakened conditions

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Debris removal can take place for months

Further exacerbating the pavement damage while weakened

Hurricane Irma 2017
4 M CY Miami Dade
3 M CY Palm Beach
3.6 M CY Collier
2.7 M CY Lee

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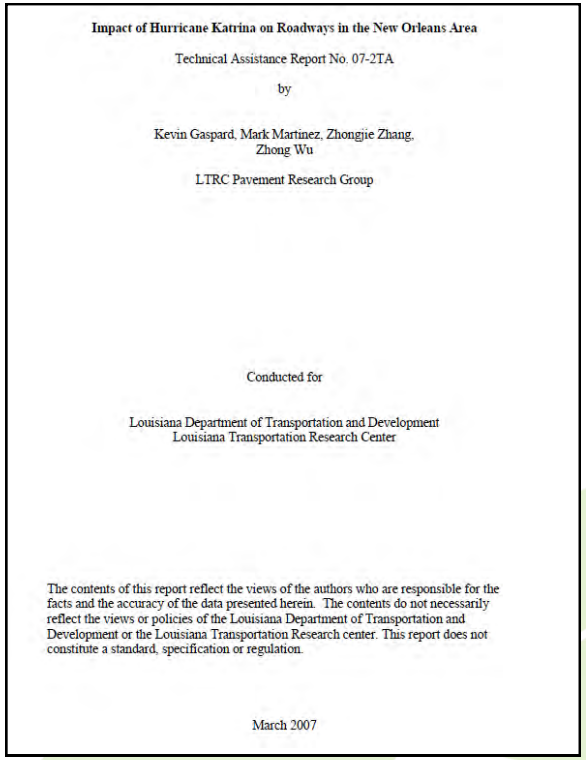
Key finding for Pavements submerged by Hurricane Katrina

Submerged pavements were weaker than non-submerged pavements

- **Asphalt pavements**
  - Overall strength loss ffi two inches of new asphalt concrete
    - Damage occurred regardless of the length of time the pavement was submerged
  - Cost: $50 million to rehabilitate 200 miles of submerged asphalt roads

- **Concrete Pavements**
  - Little relative loss of strength due to flooded conditions
    - Resilient modulus(Mr) is similar for submerged and non-submerged pavements
  - No information given on repairs or repair costs



Impact of Hurricane Katrina on Roadways in the New Orleans Area

Technical Assistance Report No. 07-2TA

by

Kevin Gaspard, Mark Martinez, Zhongjie Zhang, Zhong Wu

LTRC Pavement Research Group

Conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Louisiana Department of Transportation and Development or the Louisiana Transportation Research center. This report does not constitute a standard, specification or regulation.

March 2007

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Impact of Hurricane Katrina on Roadways in the New Orleans Area, Technical Assistance Report No. 07-2TA
Kevin Gaspard, Mark Martinez, Zhongjie Zhang, and Zhong Wu; LTRC Pavement Research Group, March 2007

Flooded pavement research in Australia

Road authorities consider changing roads into flood-resilient pavements

A rigid pavement performs better than composite and flexible road groups

- Composite and flexible road groups show similar performance up to 2–3 years.
- Rigid pavement performs the best at any probability of flooding, and flooding effect is not critical

A pavement's strength may be enhanced by:

- Strengthening with an overlay
- Layer stabilization.
- Converting the road into a rigid or composite pavement through granular layers' stabilization.

Estimating Pavement's Flood Resilience

Misbah U. Khan, CPEng.[1]; Mahmoud Mesbah, Ph.D.[2]; Luis Ferreira, Ph.D.[3]; and David J. Williams, Ph.D.[4]

Abstract: Although several studies observed pavement responses after flooding, no detailed quantification has been done to date. This paper has estimated different pavements' performances with flooding to identify flood-resilient roads. This was shown through (1) new roughness and rutting-based road deterioration (RD) models, (2) the relationship between changes in roughness [International Roughness Index (IRI)] versus time and modulus of resilience (Mr) loss at granular and subgrade layers versus time, and (3) flood consequence results. The comparative analysis on different pavement performances shows that a rigid and strong pavement built to a high standard is the most flood-resilient, which may be adopted as a preflood strategy. Results obtained using two proposed new gradients of IRI (incremental change in IRI, ΔIRI) in Year 1 over probability of flooding ($\Delta IRI/Pr$) and ΔIRI in Year 1 over loss in Mr ($\Delta IRI/MrL$) as well as flood consequences provided similar results. Road authorities should consider changing their roads to flood-resilient pavements in the future. It is recommended to investigate after flood roads' structural conditions and performances to validate the new ratio values of $\Delta IRI/Pr$ and $\Delta IRI/MrL$. **DOI: 10.1061/JPEODX.0000007.** *© 2017 American Society of Civil Engineers.*

Author keywords: Road deterioration; Modulus of resilience; Flooding; Flood-resilient pavement.

