Final Report

Permeable Pavement Road Map Workshop
and
Proposed Road Map for Permeable Pavement

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Final Report: Permeable Pavement Road Map Workshop
and
Proposed Road Map for Permeable Pavement

Sponsored by: Interlocking Concrete Pavement Institute, National Asphalt Pavement Association, National Ready Mixed Concrete Association, Tongji University Sponge City Project

Organized by: University of California Pavement Research Center, National Center for Sustainable Transportation

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1.0 Overview of Workshop and Proposed Road Map

In early 2017, the University of California Pavement Research Center (UCPRC) and the National Center for Sustainable Transportation (NCST), working with the Interlocking Concrete Pavement Institute (ICPI), identified gaps in knowledge and other barriers to wider implementation that were perceived to be holding back the full potential for deployment of pavements that can simultaneously solve transportation, stormwater quality and flood control problems. Further discussion with the National Ready Mixed Concrete Association (NRMCA), the National Asphalt Pavement Association (NAPA) and the Tongji University Sponge City Project (Shanghai, China) led to the organization of a workshop with the goal of identifying knowledge, information, and communication barriers to adoption of permeable pavement[1] of all types, and creation of a road map to address and overcome them. The workshop brought together a diverse group of stakeholders from the planning, stormwater quality, flood control and pavement communities to hear presentations, exchange and discuss unanswered questions identified by the group, and then discuss a proposed road map to fill the gaps in knowledge, processes and guidance. The conference website is: https://ncst.ucdavis.edu/events/permeable-pavement-workshop.

The result is a comprehensive discussion that identifies challenges to be solved and a road map with "routes" of proposed actions to remove technical and institutional barriers so that the goal of making permeable pavements a fully viable design solution alternative in standard practice becomes a reality. The full journey through all of the routes needs to be traveled to arrive at the goal.

The following is a summary of the 10 proposed routes that lead to achieving the goal of making permeable pavements a choice that can be considered with confidence. These are presented in sequential order, although some activities are identified that could run concurrently.

Route 1. Reliable pavement structural designs: Complete development of reliable structural design tables that account for long-term saturated soils typical to permeable pavements. This will likely require a significant investment in materials research, full-scale pavement testing and mechanistic modeling that covers a range of soil conditions and traffic loads. Hybrid pavement systems that have some combination of pervious concrete, porous asphalt and/or concrete pavers must be explored to achieve higher capacity, more reliable structural designs that perform well in saturated soils. Demonstration projects are encouraged.

Route 2. Reduction of target pollutants to meet water quality requirements: Develop design decision trees/menus for reduction of target pollutants which are mostly agency and site dependent from existing and additional research. Include runoff reduction as an integral part of water quality management objectives and pollutant reduction credits.

[1] The term "permeable pavement" is used generically in this report and road map for all pavements that are intended to capture stormwater and infiltrate it into the subgrade and/or retain it for slow release into the stormwater management system. This type of pavement is also commonly referred to as "pervious pavement" when it has a pervious concrete surface and "porous pavement" when it has a porous asphalt surface.

Route 3. Reduction of urban flooding risks: Develop approaches for considering permeable pavement in flood modeling for use in zoning, planning, land development codes and flood control design.

Route 4. Routine achievement of high quality construction: From the above research, improve construction guide specifications that include improved construction methods, especially quality control and quality assurance test methods and inspection protocols/checklists.

Route 5. Maintenance and rehabilitation costs and methods: Information regarding best practices for maintenance methods are their costs must be refined for different applications and made widely available. Identify designs that minimize sediment transport and deposition that require more maintenance. Improve maintenance methods including surface cleaning techniques and equipment, potential deicer use reduction. Identify best practices for hydrologic and structural rehabilitation and reconstruction methods for aging permeable pavements.

Route 6. Incorporation of permeable pavements into asset management systems: Based on results from the five routes above, develop/refine asset management tools for stormwater and road agencies. These include inspection methods/standards, and maintenance costs. Concurrently improve, and where possible validate, at the site scale, drainage system scale, and regional watershed (flood) scale the quantitative performance models appropriate to each.

Route 7. Accurate life cycle cost analysis and environmental life cycle assessment tools: Concurrent with asset management, perfect life cycle cost analysis (LCCA) tools that account for on and off-site costs and benefits to support designer, stormwater and road agency decisions regarding use of permeable pavements. This route should include development of life cycle assessment (LCA) tools to calculate environmental impacts considering the full life cycle including manufacturing, construction, use, and end-of-life stage environmental impacts for the full functional unit of permeable pavements included their related off-site impacts. This requires flexible, site-specific system boundary condition definitions. Integrate these measured impacts into pavement design and asset management programs.

Route 8. Infrastructure management organizations that consider the full functionality of permeable pavements: All the above science and empirical information inevitably points to institutional changes, i.e., bridging the gap between stormwater agency and road agency priorities and cultures. The outcomes of the first seven routes will provide information for creation of clearer frameworks moving forward for updating existing local and state regulations, zoning, site design and building codes, as well as flood control management. The outcomes will provide the information needed to address reforming federal, state and municipal agency structures for urban hardscape[2] infrastructure management to consider the full range of approaches, including permeable pavement, for meeting multi-functional goals of transportation, stormwater quality and flood control. Multi-functionality needs to be considered over

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[2] "Urban hardscape" can be defined as manmade horizontal surfaces in contact with the earth which include streets, parking areas, sidewalks, driveways alleys, paths, plazas and courtyards. In urban areas developed since introduction of the automobile urban hardscape often occupies 25 to 45 percent of the surface of urban areas.

the life cycle of hardscape/pavement/transportation infrastructure planning, design, management and maintenance.

Route 9. Planning guidance that considers the multi-functionality of permeable pavements: this route also capitalizes on the above research and expanding experience with permeable pavements. This route includes developing planning guidance, reviewing long-term performance of existing installations, developing criteria for user comfort and developing idea books, some of which will include case studies in various climates, soils and applications.

Route 10. Efficient and comprehensive access to the best information: This path includes developing a clearinghouse and/or a center or centers for permeable pavements, as well as communications. It also includes finding funding to execute this road map.

2.0 Summary of Workshop Program

The workshop was held at the Oddfellows Hall in downtown Davis on November 14 and 15, 2017. The workshop registration and operations were organized by the National Center for Sustainable Transportation. ICPI, NAPA, NRMCA and Tongji University supported the cost of the venue and catering for the workshop. The participants paid their own travel costs.

2.1 Participants

Conference participation was by invitation only due to the limited funding and the size of the workshop meeting site. The result was a diverse, experienced group including those with pavement, stormwater quality, flood control, planning and landscape architecture areas of expertise, and participation from the government, consulting, construction and materials, and academia sectors. The expertise and practice sectors of the 57 participants are shown in Table 1 below. The participant list is in Attachment A and on the website[3]. Sixteen of the 24 participants from the government sector were from local government, primarily from California but also from several other states and a Canadian province. Six participants were from three different divisions of the California Department of Transportation (Caltrans): Environmental Analysis, Maintenance [Pavement] and Research, and two were from the Federal Highway Administration. Beyond the 57 invited participants, an additional 19 were UCPRC staff and students who served as note takers throughout the conference, several of whom also helped organize the final workshop content for posting on the internet and use in this report. The staff and students were led by Ali Butt, Jeff Buscheck and Arash Saboori.

Table 1. Summary of participants by expertise and practice sector

	Practice Sector				
Expertise	**Government**	**Consulting**	**Construction & Materials**	**Academia**	***Total***
Pavement	4	1	12	10	*27*
Stormwater Quality	6	3	0	2	*11*
Flood Control	10	3	0	0	*13*
Planning	3	1	0	0	*4*
Landscape Architecture	1	1	0	0	*2*
Total	***24***	***9***	***12***	***12***	***57***

[3] http://www.ucprc.ucdavis.edu/permPvmt/Participants.aspx

2.2 Program

The program for the workshop, shown in Attachment B, began with a half day of invited presentations. These provided all participants with a range of perspectives on the opportunities and limitations for using permeable pavements to solve different planning, transportation, flood control, stormwater control and other objectives. The presentations can be seen on the workshop website[4] .

During the presentations, all participants prepared questions for later discussion based on information they had prior to the workshop and in response to the presentations. The questions were gathered at the end of the first day, transcribed by UCPRC staff and students, and then organized by topic area prior to the start of the second day. A total of 76 questions, shown in Attachment C and on the website[5], were finalized by the workshop chair from the results of the first day. These are organized into the following topics:

- Costing and cost decision support
- Materials and pavement performance
- Education and training
- Communication
- Project-level design issues
- Watershed and flood control design issues
- Designing for additional benefits and impacts
- Construction standards and issues
- Maintenance
- Asset management
- Funding for research, development, implementation
- Planning and development codes

The second day began with two 90-minute breakout sessions in which groups of five to seven participants (noted in Attachment D) with diverse representation from the matrix of expertise areas and practice sectors, discussed the questions and possible actions to answer them. UCPRC staff and students documented the discussions. The groups were instructed to address questions they selected from the three topic areas assigned for each group in the first morning session (shown in Attachment D), and another three topic areas in the second session. Topics that had the most questions were assigned to more than one group.