Introduction

Pavement performance shows deterioration of roads with time in its service life, which is dependent on traffic loading, material properties (pavement type, structure, strength, and subgrade strength), climate and environment, drainage, initial road condition, and maintenance activities (Hunt and Bunker 2001). It is generally expressed by roughness versus time. Roughness is related to pavement structural and functional conditions, traffic loading,

Monismith (1992) and Huang (1993) found an increase in pavement deflection due to a lower Mr, and consequently a reduced pavement life. There are no studies that can address pavement performance with flooding.

Recently, Khan et al. (2014a, 2017c) and Khan (2017) developed project and network levels roughness and rutting-based road deterioration (RD) models at different probabilities of flooding. Additionally, Khan (2017) and Khan et al. (2017a) determined pavement responses during flooding using the Mr loss values in granular

flood. The newly derived RD models are valid for a short period up to 2–3 years (Khan 2017; Khan et al. 2017c). The RD models with flooding, ΔIRI in Year 1 divided by the percent of probability of flooding ($\Delta IRI/Pr$) and ΔIRI in Year 1 divided by the percent of Mr loss at subgrade and granular layers ($\Delta IRI/MrL$) for different road groups and flood consequence results provide valuable information in this regard.

The current paper has proposed two new gradients: (1) $\Delta IRI/Pr$, and (2) $\Delta IRI/MrL$ using the IRI versus percent probability of flooding and IRI versus percent Mr loss relationships, respectively. The consequence of a flood for a road group using ΔIRI also gives useful information. The gradient of rutting (ΔRutting) versus the percent probability of flooding provides similar relationships; hence, the ΔRutting in Year 1 over probability of

[1]Ph.D. Candidate, School of Civil Engineering, Univ. of Queensland, Brisbane, QLD 4072, Australia; Senior Asset Systems Engineer, Central Coast Council, 2 Hely St., Wyong, NSW 2259, Australia (corresponding author). E-mail: misbah_70@yahoo.com
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Note. This manuscript was submitted on October 13, 2016; approved on April 27, 2017; published online on June 22, 2017. Discussion period open until November 22, 2017; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Transportation Engineering, Part B: Pavements*, © ASCE, ISSN 2573-5438.

"It's settled that a rigid pavement is the more flood-resilient." (p-5)

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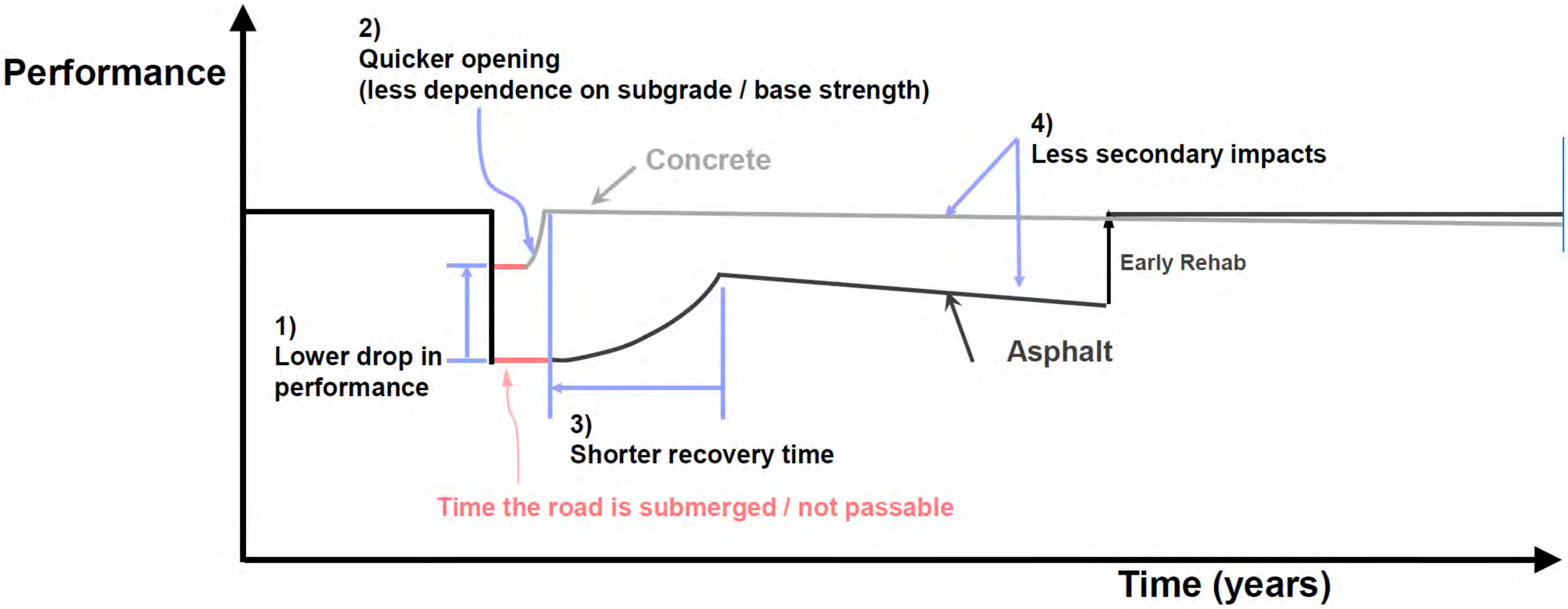
Estimating Pavement's Flood Resilience; Misbah U. Khan, CPEng; Mahmoud Mesbah, Ph.D.; Luis Ferreira, Ph.D.; and David J. Williams, Ph.D.; American Society of Civil Engineer's Journal of Transportation Engineering, Part B Pavements, 2017

Key Performance Measures

- A drop in performance induced by the event
- Time required for recovery
- The ability to withstand loading while in a weakened state

Stiffer Pavements are more Resilient to Inundation Flooding



Stiffer Pavements are less impacted by sub grade strength loss and recover faster
(stiffer = concrete, cement stabilized bases, increased asphalt thickness)

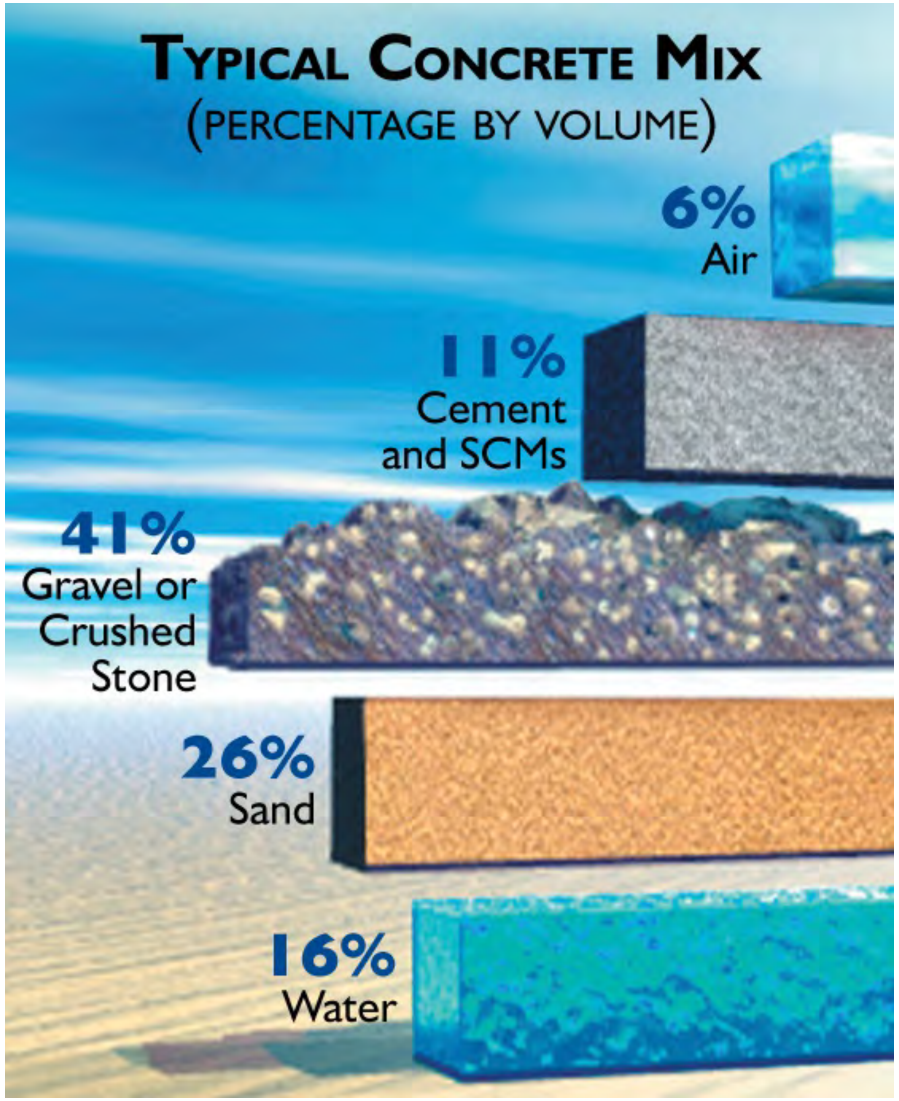
More information on Resilient Pavement

[Florida Concrete & Products Association YouTube Channel]