All participants gathered together after lunch on the second day to hear summary reports from each discussion group covering the salient points of their discussions. The discussion group reports are

[4] http://www.ucprc.ucdavis.edu/permPvmt/Presentations.aspx

[5] http://www.ucprc.ucdavis.edu/permPvmt/PDF/Questions%20from%20Permeable%20Pavement%20Workshop%20Day%201.pdf

summarized in this report by topic area and the presentations made by the groups summarizing their discussions can be seen on the workshop website[6].

The workshop chair then prepared an outline of the proposed road map for permeable pavements based on the group reports, which was followed by discussion by all workshop participants. Included in the discussion were additions to the proposed road map, who should be involved in reviewing and implementing the road map, sources of funding, next steps and a schedule for moving forward.

At the close of the workshop, all participants were asked to help identify a name for the road map and by extension for the concept of multi-functional hardscape, identify who else should be involved in reviewing and implementing the road map, and who else should be involved in helping to move the technology into practice through communication and training.

2.3 Summary of the First Day Presentations

After a brief welcome, the co-chairs and sponsors of the workshop presented a charge to listen to each other, offer their insights, opinions and ideas, and have fun learning from colleagues with a wide range of experience with permeable pavements.

John Harvey with the UCPRC presented a summary of a 2017 Caltrans sponsored research survey[7] regarding obstacles to implementation of permeable pavement (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Harvey_Overview.pdf). The survey had 64 respondents, primarily from California agencies and consultants and a few from other states. Approximately half of the respondents had experience with permeable pavement and half did not. The conclusions were that experienced designers and their stakeholders generally perceive permeable pavement to be successful, while many of those with limited knowledge or experience remain unconvinced that it can work well. Concerns remain regarding maintenance and life cycle costs, and gaps in knowledge about initial costs, maintenance frequency and methods, design guidelines, project selection guidance, and the risk-averse culture within civil engineering.

David R. Smith (ICPI), Brian Killingsworth (NRMCA) and Richard Willis (NAPA) presented their summaries of the perspectives of permeable pavement materials producers and contractors represented by their organizations.

David R. Smith (www.icpi.org), who has been working in the permeable pavements arena for many years, summarized progress regarding hydrologic design, measurement of runoff volume and pollutant reductions, and structural design for heavy vehicles, including publication in 2018 of American Society of Civil Engineers (ASCE) standard for permeable interlocking concrete pavements (PICP) (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Smith_Industry_Perspectives.pdf). He noted that despite this progress there are few state transportation departments with standard designs and specifications, which he attributed to lack of sufficient ownership to justify research for permeable pavements compared with conventional impermeable pavements. He also noted a high prioritization by

[6] http://www.ucprc.ucdavis.edu/permPvmt/Breakouts.aspx
[7] See http://www.ucprc.ucdavis.edu/PDF/UCPRC-TM-2017-03.pdf

state and municipal road agencies of safety for vehicle operators and lower prioritization of stormwater concerns, and pavement engineers' concerns regarding maintenance and life cycle costs for permeable pavements. On the other hand, meeting NPDES permit requirements is the priority for stormwater engineers and managers, plus maintaining safety and resilience of stormwater management infrastructure. In this context, many sense a lack of sufficient information regarding permeable pavements. He proposed that a plan for government, industry and academia to come together is needed to do research, development and training that addresses the needs of transportation and stormwater owners of permeable pavement.

Brian Killingsworth (www.nrmca.org) discussed the design and construction of pervious concrete pavement as a system and stormwater quality benefits (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Willis_Killingsworth_Industry_Perspectives.pdf). He also summarized extensive information on pervious concrete available from NRMCA for consumers, specifiers, designers, contractors and owners. This includes technical information, specifications, a contractor certification program, and a program for "just-in-time" training for contractors. NRMCA also has information regarding maintenance and operation of pervious concrete pavement for owners.

Richard Willis (www.asphaltpavement.org) discussed the asphalt industry's perceptions of the status of current information, gaps in knowledge for porous asphalt pavements, and ideas for overcoming obstacles from the perspective of porous asphalt materials produces and contractors.

Amir Ehsaei (Project Engineer with AECOM with help from Tom Sweet, AECOM Senior Engineer) (www.aecom.com) discussed permeable pavement as a stormwater best management practice (BMP) and summarized experience on several recent projects converting streets to permeable pavement in the Bay Area, sometimes combined with bio-retention (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Ehsaei_Sweet_Thoughts_on_the_Future.pdf). He discussed good experience with all three typical surface types (pavers, concrete, asphalt), various types of subgrades resulting in design for infiltration with or without the need for additional drainage features, and use in streets and sidewalks. He called out the need to consider proximity to underground basements, below grade driveways, available street widths to handle stormwater loads, underground utilities, the need to drain contributing areas larger than the street, landscaping, trees, sediment producing slopes, check dams for infiltration on slopes under the pavement, and bicycle and skateboard ride quality concerns, as well as potential benefits for traffic calming when evaluating a candidate site. Case studies he presented showed design solutions combining permeable pavement and bio-retention to share the stormwater and sediment loads. Participants asked questions after the discussion regarding whether there is sufficient site selection and design guidance for all of these considerations. Such tools exist for decision making.

Janet Attarian from the City of Detroit (http://www.detroitmi.gov) discussed planning and conceptual design for permeable pavement (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Attarian_Planning_and_Design.pdf). She emphasized that a permeable pavement is one means to the end of creating safe, beautiful and sustainable streets. She discussed three documents developed for Chicago and now being used in Detroit: *Complete Streets Guidelines* which provides guidance on modal hierarchy and mode sharing, upcoming *Placemaking Guidelines* which address economic development, open space creation and public enjoyment, and *Sustainable Urban Infrastructure Guidelines* (SUIG) which address ecological services. In terms of financial sustainability, she reviewed data from Chicago that showed that costs of "green build" streets are often less than projected, have similar order of magnitude as "business as usual" streets, but have much greater benefits which result in much higher benefit to cost ratios over a 30-year life cycle analysis period.

The SUIG includes municipal objectives and performance metrics for economics, energy, climate and air quality, beauty and community, water, materials and waste, and commissioning (maintenance, continuous improvement of design tools, and performance prediction and measurement). A complete project delivery process is provided in a Project Delivery Summary Sheet and Notebook. To facilitate "ownership" through the delivery process, the notebook is handed from the planner to the design project manager to the construction resident engineer and then back to the project manager for commissioning and establishing maintenance, which also helps build project data sets for use in performance measurement and continuous improvement of the process.

As part of its renovation of the urban land area in the face of depopulation and stormwater quality requirements, Detroit is charging property owners a fee for impervious surfaces, which they can reduce up to 80 percent by changing to permeable surfaces, which can include permeable pavement. Permeable pavements, particularly parking lots and streets, drain themselves as well as that from rooftops. These plans have required changes in municipal design and construction standards.

Planning that considers stormwater handling and place making is being done on a neighborhood basis, connected by stormwater/park/urban place making corridors that lead to the Detroit River. The organizational structure includes the Detroit Water and Sewerage Department, funders and developers, and neighborhood management councils who bring together the city agencies and funder/developers with property owners.

Keith Lichten from the California Water Board www.waterboards.ca.gov) discussed permeable pavement in the context of California stormwater regulation and codes. He began by noting that the general approaches to meeting stormwater quality requirements are "slow it, spread it, sink it" and that permeable pavement offers another tool to fulfil those approaches (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Lichten_Regulations_and_Codes.pdf).

The main regulatory drivers for stormwater are the Clean Water Act, regulations for fishable, swimmable waters, groundwater supply and protection, public safety, flood management and infrastructure protection. The regulatory framework for the Clean Water Act consists of water quality standards that consider water quality parameters, beneficial uses and anti-degradation of water quality. The regulatory tools of the Clean Water Act are the water quality design storm, Total Maximum Daily Load (TMDL) waste load allocations, and reductions in combined sewer overflows (CSO). TMDL allocations help restore impaired waters by identifying the maximum amount of a pollutant that a body of water can receive and process while still meeting water quality standards. CSOs occur in older parts of cities when stormwater flows overwhelm the capacity of sewers that also carry wastewater. This combined flow also overwhelms the capacity of wastewater treatment plants to process it. The result is often untreated discharges into river, lakes, bays and oceans.

He identified permeable pavements as offering opportunities for significant co-benefits through hydromodification to address flooding that threatens infrastructure while meeting stormwater management requirements, and replenishing water supplies. Co-benefits that permeable pavements can potentially provide are creating a high-quality built environment, potentially reducing air and heat island impacts of urban hardscape and ADA accessibility. Major challenges he identified were in retrofitting legacy built environments, and standardization of best practice for design, construction, maintenance and operation of permeable pavement so that it will provide stormwater and other co-benefits.

Dave Hein from ARA (www.ara.com) discussed gaps regarding permeable pavement design, maintenance and performance for vehicle traveled ways and other urban hardscape applications (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Hein_Design_and_Maintenance.pdf). He noted that structural design can use relatively simple empirical methods, or mechanistic-empirical (ME) methods that are more complex but better tied to pavement mechanics and which can consider more specific project details. To move to ME methods, performance information is needed from accelerated pavement testing (APT) and field performance observation of structural and functional degradation, which includes measurement of mechanistic materials properties as well as stresses and strains.