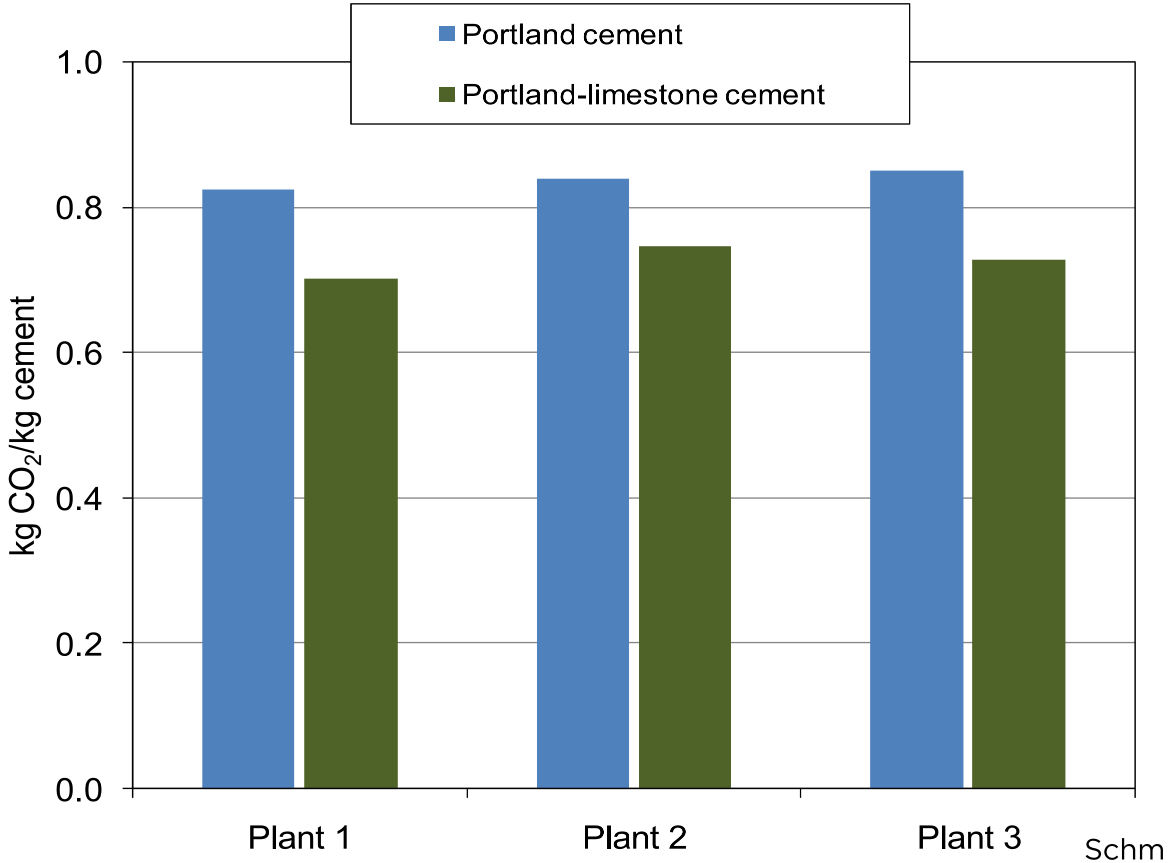
TOPICS COVERED

Manage Stormwater
Improving Safety
Reducing Urban Heat Islands
Improve Resiliency
Reduce Embodied Carbon

Reduce Embodied Carbon

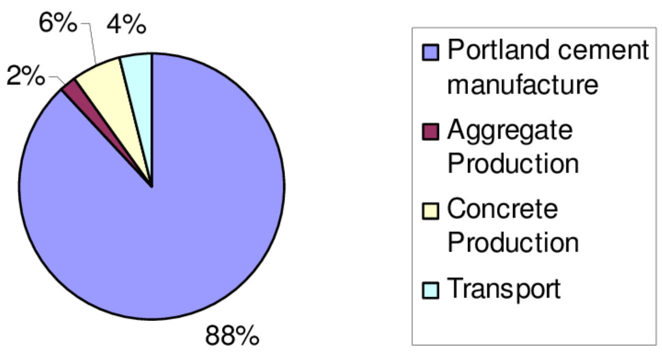


Environmental Benefits



Schmidt 1992

Reduced CO2 by 10 - 12%



CO2 Emissions in Concrete

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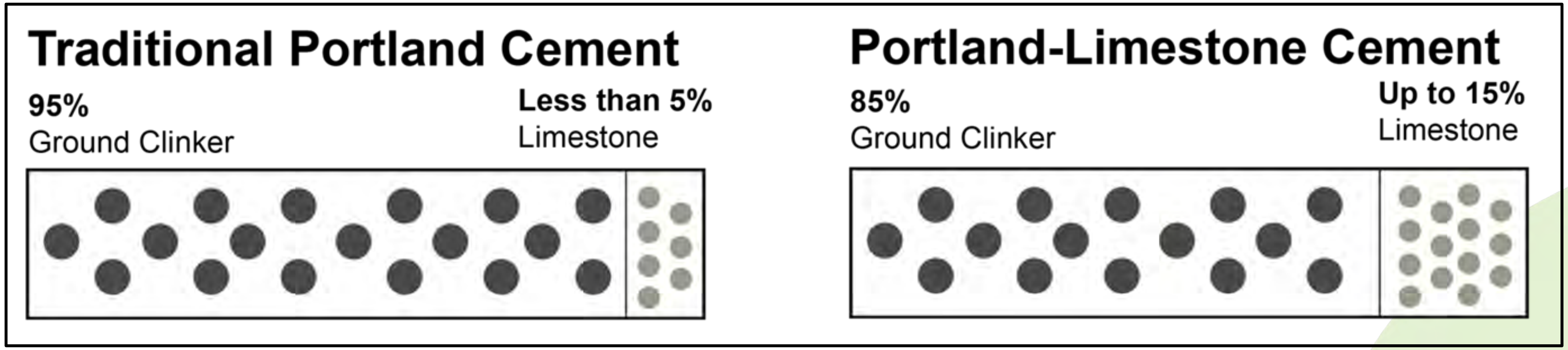
What is portland-limestone cement?