He also noted that the move to ME design methods has begun with accelerated pavement testing (APT) in 2014 at the UCPRC on permeable interlocking concrete pavements (PICP), which produced information also applicable to design for subgrade protection for PICP and other types of permeable pavement. More work of this type is needed to answer additional questions regarding confirmation of the mechanics and performance of permeable pavements of all types. Identification of which structural distresses should to be included in ME design is needed, as well as definition of functional failure. This work will lead to development of standardized design details and specifications, which need to be created for a range of different applications of permeable pavement from roads and streets to sidewalks and trails, and consideration of shoulder retrofits and other applications that do not cover the full traveled way.

Gaps exist in agreement on mix designs for pervious concrete and porous asphalt and resulting functional properties, and on the relationship of pervious concrete strength to structural design. In addition, little is understood on the structural benefits of using pervious concrete for soil subgrade reinforcement. Gaps were also identified regarding experience in constructing permeable pavements and how to overcome them through education and certification, lack of designer specification experience, and lack of owner quality assurance inspection and testing experience. Finally, gaps were identified for information needed to appropriately include permeable pavement into pavement asset management systems. This includes standardization of key performance indicators (via surface distresses) that can be routinely surveyed, reliable information regarding long term durability (surface condition, permeability and structural condition), appropriate treatments to correct functional and structural problems, and general awareness on the part of the public and maintenance staff of where permeable pavements exist in the system and how to deal with them.

Mike Adamow from the San Francisco Public Utilities Commission (www.sfwater.org)(discussed gaps in permeable pavement specifications and construction (www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Adamow_Specifications_and_Construction.pdf). He focused on trying to address the question of what specifications and other technical information are necessary to overcome real and perceived problems regarding permeable pavement. He illustrated the problem using a case study in San Francisco where a well-established, standard design guide that requires a composite, impervious pavement for all city streets stopped the use of permeable pavement in the project, despite presentation to the sister department in charge of streets of extensive evidence from Caltrans, FHWA and other technical publications regarding the design of permeable pavements.

The presentation concluded with a call for a permeable pavement support group for local governments to help them overcome barriers to permeable pavement acceptance and implementation. An example of a similar organization is the Green Infrastructure Leadership Exchange (http://giexchange.org). Activities for the support group would include collection and communication of data and case studies regarding costs and benefits, performance and other technical information, normalizing and developing standards, guidance, policies and regulations, and provision of training and technical support for public and private practitioners.

Dave Hein also discussed issues with life cycle cost analysis (LCCA) and feasibility ranking of permeable pavement characteristics and comparing costs with impermeable pavements and other stormwater BMP options (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Hein_Life_Cycle_Cost.pdf). The primary problems he identified were how to quantify the many off-road co-benefits of permeable pavement compared with impermeable pavement, and lack of basic information for life cycle analysis regarding maintenance and rehabilitation costs and timing. An example list of 22 co-benefits was shown in the presentation. The co-benefits are primarily related to stormwater quality, elimination or downsizing of traditional stormwater handling and treatment, and flood control benefits which should be relatively straightforward to quantify, and others that are more difficult to quantify including groundwater recharge and interaction with urban forestry, safety and more efficient land use. The conclusion was that a defensible framework needs to be developed for LCCA and ranking feasibility ranking that is not overly complex and not difficult to use in practice.

Mike Carlson from the Contra Costa County Flood Control and Water Conservation District (http://www.co.contra-costa.ca.us/5743/Flood-Control-District) discussed communication between stormwater and pavement practitioners from planning through maintenance (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Carlson_Communication.pdf). He identified common gaps among people within different knowledge domains who are stakeholders in permeable pavement, the different goals of stormwater and pavement departments, and ideas on fixing them. The first gap he identified is basic lack of understanding of the fundamental concepts and goals for stormwater and transportation (road departments) within and between their domains when considering permeable pavements. Stormwater people must manage watersheds and are primarily focused on designing and maintaining the hydraulic performance of a permeable pavement, while transportation people are primarily focused on designing and maintaining vehicular movement and other transportation modes. Because permeable pavements on streets are generally considered the responsibility of the street department (pavement people), there is a concern from stormwater people that the hydraulic functionality of permeable pavement may not be properly designed. They are especially concerned that permeable pavement will not be a maintenance priority.

Specific differences in operation of water and street departments are:

- Stormwater management operates under permit, completely outside the realm of thinking for pavement management.
- Green Infrastructure Plans are a major consideration for stormwater management, but generally only considered for streets for new developments not so much for retrofitting built infrastructure.
- Stormwater infrastructure requires ongoing monitoring for functionality to ensure that the permit requirements are being met, which is also outside the realm of thinking for local government pavement management.
- Pavement maintenance funding is generally budgeted only for maintaining the pavement's transportation functionality, not for maintaining the stormwater functionality.

The trends in consideration of stormwater infrastructure were illustrated by the example of the Contra Costa Clean Water program that was started in 1992. The initial focus was on site controls for runoff, then on water quality features for new development. The current permit is focused on the built environment. The need for better understanding and communication between the stormwater and transportation domains in improving the built environment is particularly important because of limited funding for both, the need to retrofit the built environment for both functionalities, and the need to find the best solutions to limit long-term maintenance and operation costs. In addition to improved communication and consideration of both functionalities, he also identified the need for flexible funding to facilitate projects that meet both needs, compared with many current funding schemes that are required to be used for one or the other.

John Harvey discussed the need to develop a framework and better information for life cycle assessment (LCA) of permeable pavement (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Harvey_Life_Cycle_Assessment.pdf). This quantification would allow comparison of environmental and resource use impacts, in addition to life cycle cost analysis. He also summarized new functional requirements for pavement in "urban hardscape" that should be included in LCA frameworks including consideration of transportation modes, urban forestry and thermal comfort, plus changing trends for automobile ownership in urban areas which may reduce the need for parking, and the future use of automated vehicles.

The final session of the day reviewed the potential for a focused, fast, intense, high investment, high return program filling the gaps for permeable pavement, in other words a Strategic Permeable

Pavement Research Program, like the Strategic Highway Research Program (SHRP) for pavement materials design from 1988 to 1992, although at far less cost. John Harvey noted that the original SHRP program planned in the 1980s[8] was conceived to resolve problems from lack of technology change in asphalt mix design, need for improvements in concrete for pavement and bridges, improvements in operations, and lack of consistent and comprehensive information on long-term pavement performance (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Harvey_What_was_SHRP.pdf). The pavement realm was ripe for a large and rapid jump in implementable technology then not being solved due to unfocused and incrementally funded work that had progressed for decades. The proposed solution was a short (five year), intense, large investment with clear objectives to produce system-changing, implementable technology.

SHRP was authorized by Congress in 1987. It was managed by a committee of top-level managers from state highway agencies, industry, and academia, operated by a temporary unit of the National Research Council. It was funded by states contributing 0.25% of their federal-aid highway funds. A major part of SHRP was focused on making the new technologies implementable, and working to inform and train people to use them. *SHRP may provide a suitable model for advancing permeable pavements nationally to help address and compensate for neglected stormwater impacts from highway and local road pavements.* The success of the first SHRP program led Congress to authorize a second SHRP program that addressed safety, renewal, reliability and capacity issues[9].

Liv Haselbach with Lamar University (near recently flood-ravaged Houston) (https://www.lamar.edu) framed permeable pavement and other low impact development (LID) as a flood control measure, particularly in watersheds that include urban areas that exist in series within a watershed (http://www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Haselbach_Stategic_Research_Program.pdf). The example provided was in east Texas watersheds along rivers. Urbanization and growth of impervious surfaces released runoff simultaneously from local reservoirs. This exacerbated lower watershed and river flooding from Hurricane Harvey. She noted that if permeable pavements were the norm for development, wider downstream flooding might have been attenuated. What often happens is that detention ponds are designed and operated to release water at a given rate for a given design storm. The designs are based on runoff coefficients at the time of design. As more area is paved with impervious urban hardscape the frequency of occurrence of release is increased because water is flowing faster into the detention facilities.

Release rates and volumes increase for a given storm increase as the surfaces in urban areas geographically aligned within a watershed are paved and become impervious, while their stormwater facilities are designed and operated in isolation from each other. When a large storm such as a hurricane occurs, this can lead to massive flooding, particularly for downstream cities whose flood conveyance was designed assuming previously more permeable conditions upstream that had lower

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[8] Summary of the first SHRP program from the National Academy of Sciences, Transportation Research Board at https://www.nap.edu/read/10223/chapter/1#xi, in particular see Chapter 2 summary of the first SHRP program and its outcomes at https://www.nap.edu/read/10223/chapter/4 .

[9] http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Blank2.aspx

flows entering their systems. The combination of increasing impermeability upstream, and increases in the frequency and intensity of storms in many parts of the country is making this a growing problem in many watersheds, particularly areas east of the Rocky Mountains. Increasing urban hardscape permeability and water storage using permeable pavements and other permeable LID treatments are a means of slowing and/or postponing the releases in the urban areas, as well as for downstream urban areas receiving them. The presentation spoke to the role that permeable pavement might play in increasing flood resilience in urban areas.