- Portland-limestone cement is made by inter-grinding regular clinker with up to 15% limestone while regular portland cement contains up to 5% limestone (Type IL blended cement in ASTM C595/AASHTO M240)

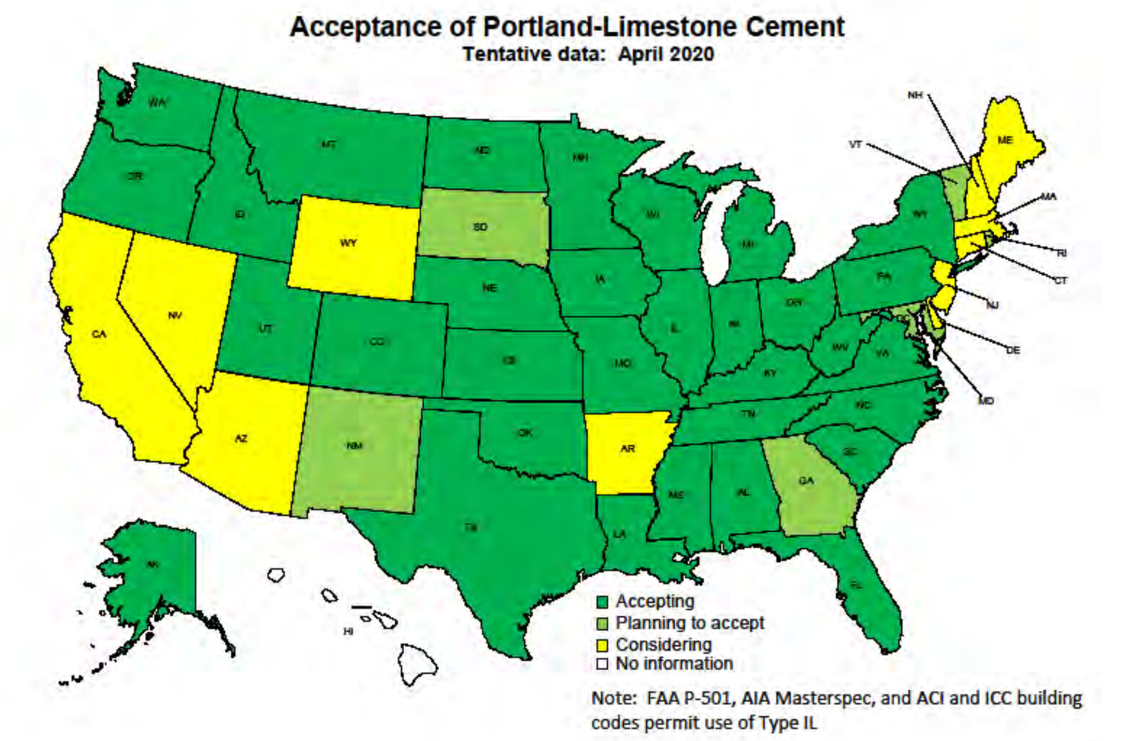
- Portland-limestone cement is a finer ground product than regular portland cement



Portland-limestone Cement

Portland-limestone Cement

- 5% to 15% limestone
- History of use: Europe (50+ yrs), Canada (10+ yrs), US
- PLCs becoming more popular in the USA
- ASTM C 595 Type IL
- Accepted by state DOTs



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Benefits in Ready-Mix Concrete

- **Equivalent strengths to traditional Type I/II portland cement**
- **Works well with supplementary cemeticicous materials**
- **Improved finishing and pumpability of concrete**
- **Contributes to the environmental footprint of structures**

FRESH CONCRETE PROPERTIES WITH PLC

Property:	
Workability	Increase
Bleeding	Decrease (because of Higher surface area)
Set Times	Equal
Heat of Hydration	Slightly increase

** Broader particle size distribution because there are finer limestone particles mixing with clinker particles hence improving packing in addition to the way particles react with one another.