Neil Weinstein (www.lowdevelopmentimpact.org) covered a range of topics. He noted that the same hydrologic performance metrics for bioretention or other LID should not be applied to permeable pavements. Volume reduction is the primary benefit of permeable pavements with commensurate pollutant reductions. Other LID tools cannot come close to what permeable pavement can offer in volume reduction. He then turned to state regulations on permeable pavements and the variations among them. For example, the Maryland Department of the Environment offers an unusual credit for using permeable pavement: only rainfall that lands directly on it is counted as being treated. This ignores dozens of in-situ permeable pavement studies that demonstrate effectiveness in reducing pollutants from surrounding impervious area runoff.

Pollutant credit trading is happening and holds much potential when using permeable pavements. There may be opportunities to take advantage of increased performance through design aimed at reducing target pollutants, as well as from more rigorous maintenance. Most maintenance recommendations are prescriptive (e.g. sweep twice a year) rather than providing key inspection criteria and maintenance actions. Asset management systems developed specifically for permeable pavement will help provide a clearer relationship among conditions, remedies and costs. The San Francisco Public Utilities Commission is providing leadership in this area. Technology advances for monitoring such as drones, imaging, real-time inspection and controls over performance will help improve maintenance

He noted that only 8 to 10 state stormwater agencies are moving permeable pavements ahead by developing design and construction criteria as well as maintenance guidelines. This state level is where the biggest impact can be made for advancing permeable pavements since most states administer their NPDES permits. Furthermore, resources and money for compliance begins at the state level and is directed to municipalities. The federal government has broader policy directives and somewhat symbolic role while sometimes underwriting research. Along these lines, the Federal Emergency Management Agency (FEMA) may have a role should they embrace permeable pavements. Resiliency and flood control are typically managed by regional/district and local agencies. These agencies and their insurance partners present opportunities for discussion, modeling and implementation.

Cost comparisons with other practices are not well developed, as well as the off-site benefits of permeable pavements that help justify their higher initial cost. There are significant differences in permeable pavement designs and maintenance costs for projects funded by the public sector compared to those funded by the private sector. The differences are caused by differences in procurement systems used by each sector. Lowest lump sum bidding used by government often means “you get what you pay for” regarding design and maintenance. Bidding permeable pavement specifications based on unit costs (work items) and task orders would allow some flexibility in construction, especially in public sector projects.

Soils investigations for some permeable pavements in urban areas often are overdone. The expense must align with managing design risks. The extra expense sometimes doesn't produce data that will help the designer, or provide a high confidence level. Many of the tests, such as infiltration, can be very disruptive to sites and not accurately depict the soil conditions.

Life cycle cost analysis should be different for the public and private sector projects. The private sector may treat permeable pavements as assets which can be depreciated. This presents a financial advantage. To repeat an earlier point, some agencies don't understand (or want to understand) the hydraulic performance of permeable pavements and then provide suitable credits for using it. National standards published by ASCE, the American Concrete Institute, or other organizations can help by giving regulators some substance they can translate into policy, specifically pollution credits via volume reductions.

2.4 Summary of the Second Day Group Discussions on Questions

This summary of the breakout group discussions of the 76 questions shown in Appendix C is organized below by the question categories.

2.4.1 Integration of Multi-Functional Priorities and Responsibilities

Guidance and information are needed for planners to help identify appropriate applications of permeable pavement, and the issues that must be resolved for successful use. At the site scale, guidance is needed on design practices by civil engineers, hydraulic engineers, pavement/geotechnical engineers and landscape architects responsible for different aspects of permeable pavement implementation. Such information is available from ASCE or others, but lacks widespread recognition.

Additionally, ASCE needs to transcend the bifurcation of permeable pavements within two of its institutes, Transportation & Development where pavement interests lie, and Environment & Water Resources where stormwater management interests are centered. ASCE may need to create another organizational model that overcomes contested ownership of practice areas, their deliverables, standards and staff resources by different committees. This integration would encourage communication between these two spheres of civil engineering and professional practice.

Guidance is needed on how to change practices regarding communication, roles, responsibilities, budgeting, design, asset management, and maintenance of permeable pavements within local governments. Upper management buy-in within municipalities is essential. Methods of communicating what needs to be done to overcome institutional barriers needs to be developed with upper management as the audience and participant.

There needs to be an integrative administrative process within municipalities that reflects the multiple functions of permeable pavement. This likely means roles and responsibilities may need to cut across current responsibilities and budget boundaries in local governments. The guidance needs to offer recommendations on how to change technical practices with administrative structures. This guidance can be illustrated through successful permeable pavement case studies as a start.

Permeable pavements require different technical and administrative considerations in addition to those for impermeable pavements. Whether in the public or private sector, project owners need information on the entire project delivery process. This includes cost information and where to obtain expertise on site suitability as well as design, construction and maintenance. This would provide significant support to projects where there is not much owner experience with permeable pavement. A likely best approach is combining owner expertise and industry expertise into one information set. This would then receive critical review by both groups to ensure that owner concerns are addressed and that technical information is accurate. The information should include identify where “corner cutting” results in problems.

2.4.2 Planning and Development Codes

Opportunities abound for including permeable pavement in municipal codes, zoning ordinances, infrastructure standards, LID and complete street guidelines for road agencies. Greater confidence by road agencies on performance and designs for low maintenance will help gain acceptance and reduce stormwater-versus-road agency bifurcation of interests and priorities. Road infrastructure resilience may be key to getting road agencies to adopt permeable pavements, as stormwater management doesn’t hold a top priority or a compelling interest for adoption by many road agencies.

Current landscaping codes, stormwater codes, street codes, utility codes and other applicable codes need to be reviewed and updated to consider the multi-functionality of permeable pavements. Unfortunately, permeable pavements are not yet included as acceptable BMPs in many stormwater codes. An example of well-established guidance is that permeable pavements should probably not be used where vehicle speeds are faster than 35 mph because of noise and smoothness concerns with surfaces. However, codes need to be reviewed for arbitrary and unnecessary obstacles to use of permeable pavements. Guidance regarding how to evaluate typical codes for real risk versus unnecessary obstacles regarding permeable pavements is needed. An example of an obstacle that needs more scientific research regarding risk is restrictions based on depth to groundwater table. Better guidance on groundwater behavior, models and mounding risks are needed.

In summary, obstacles to including permeable pavement as a BMP need to be fully identified; information and practices developed to overcome them. Documentation of how to successfully use permeable pavement as a BMP needs to be developed and made available. Such information is available but in diverse places.

2.4.3 Comprehensive Planning

Permeable pavements work best as part of a comprehensive planning, design, construction, maintenance and operation process organized on a neighborhood/watershed basis. Permeable pavements should be part of a complete set of tools used by municipalities for meeting many objectives, including transportation, stormwater quality, flood control and aesthetic contributions to “place making.” In particular, ideas and guidance are needed for planners and neighborhood stakeholder groups to consider use of permeable pavement to create open space by using the same surface area for transportation and stormwater handling.

The potential for a large increase in the market size for permeable pavement appears to be on the horizon, maybe doubling or tripling over the next several years. The speed and success of that growth depends on the issues identified in this workshop being addressed. A major application appears to be retrofitting of existing impermeable urban hardscape, i.e., conversion to permeable surfaces. Such conversion should be identified as part of a comprehensive planning process that considers multi-functionality of hardscape for transportation, stormwater quality, flood management and place making.

Planning for permeable pavement should include those who will be responsible for maintenance. The checklist for planning should include consideration of maintenance budgets and approaches (direct forces, contracting, etc.) for permeable pavements.

Standard processes should be developed to produce planning maps that include soil types, existing infrastructure, and stormwater flow and water quality modeling that identify areas with constraints and potential for permeable pavements should be considered as an alternative to increasing impervious surfaces. These maps can serve as overlays with other maps typical to urban planning used in the comprehensive land use planning and development/redevelopment process. These maps might identify land use and resulting parking lots and streets, impervious cover, storm drainage systems, areas where local flooding might occur, and soil types (and aquifers) amenable to infiltration by permeable pavements, although infiltration is not a prerequisite for use of permeable pavements to help mitigate flooding and stormwater quality issues. Such integrated planning information focused on using permeable pavements as a major player in land use can result in better coordinated flood control, stormwater management, CSO management, land use (as it relates to impervious cover), and transportation needs.

Modeling and analysis processes are also needed for creating and updating planning maps for use on a watershed scale that allow consideration of land uses with permeable and impermeable hardscape. The example from Houston presented by Liv Haselbach, with multiple cities aligned in a watershed and the impact of major storm events, should provide the impetus for development of these processes and maps.

2.4.4 Costing and Cost Decision Support

Compared to conventional pavements, there a paucity of information available regarding initial and life cycle costs for permeable pavement due to their relative newness. While there have been some project-scale cost studies in the past, a comprehensive effort is needed to collect this data and make it available for different regions and contexts.

Unlike approaches for traditional pavements, life cycle costs analyses must include off-site benefits. A life cycle cost analysis (LCCA) framework and tools need to be developed to allow comparison of alternative options for handling stormwater and transportation functions. The framework needs to include the costs and performance outcomes for traditional street and stormwater handling infrastructure and for use of permeable pavements in alternative systems. The framework should consider stormwater and pollution credits and rebates. The tool should be able to include data input by the designer and would preferably include data collected by the local agency. Industry has initiated development of LCCA tools. However, such tools need broader critical review that results in acceptance and wider use by project owners and design consultants.