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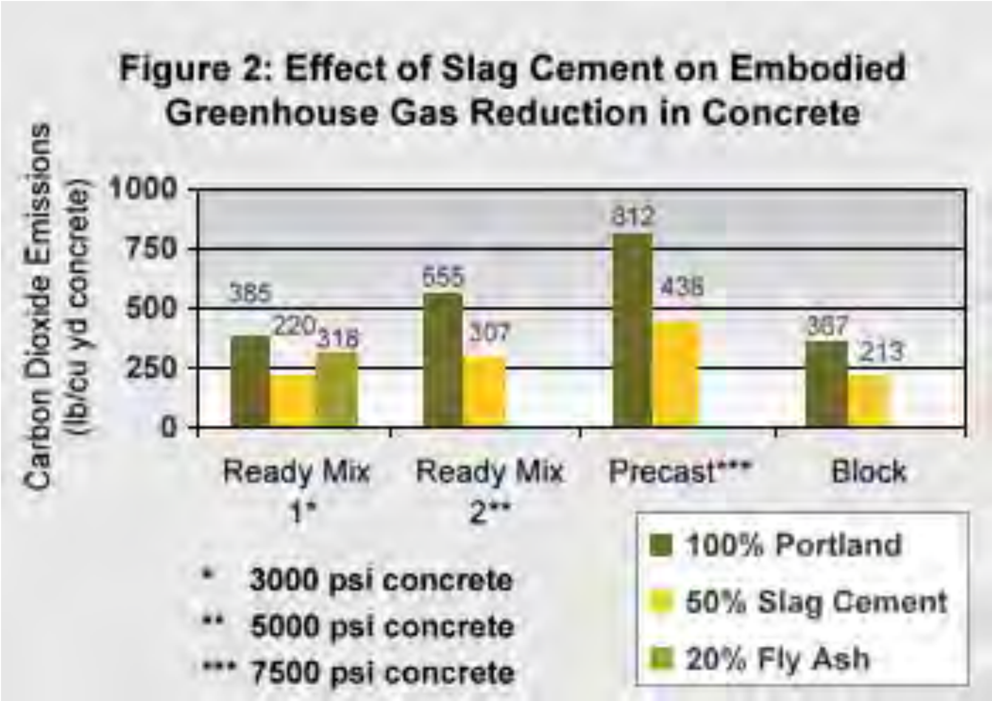
Interactions with SCMs (Supplementary Cementicious Materials)

Synergies between PLCs and moderate amounts of slag

- Greater strength VS slag/OPC blends
- Improved durability (Small improvement but be increased with modifying W/C)

Synergies between PLCs and some sources of Fly ash

- Effect varies with Fly ash source, fly ash composition and cement chemistry



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Bay Shore Condominiums High Rise in Tampa, FL

18,000 CY

- 8,000 psi post tensions slabs – straight Type IL mix
- 10,000 psi shear walls and columns - 50% Type IL / 50% slag mix

Bayway Bridge - Tierra Verde/Fort Desoto, Florida

Construction Cost $56.3 million

- Estimated Completion Summer 2021
- Type IL (10) used in most of the mix designs - 30% Type IL / 70% slag mix

More information on Portland Limestone Cement

[Florida Concrete & Products Association YouTube Channel]

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LEED Projects

Sustainable Sites

- *Rainwater Management*
- *Heat Island Reduction*

Water Efficiency

- *Outdoor Water Use Reduction*

Materials and Resources

- *Building Life-Cycle Impact Reduction*
- *Building Product Disclosure and Optimization - Environmental Product Declarations*
- *Building Product Disclosure and Optimization - Sourcing of Raw Materials*

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LEED Projects

EPD (Environmental Product Declaratio

- *Industry EPD*
- *Concrete Producer EPDs*

NRMCA Database of EPDs available

- *Third party verified*

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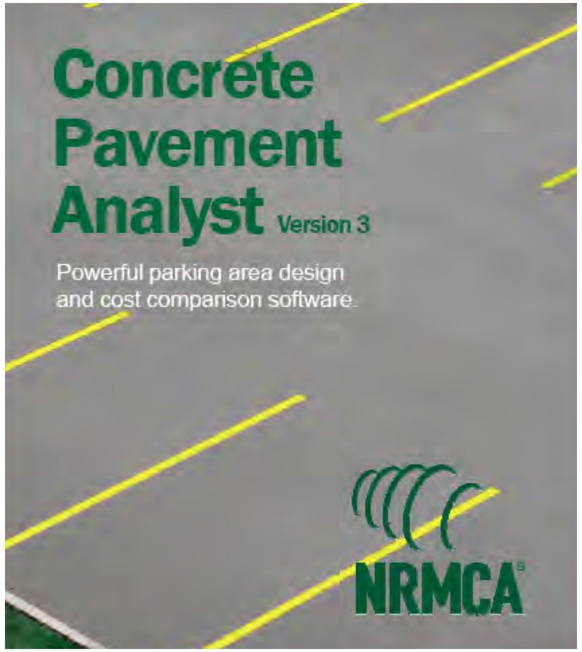
What about costs?

- ➢ Construction costs?
- ➢ Ownership costs?