Life cycle costs need to consider surface cleaning and any other costs necessary to maintain the stormwater functions of permeable pavement (i.e., stormwater quality and flood control) in addition to the maintenance costs associated with maintaining transportation functions. As for all pavements, life cycle costs for permeable pavements are built around maintenance and rehabilitation schedules which require performance data on stormwater and transportation functions. This information is best standardized to the maximum extent possible into existing local government pavement management systems[10]. This would likely be facilitated by development of a model permeable pavement asset management system. Asset management systems that include permeable pavements are in their formative stages in cities such as San Francisco to comply with court-ordered CSO reductions. Once a framework for LCCA comparison of alternatives is developed, case studies should be prepared demonstrating how it works. Examples should include cases where permeable pavement was the lowest cost alternative and where it wasn't.

Development of a framework for asset management of permeable pavement and other LID will help in the population of cost and performance databases in the future. Costs of monitoring permeable pavements to meet stormwater quality permit requirements need to be identified. Those costs need to be considered in a standard life cycle cost framework with maintenance costs and stormwater benefits. Collecting performance and cost information for stormwater management functions needs to be included in pavement asset management systems. These are generally owned by the transportation agency (also called street department, road department, public works department) in a local or state government. Pavement managers need training in how assess and rate the hydraulic performance of permeable pavements.

Continued initial and maintenance costs must be monitored and collected. There is a national BMP database maintained by the Water Environment Research Foundation (WERF) (http://www.bmpdatabase.org). Contributions to this database are voluntary. However, it is sparsely populated with data on permeable pavements. Other performance data exists in the literature on permeable pavements and stormwater and literature reviews. More agencies should build test sections, track maintenance practices and costs, and make the data available to researchers and developers who can analyze and publish the information or do that work themselves. This has happened in a few dozen instances around the U.S. and Canada. As a result, performance data has been collected and published by the US EPA, state and local stormwater agencies, academia, ASCE and industry.

[10] The most commonly used pavement management systems in California according to the 2018 Local Roads Needs Survey are: StreetSaver 51%, MicroPaver 19%, 14% no PMS, 13% Cartegraph, 13% other systems.

2.4.5 Stormwater quality design concerns

Although there have been many studies on the ability of permeable pavements to capture pollutants, there are still many questions regarding the transport and fate of pollutants including interactions with groundwater. There needs to be an assessment of the life time effectiveness of permeable pavements as their surface and subgrade infiltration capability diminishes over time, even with maintenance.

These questions need to be answered sufficiently in different contexts for permeable pavements to be considered as a stormwater quality BMP, based on comparison with other stormwater BMPs. Modeling and field validation are needed to answer these questions. The resulting information needs to be incorporated into design guidance, and to be considered in stormwater permit development and compliance processes.

2.4.6 Watershed and local flood control design concerns

Permeable pavements have the potential to reduce flooding and contribute to a more resilient infrastructure. Permeable pavement will likely have the biggest impacts on frequent small rainfall events and less impacts on rare large events, although the cumulative effects across a large area or of urban areas in series along a watershed may be important.

Research, modeling and case studies are needed to quantify the potential flood control impacts. Cities such as Atlanta and New Orleans are using permeable pavement to control flooding, i.e., the road system is also the runoff storage and conveyance system, and comparing the use of permeable hardscape with conventional stormwater sewers flowing into cisterns, and detention or retention ponds. However, there is inadequate standardized guidance for consideration of permeable hardscape and beneficial impacts in flood control studies. The guidance should include consideration of ratios of impervious to pervious surfaces for water quality and, more importantly, for stormwater volume and flow management.

US EPA SWMM and Innovyze INFOWORKS are models used for managing drainage systems in cities. These and others should be evaluated for their ability to characterize permeable pavements and improved where necessary. Once capable of considering permeable pavements, the use of permeable pavements and effects on flood management and on discharges to receiving waters to meet permit conditions should be done for case studies. Guidance should be developed for using these models when considering permeable pavements.

There are no models at the federal level for watershed modeling that consider/compare permeable and impermeable pavement impacts on flood management. This might be a task for the U.S. Army Corps of Engineers or FEMA. Other localized models are available such as a spreadsheet model developed for San Francisco by the California State Water Board (currently in its 5th edition) that consider multiple BMP scenarios. The model has been calibrated and covers 2 to 5-acre catchments rather than larger watersheds. Further development, calibration, guidance and implementation support for this type of model is needed to be able to use it for project-level design.

2.4.7 Pavement Design Concerns

There is information available for pavement structural design regarding design details, standard methods for soils investigations, and structural design tables developed from full-scale load testing for permeable interlocking concrete pavement. A similar testing approach is needed for pervious concrete and porous asphalt. Hybrid designs that offer increased structural capacity (i.e., several million equivalent single axle loads or ESALs) need further research as well. Hybrid or "combined technologies" using porous asphalt, pervious concrete and/or concrete pavers may provide improvements in structural capacity, life cycle cost, durability and functionality over use of a single surface/base structure.

Further, proof of structural performance is needed to raise user confidence, which currently come from a few well-documented field studies that cover a range of applications. However, there is a pressing need for accelerated pavement testing and mechanistic modeling that results in easily referenced, reliable design tables or catalogs. Designers and road agencies do not want to be the first or last to try permeable pavements. Full-scale accelerated testing will promote full-width street applications, including those with heavy vehicles. Moreover, such validation will provide information needed for more municipalities to adopt permeable pavements into their catalogs of standard specifications and drawings. The development of designs should include consideration of stiffer subbases below the reservoir layer, and appropriate use of interlayers for filtration and for improvement of structural performance. Because permeable pavement bearing capacity is so dependent on the properties of the "lightly" compacted (i.e., not compacted to a minimum of 95% standard Proctor density) and saturated subgrade compared with the bearing capacity of the well compacted and relatively dry subgrades under impermeable pavements, design tables need to be climate region and soil type specific (i.e., based on properties other than soil classification alone).

Improved ME designs must include better estimates of the time that the subgrade has a standing head above it, is saturated with no standing head, and is wet for different climate regions and subgrades, as well as the properties of different compacted soils under these moisture conditions. Gaps in existing data describing the relationships among infiltration, stiffness, strength and permanent deformation properties need to be filled, and sufficiently validated with full-scale accelerated pavement testing. This would provide the data needed to support ME design methods and summary tables. Some of this information has already been developed and is suitable for designing now, but it can be made more comprehensive and better validated.

Standard guidance is needed for site investigations for conceptual and project-level design. It should consider existing pavement, utility identification to depths needed for permeable pavements, stormwater flow loading and source (sources of clogging materials, stormwater quality issues) characterization, and traffic loading characterization (e.g., vehicle loads and speeds, active transportation modes, etc.). This guidance would include information on failures and on preventing them given a range of site conditions.

Better methods and guidance are needed for using and interpreting measurements from deflection testing or other equipment to evaluate permeable pavement structural condition. This includes development of lightweight deflectometers (LWD) to assess deflection of soil subgrades and especially compacted, open-graded aggregates. Current technology to assess the density of the latter using nuclear density gauges is nearly useless. LWDs can increase construction quality control and quality assurance from compaction and help reduce long-term settlement associated with permeable pavements.

Information is needed regarding design tools, including ranges of applications, comparisons where there are alternative tools, and better information regarding how to use them. There is a need for better information regarding typical or even standardized approaches for designing systems that include permeable pavement, including required elements to consider, input data needed, tools that can be used, and information needed to compare alternative designs. The information regarding design should address multiple audiences, including: design policy decision makers, designers, and other stakeholders who are investing funding to obtain social and environmental benefits.

More research is needed regarding use of permeable pavements near existing below-grade infrastructure and basements, foundations, etc. There is little or no information available regarding these scenarios and there was considerable debate and fundamental disagreement at the workshop as to the best approaches.

Currently available information (City of Seattle, 2015 ASCE book, *Permeable Pavement*, 2018 ASCE/ANSI PICP standard, City of Atlanta, etc.) needs to be identified regarding use of check dams in bases when permeable pavements are built on sloped subgrades. This information needs to be incorporated into standard design guidance.

There is no confidence on the part of state transportation agencies that permeable shoulder retrofits will work. The primary concerns are safety, durability, structural capacity and how to design for lateral infiltration from the permeable shoulder under the impervious traveled way. Validation of designs, using full-scale accelerated load testing and ME, improving where necessary, are needed. This can be further improved with well-documented pilot demonstration projects in relatively low-risk locations as a start (rest stops, ramps, etc.).

2.4.8 Materials and Pavement Performance

Tests are needed to characterize strength, stiffness, fatigue, permanent deformation properties of subgrades and permeable pavement materials for mechanistic-empirical pavement design. Research, development and implementation are needed to identify or develop appropriate tests and move them to standardization via ASTM, AASHTO, ASCE or other standards organizations.

Pervious concrete and porous asphalt material performance can be improved. Information regarding approaches to improve mix designs needs to be gathered, organized as industry best practices, and then communicated to industry manufacturers and contractors, as well as to designers through guidance information. There have been advances in knowledge regarding mix designs that balance durability with hydraulic capacity. Research is needed to improve some of the processes, and new admixtures are needed to address some of the problems.

More pilot projects, specifically street and road shoulder demonstration projects are needed.