- Life Cycle Costs Analysis
- Compares Asphalt and Concrete designs per industry standard specifications
- As well as Local Design Specification
- Allows owner to make a more educated decision

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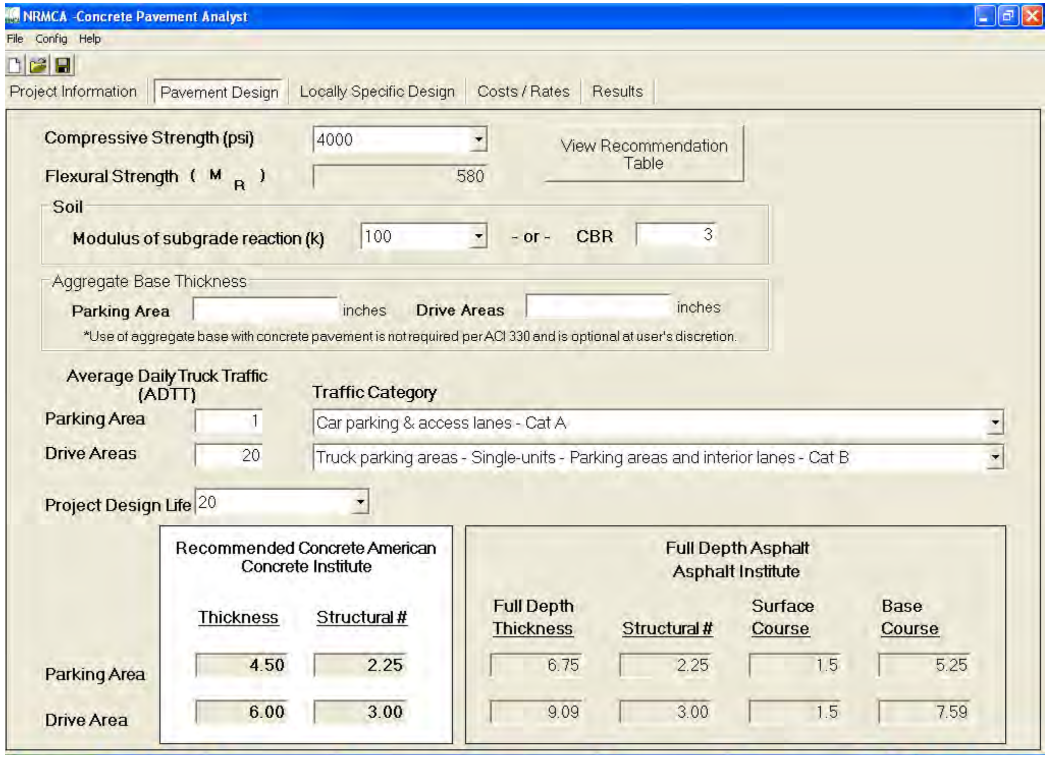
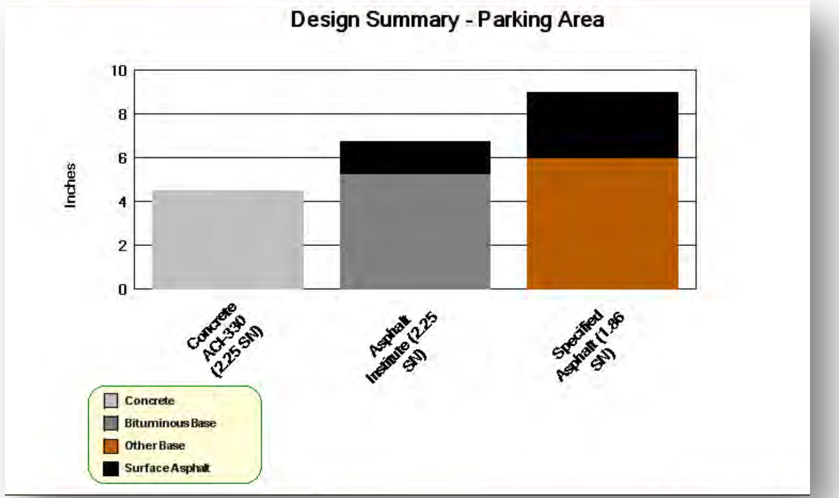
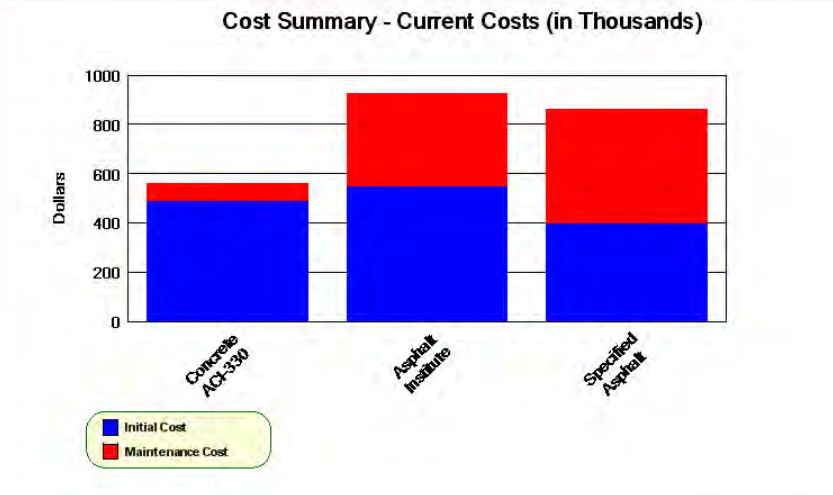
Life Cycle Cost Analysis

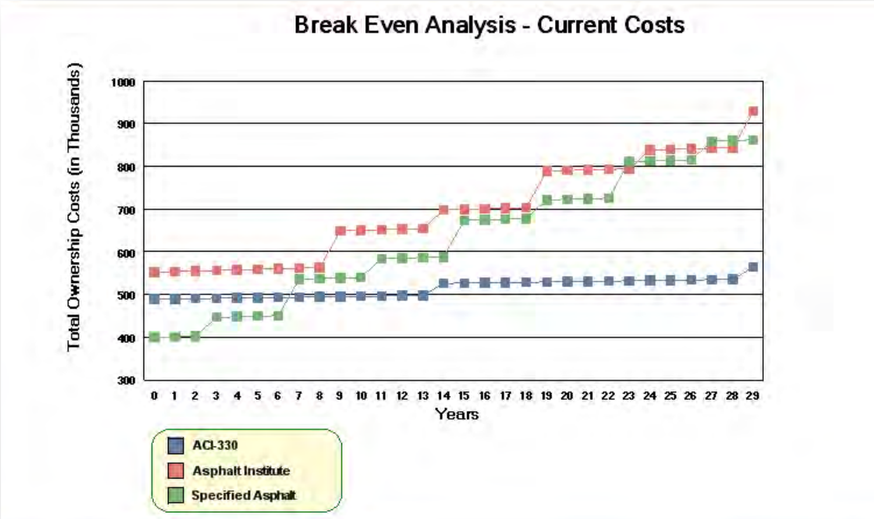


- Project Information
- Soil Information
- Traffic information

Life Cycle Cost Analysis







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Design Assistance Program

Looking for design assistance on your next project? PaveWise is here to help.

Simply fill out the form below and we'll get back to you as soon as possible.

Questions

Manage Stormwater

Improving Safety

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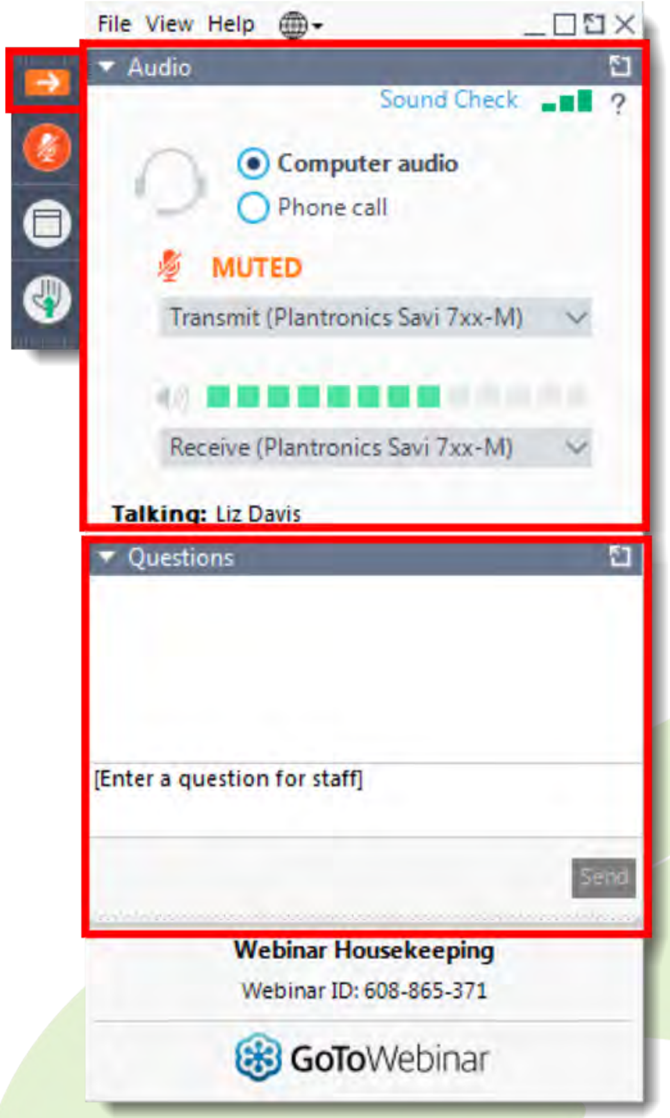
Improve Resiliency

Reduce Embodied Carbon



Thank you

Florida Concrete and Products Association

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