Performance information in snow and ice locations needs to be brought together, organized and included in communication and guidance. While some research has been conducted, permeable pavements hold the potential to reduce deicer use, thereby reducing a significant pollutant currently causing millions of dollars of damage to the recreation industry, and reducing personal liability from reduced ice formation and slip hazards.

2.4.9 Designing for Additional Benefits and Impacts

Permeable pavements have many benefits beyond stormwater management. These benefits need to be quantified and some need to be measured through full-system life cycle costing, environmental life cycle assessment and other analyses. Standardized methods for conceptual and project-level quantification need to be developed. The additional benefits include stormwater quality, flood control, groundwater recharge, reduced need for watering for landscaping, and potentially localized thermal cooling effects. More difficult to quantify are aesthetic benefits from architectural incorporation of permeable pavements.

Information needs to be developed for planning, life cycle costing and asset management regarding how long environmental benefits last, what is needed to restore benefits when they degrade (maintenance and rehabilitation), and when reconstruction is needed to restore them.

Information needs to be developed regarding permeable pavement surfaces and bicycle ride quality and wheelchair user comfort using recently published research from the US Access Board.

Design “idea books” and standards need to be developed and published that include use of permeable pavements integrated into generally impermeable pavement areas such as borders of parking areas at low points. The idea books should be backed up by documentation of multi-benefit cases based on post-construction user perception of benefits received, including consideration of reduced downstream flood peaks, reduced size of drainage infrastructure for stormwater, enhanced ecosystems due to improved water quality, freeing up of valuable urban space due to no need for detention or retention ponds. Case studies focusing on projects would be a worthwhile start.

2.4.10 Construction Standards and Issues

Continued contractor training and construction QC/QA are essential, as well as refinement of specifications, and adoption into state and local standards. Better standardization of construction quality specifications is needed for all types of permeable pavements. This can support owners by helping them take responsibility to enforce the specifications. More training for material producers and contractors is needed, and consideration of the qualifications when selecting contractors is important.

Consideration should be given in development of guidance for construction specifications to including requirements that material manufacturers be involved with the contractor during construction, until sufficient experience has matured within industry. This can be a part of developing lists of pre-qualified materials suppliers and contractors.

Construction sequencing in urban areas is a major issue. Information regarding construction duration and how to manage traffic during construction is needed in guidance and case studies. There are no certified inspectors for permeable pavement. There is a need to develop training and certification procedures.

There are ASTM tests for acceptance of permeable pavements that can be conducted for hydraulic performance and material acceptance. The former are generally not yet regularly used in construction, or tied to design objectives, or linked to construction inspection. Tests for construction acceptance and inspection information need to be developed through ASTM, ACI, ASCE/ANSI or other standards organizations and included in construction guidance. This area is developing based on industry investments.

Information and generic specification language for warranties for permeable pavement systems are needed. These should include the performance measures, how to test them, how to enforce fixes where outcomes are not met, and other information needed in a warranty. Information regarding case studies of warranty successes and problems should also be gathered and documented.

2.4.11 Maintenance

Systematic collection of maintenance data and costs is needed, especially for surface cleaning, as well as utility repair guidelines and costs. As for other stormwater BMPs, comprehensive information regarding appropriate maintenance schedules for permeable pavements is not well organized, and is currently in pavement-type specific information from industry. There was some disagreement as to whether existing information is insufficient, or it is sufficient but not well communicated.

There is also a lack of standardized information regarding best practices for monitoring surface permeability as part of asset management. Other types of low impact development, including berms and small infiltration basins, similarly require monitoring and measurement of effectiveness as part of asset management, and better information regarding how to maintain or restore infiltration effectiveness. It was noted in group discussions that filters are also difficult to monitor. The discussion indicated that permeable pavements and other LID need much better information regarding maintenance monitoring, management, practices and costs, and better distribution of this information.

Standard practices and specifications for maintenance of permeable materials need to be further developed and included in local government standards. Better information needs to be collected, organized and made available regarding specific types of surface cleaning machines and practices for using them, as well as costs and alternatives for procuring the equipment and using it with direct forces or through procurement of services. Differences will most likely exist for different types of pavement surface (permeable pavers, pervious concrete, porous asphalt, pre-cast pervious concrete slabs).

Identification of best practices for restoring permeable pavement after accessing utilities is needed, and development of practices or improvement of practices. This includes materials, cross sections, and construction quality control and assurance practices. Damage from utility cuts also continues to be an ongoing issue for impermeable pavements as well. Demonstration and validation of best practices for utility cut restoration through performance monitoring and/or accelerated pavement testing will help produce confidence in guidance and standards. Maintenance guidance needs to include information for locations with snow and ice.

In sum, training is needed for maintenance and construction forces regarding best practices and inappropriate practices for permeable pavement.

2.4.12 Asset Management

This is an emerging field. While most local governments have some form of a pavement management system, there is no established framework for asset management of permeable pavement or other LID practices to develop maintenance plans, track costs, and develop better asset management practice. The asset management framework needs to include monitoring for stormwater quality to meet BMP requirements and effectiveness of surface and subsurface infiltration, not just surface condition as for conventional pavement management.

Integration of stormwater quality and flow considerations into existing pavement management systems is the most likely approach for most agencies. Where there is an asset management system for stormwater infrastructure further consideration of integration of permeable pavements will be needed. The "ownership" of the asset, either a street agency or a stormwater agency, will need to be considered. The ideal situation is to have modules within an overall asset management system for pavement, stormwater and underground utility infrastructure that share common location referencing systems and other common data. The asset management framework needs to include surface condition monitoring information for the different kinds of permeable surfaces, and monitoring for stormwater quality to meet stormwater quality permit requirements where applicable, and effectiveness of surface and subsurface infiltration.

Guidance is needed regarding how to update asset management systems to consider permeable pavements. Asset management systems need to be updated to identify permeable pavements in the asset inventory, as they currently identify different types of impermeable pavements, so that their multi-functionality is considered in all asset management processes. Where needed, maintenance crews can utilize field identification of permeable pavement to know where treatments are needed and to avoid using seals and other typical treatments for impermeable pavements. Field marking is also needed to avoid storage of clogging materials on permeable pavements such as landscape debris and soil, and for guidance of street cleaning staff which requires different equipment and treatment for permeable and impermeable pavement.

Performance measures for stormwater quality and flow need to be developed that can be used as part of an asset management system. Stormwater quality is currently assessed using testing methods required by stormwater quality permits. The information from those testing approaches, which test the quality of water going to receiving waters, needs to be considered when developing measurements that can be taken as part of an asset management system.

Condition survey tools are needed that include stormwater/infiltration performance as well as surface and structural performance for municipal transportation agencies to be able to include permeable pavements in pavement asset management software programs. Standard operations and maintenance guides need to be created and standardized. Processes for surveying permeable pavements need to be incorporated into existing pavement condition survey procedures and asset management system databases.

All permeable pavements eventually need rehabilitation or reconstruction, whether it is needed for restoration of transportation functions due to unacceptable roughness or macrotexture, or due to lack of water inflow due to surface clogging, sediment build-up in the reservoir layer or loss of subgrade infiltration capacity. There is very little information available regarding appropriate methods for rehabilitation or reconstruction to restore these functions. Information is needed regarding constructability, costs and performance of partial or full replacement of the surface layer and bedding layers between the surface and reservoir, removal or cleaning and replacing of the reservoir layer gravel (as can be done with railroad ballast), or how to deal with subgrades that have lost infiltration capability.

Network-level performance models are needed for pavement performance and the environmental benefit performance of permeable pavements to conduct effective asset management. Initial performance data will have to be interpolated and extrapolated from existing data augmented with judgement. Performance models can be improved once measurements of both become part of a standardized periodic condition data collection process for asset management. Most local government do not currently have impermeable pavement performance models based on their own local data now.

2.4.13 Communication Between Industries and Users

Current information is scattered across several publishers and title series, and is often not comprehensive. The name “permeable pavement” does not capture the transportation, stormwater quality, flood control multi-function, integrative nature of these pavement systems. A new name for this is needed; it needs to be simple, but convey this multi-functionality message.

Communication material focused on elected officials and managers is needed that outlines the potential benefits of systems of permeable pavements, how they work, situations where they have low probability of success, what it takes to make them successful, and typical obstacles to using permeable pavement and successful approaches that overcome obstacles.

Guidance regarding permeable pavements needs to be targeted to different knowledge and practice domains to fully inform any decision maker in the planning, design and asset management processes regardless of their background as stormwater, pavement or flood control engineers, planners, or landscape architects. Training is also needed for maintenance forces regarding inclusion of permeable pavement in standard operations and best practices, as well as inappropriate ones.

Training material is needed that can be given to combined audiences for the different expertise areas that covers consideration of the full multi-functionality of permeable pavement. Documentation of examples of successes for permeable pavement are needed illustrating the steps in planning, design, construction and maintenance necessary to achieve success, and where possible, examples of practices that do not work (these are often difficult to get people to put forward).

The “Every Day Counts” program at FHWA solicits inputs for BMPs. Permeable pavements could be promoted through that program as well. FHWA may also be able to influence implementation through other routes such as encouraging conformance to Clean Water Act regulations. FHWA has published Tech Briefs on porous asphalt, pervious concrete and PICP. In addition, FHWA has supported permeable pavement webinars and a handful of in-person seminars via the Local Technical Assistance Program (LTAP) centers. More support is needed for these activities. Development of a National Highway Institute or similar in-depth training course or courses on design, specifications, construction, inspection and maintenance would provide additional support to LTAP centers.

A clearinghouse would be very helpful for public access, experience sharing, organization and distribution of performance information, guidance, example specifications and standards, and case studies. An organization, most likely an existing non-governmental organization such as the Green Infrastructure Leadership Exchange, a university center, or a consortium of these types of organizations would be the most likely manager for a clearinghouse. Industry and design professional organizations should support such efforts.

A matrix of existing organizations producing and publishing information on permeable pavements and the bigger systems in which they are used should be developed as a starting point for developing a more organized communication system. Initial identification of potential partnering organizations by participants was the last action of the workshop.

2.4.14 Education and Training

Continuing the training theme from the previous section, permeable pavements and low impact infrastructure are not a core institutional concern for universities in many cases, and there is scattered offering of training for practicing professionals. Education and training need to be multi-disciplinary to cover the multi-functionality of permeable pavement.

Information for use in university classes regarding permeable pavement needs to be developed for courses in the areas of planning, hydrology, stormwater quality, engineering pavement design and in landscape architecture. Permeable pavement should be included in pavement textbooks, and/or low-cost, stand-alone information should be developed for university teaching and made freely available.

Instructional material for professional development courses needs to be developed and made available beyond existing industry-sponsored programs. The delivery methods can be web-based and in-person. The content should cover planning including identification of multi-functional needs, design for multi-functionality, types of systems (different types of systems for multi-functionality), consideration of alternatives including LCCA maintenance and rehabilitation/end-of-life, as well as construction and inspection. The latter should probably be in-person with hands-on demonstrations by contractors and inspectors for contractors and inspectors.

Short informational webinars, self-paced, as well as live webinars, are needed to provide basic information to interested decision-makers, designers and other stakeholders. These webinars should cover planning including identification of multi-functional needs, design for multi-functionality, types of systems (different types of systems for multi-functionality), consideration of alternatives including LCCA, construction (this should probably be in-person with hands-on demonstrations) and inspection, maintenance and rehabilitation, and end-of-life actions. This information should also include a segment aimed at management and elected officials that covers typical obstacles to using permeable pavement and approaches that have been successful to overcome the obstacles.

2.4.15 Funding for Research, Development, Implementation

Funding sources for research to model and measure the performance of stormwater management infrastructure and practices has been scattered across industry, municipal, state and federal sources, and is uncoordinated. More research is needed on structural performance of permeable pavements and on the effects of use of permeable pavements on watershed flood control.

Industry will respond to customer needs; however, industry does not have capacity or funding to resolve questions regarding asset management, planning guidance, structural testing/design, standards and specifications, quantification of co-benefits, environmental impacts and resolution of roles, responsibilities and budgeting in implementing agencies. Funding for those needs should be led by government users which will have spillover benefits when implemented by private owners of pavement and developers. This is the current framework for advancing impervious pavements and it should be applied to permeable pavements.

An intense, sufficiently funded and coordinated research and development program can fill most of the gaps identified in the road map in a short period of time. It would likely produce very large benefit to cost ratios over a relatively short period of time as urban areas are retrofitting their infrastructure to handle new requirements for efficient use of available space, response to changes in weather patterns, rising seas, changes in transportation patterns, and changes in urban design.

Creation of a university center focused on permeable pavement to coordinate a research, development and implementation support plan may be a solution. The center would also function as a clearing house for public access to information and sharing of experience, and could facilitate promotion of guidance, example specifications and standards, training materials, and other information. Using a university would allow information to be put out that cuts across all industries and addresses transportation, stormwater, flood control and place making functionalities, as well as facilitating involvement and awareness for students (future professionals).

An alternative or in addition, regional centers would be able to better provide more locally relevant information and would be better able to respond to questions and requests for information.

The multi-functionality of permeable pavements results in lack of a clear champion to fund a program. Permeable pavements are mostly used by cities and to a lesser degree by counties, while state transportation agencies fund most of the pavement research in the US, either directly or through the National Cooperative Highway Research Program funded by AASHTO and operated by the National Academy of Science's Transportation Research Board (TRB). AASHTO and TRB were how the SHRP program was funded and operated. The Federal Highway Administration also funds pavement research, however, it is also primarily focused on state highways, not local streets and roads except when they are in the National Highway System.

The National Science Foundation generally does not fund pavement research due to the large amount of pavement funding from states, TRB and FHWA. In contrast, local governments do not have an organized, well-funded research program for urban infrastructure. Organizations such as the National Association of City Transportation Officials, Complete Streets America, the Low Impact Development Center and others are primarily involved in organizing available information and publishing guidelines and standards. They are a primary means of distributing and communicating information, but not for funding development of new information. They often rely on consultants who evaluate, organize and summarize existing information and add valuable information from practice, rather than academic institutions dedicated to research and development.

ASCE has been organizing academic research and knowledge from practice into guidelines and standards. These research papers and publications are more comprehensive than industry-sponsored work in terms of their consideration of different pavement types and provide more coverage regarding stormwater quality and flood control benefits in addition to transportation functions. Work by ASCE is driven by volunteers, primarily from consulting practice and academia. The paving industries (concrete, asphalt, pavers) have also funded guidance for their respective pavement types, and have contributed to ASCE efforts. This includes a national ASCE/ANSI standard guide on PICP design, construction and maintenance. A similar standard exists for pervious concrete, ACI 522, as published by the American Concrete Institute.

Most of the existing efforts on research, development, and implementation support for permeable pavement are focused on materials design, structural design, stormwater quality and quantity from a given site and some maintenance guidelines. Research typically doesn't address flood control planning, comprehensive planning, asset management, life cycle costs, life cycle assessment or maintenance in detail. Funding is likely available, but obtaining it requires a comprehensive effort to bring it together and create a sharing, coordinated program. Once funding is identified, collaboration among cities and counties, consultants and academia is needed to produce the highest quality, practical information needed to address the gaps in permeable pavement knowledge and practice.

Pooled funds efforts among different state agencies should be explored, although most local governments do not currently have any budgets for research and development. Getting upper management or political buy-in from a few large cities might be the way to move this forward.

Identification of permeable pavement as a high priority at one or two DOTs or at a national level would help create momentum for funding a consortium. Industry should lead that communication effort at a high level as they have the best access to policy makers.

2.5 Summary of Road Map Discussion after Group Presentations

The summary and discussion of the information presented by the breakout groups was the final step prior to concluding the workshop and sending the organizers off to prepare a draft road map. The discussion that followed the presentations by the breakout groups is captured with the following bullet points.

- Permeable pavement is a system for meeting four functional requirements: transportation, stormwater quality, flood control and place making. This needs a new name. The group proposed many names besides permeable pavement. Examples of some that might qualify:
  Integrated Stormwater Pavement Systems
  Combined Stormwater Transportation Systems
- Some technical information for all the topic areas from questions and group discussions is generally sufficiently available to move ahead while filling gaps and updating outdated elements. However, the information needs to be pulled together and organized, be made part of a synthesized, comprehensive detailed package of guidance, standards, example specifications and tools useable in practice at each step in project development, and then communicated and used to develop and deliver training. This started with the 2015 ASCE book, *Permeable Pavements*. ASCE has invested in webinars and training materials. However, a larger effort is required that reaches users outside of ASCE spheres.
- A full, integrated view addressing watershed, urban area, neighborhood, and project scales as well as life cycle impacts needs to be taken in all guidance and other information.
- A communication strategy is needed that addresses all the audiences who need information, at different levels and covering the four functional areas.
- Existing training programs need to be targeted, links established and delivered.
- Information for use in university classes across the four functionalities needs to be developed.
- To be able to consider change, the multi-functionality that permeable pavement can address requires identification of roles and responsibilities for those agencies working in a region or involved in a potential project to ensure that funding is available, and the standard processes assure that all functionalities and their legal and operational requirements are met. New work processes, changes in codes, and new partnerships may be needed who can work together to achieve the multi-functionality.
- New potential stakeholders need to be identified and engaged. One identified in the discussion is the flood insurance industry. Another might be FEMA.
- Establishing a university-based research, development and implementation center should be explored. It would work with academics, consultants and government to develop the information needed. The center should have regional associates to help with regionally applicable support and research.
- Establishing a central clearinghouse for organization and dissemination of quality, up-to-date information should be explored. It could be combined with the center.
- The execution of a program of intense, focused research, plus development and integration should be explored to fill gaps and assemble information. The funding and program model could be the SHRP program. The road map developed from this workshop could be a starting point for reaching desired outcomes.

Finally, permeable pavement has support from both political parties. National legislative support began in 2008 with MAP-21 that mandated technology transfer of permeable pavements within LTAP. 2018 legislation encouraged accelerated research, demonstration, and deployment of permeable pavements to achieve flood mitigation, pollutant reduction, stormwater runoff reduction, and conservation.

Demonstration projects may include roadway shoulder load testing and documenting life cycle cost efficiencies. Coordinated advocacy from industry, states and municipalities, and from design professionals is needed.

Funding is likely available for what needs to be done. Potential funders need to be identified and organized around a common program.

3.0 Proposed Road Map

3.1 Routes, projects, estimated costs and durations

The proposed road map is shown in the following tables. The basic structure and chronological movement follows. The numbered below correspond to the tables as marked with map Route 1, Route 2, etc. Estimated costs are provided for each route. Costs can be divided among the various tasks.

Route 1. Reliable pavement structural designs: Complete development of reliable structural design tables that account for long-term saturated soils typical to permeable pavements. This will likely require a significant investment in materials research, full-scale pavement testing and mechanistic modeling that covers a range of soil conditions and traffic loads. Hybrid pavement systems that have some combination of pervious concrete, porous asphalt and/or concrete pavers must be explored to achieve higher capacity, more reliable structural designs that perform well in saturated soils. Demonstration projects are encouraged.

Route 2. Reduction of target pollutants to meet water quality requirements: Develop design decision trees/menus for reduction of target pollutants which are mostly agency and site dependent from existing and additional research. Include runoff reduction as an integral part of water quality management objectives and pollutant reduction credits.

Route 3. Reduction of urban flooding risks: Develop approaches for considering permeable pavement in flood modeling for use in zoning, planning, land development codes and flood control design.

Route 4. Routine achievement of high quality construction: From the above research, improve construction guide specifications that include improved construction methods, especially quality control and quality assurance test methods and inspection protocols/checklists.

Route 5. Maintenance and rehabilitation costs and methods: Information regarding best practices for maintenance methods are their costs must be refined for different applications and made widely available. Identify designs that minimize sediment transport and deposition that require more maintenance. Improve maintenance methods including surface cleaning techniques and equipment, potential deicer use reduction. Identify best practices for hydrologic and structural rehabilitation and reconstruction methods for aging permeable pavements.

Route 6. Incorporation of permeable pavements into asset management systems: Based on results from the five routes above, develop/refine asset management tools for stormwater and road agencies. These include inspection methods/standards, and maintenance costs. Concurrently improve, and where possible validate, at the site scale, drainage system scale, and regional watershed (flood) scale the quantitative performance models appropriate to each.

Route 7. Accurate life cycle cost analysis and environmental life cycle assessment tools: Concurrent with asset management, perfect life cycle cost analysis (LCCA) tools that account for on and off-site costs and benefits to support designer, stormwater and road agency decisions regarding use of permeable pavements. This route should include development of life cycle assessment (LCA) tools to calculate environmental impacts considering the full life cycle including manufacturing, construction, use, and end-of-life stage environmental impacts for the full functional unit of permeable pavements included their related off-site impacts. This requires flexible, site-specific system boundary condition definitions. Integrate these measured impacts into pavement design and asset management programs.

Route 8. Infrastructure management organizations that consider the full functionality of permeable pavements: All the above science and empirical information inevitably points to institutional changes, i.e., bridging the gap between stormwater agency and road agency priorities and cultures. The outcomes of the first seven routes will provide information for creation of clearer frameworks moving forward for updating existing local and state regulations, zoning, site design and building codes, as well as flood control management. The outcomes will provide the information needed to address reforming federal, state and municipal agency structures for urban hardscape infrastructure management to consider the full range of approaches, including permeable pavement, for meeting multi-functional goals of transportation, stormwater quality and flood control. Multi-functionality needs to be considered over the life cycle of hardscape/pavement/transportation infrastructure planning, design, management and maintenance.

Route 9. Planning guidance that considers the multi-functionality of permeable pavements: this route also capitalizes on the above research and expanding experience with permeable pavements. This route includes developing planning guidance, reviewing long-term performance of existing installations, developing criteria for user comfort and developing idea books, some of which will include case studies in various climates, soils and applications.

Route 10. Efficient and comprehensive access to the best information: This path also includes developing a clearinghouse and/or a center or centers for permeable pavements, as well as communications.

Route 1: Reliable pavement structural designs

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Pavement structural design approaches Objectives: 1. Fill gaps, validate mechanistic-empirical models, designs and tools 2. Produce and distribute for information and tests for site investigations for new pavement and multi-functional performance evaluations for existing pavements 3. Produce new or improve materials and structures designs	Mechanistic-empirical design methods for permeable pavements that will result in faster consideration of new structures and materials	Fill gaps in mechanistic-empirical design models, validate them, incorporate into design tool(s)	1a. Comprehensive evaluation of mechanistic modeling of permeable pavement types and design features and evaluation of existing design guidance	36 months	$2.8 million	Accelerated load test facility, university or consultants, industry
	Sufficient validation of ME models for structural capacity under heavy loads for permeable pavements	Identify pavement types and features needing validation and perform comprehensive evaluation including accelerated pavement testing and field monitoring	1b. Validation of ME models of permeable pavement types and design features using accelerated pavement testing, including validation of existing design methods and new design guidance where needed			
			1c. Long-term field validation of permeable pavement types and design features			
			1d. Example case studies for design of permeable pavements using design tools			
	Guidance for site investigations for design of permeable pavements	Develop guidance and demonstrate it	1e. Guidance for site investigations for design of permeable pavements, with examples			

4. Develop and distribute information about design considering the existing built environment 5. Provide guidance and case studies for the overall design and delivery process	Guidance for structural and stormwater evaluation for existing permeable pavements	Develop test methods and processes for evaluation of existing permeable pavements, guidance and examples	1f. Test methods and processes for evaluation of stormwater functionality for permeable pavements			
			1g. Guidance for evaluation of stormwater functionality of permeable pavements			
			1h. Case studies for evaluation of stormwater functionality of permeable pavements			
	Development and evaluation of new and hybrid permeable pavement structures and materials	Develop new and hybrid structures and materials for permeable pavements	*1i. This should be a series of projects based on ideas that are generated for improved materials and structures. The projects should involve laboratory testing and mechanistic modeling. If they offer improvements, they should be validated using accelerated pavement testing and then field monitoring*			
	Best practice and guidance regarding design for permeable pavement near underground structures, for shoulder retrofit and on slopes	Review performance of existing approaches, develop alternatives where necessary, model them, do full-scale validation, do field monitoring	1j. Performance of interaction of permeable pavements and underground structures			
			1k. Performance of designs for combined permeable and impermeable pavements, including shoulder retrofits			

			1l. Performance of permeable pavements containing underground utilities			
			1m. Guidance on design of permeable pavements near underground structures, impermeable pavements and containing underground utilities			
			1n. Long-term field performance of permeable pavements near underground structures, impermeable pavements and containing underground utilities			
	Comprehensive project delivery and design guidance, tools and case studies identifying good and bad practice	Develop comprehensive guidance based on other work	1o. Comprehensive design guidance for permeable pavements			
			1p. Examples of good and bad practice for design of permeable pavement			

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Materials and pavement performance Objectives:	Good tests to characterize strength, stiffness, fatigue, permanent deformation	Identify best practice for testing in the laboratory and in the field for materials and	1q. Best practice and gaps for performance related laboratory and field tests for permeable pavement materials and structures.	24 months	$1.6 million	University research

1. Identify and improve tests for materials and pavement 2. Identify and improve best practices for materials design	properties of subgrades and permeable pavement materials for ME design	structures. Develop new tests if needed.	1r. New laboratory and field tests for permeable pavement materials and structures			
			1s. Guidance for laboratory and field testing for permeable pavement materials and structures			
	Improvement of porous asphalt and pervious concrete mix designs to better balance durability and infiltration, better admixtures	Develop better understanding of infiltration performance and then optimize mixes to have sufficient infiltration and maximize durability	1t. Optimization of asphalt mix designs for permeable pavement under different conditions.			
			1u. Optimization of pervious concrete mix designs for permeable pavement under different conditions.			
			1v. Optimization of surface layers for permeable pavers under different conditions.			
			1w. Guidance for mix design of permeable pavement materials.			
	Comprehensive summarization and guidance regarding permeable pavement in snow and ice conditions	Update guidance on permeable pavement design and operations under snow and ice conditions	1x. Guidance for permeable pavement design and operations under snow and ice conditions			

Route 2: Reduction of target pollutants to meet water quality requirements

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Stormwater quality design concerns Objectives: 1. Fill gaps in information and develop models for stormwater quality performance of permeable pavements 2. Produce and deliver guidance for designing permeable pavement to meet stormwater quality requirements	Sufficient information regarding effects of permeable pavement on transport and fate of pollutants, including groundwater and receiving waters	Gather existing information on permeable pavements on stormwater quality in different contexts, perform research to fill gaps	2a. Summary from the literature and available modeling of transport and fate of regulated stormwater pollutants for permeable pavement over its life cycle	18 months	$1.1 million	Consultants
			2b. Investigation of transport and fate of regulated stormwater pollutants for permeable pavement over its life cycle based on modeling			
			2c. Field validation of modeling of transport and fate of regulated stormwater pollutants for permeable pavement over its life cycle			
	Design models for transport and fate of pollutants over permeable pavement lifetime	Develop models for use in design practice for effects of permeable pavement on transport and fate of stormwater pollutants, incorporate into a tool	2d. Design models and tool for use of permeable pavement to manage stormwater pollutants			
			2e. Example case studies of modeling of transport and fate of stormwater pollutants for permeable streets and hardscape			
	Guidance for designing permeable pavements to	Develop guidance for use in design practice for effects of permeable	2f. Guidance for use of permeable pavement to manage stormwater pollutants			

	meet stormwater quality permit requirements	pavement on transport and fate of stormwater pollutants	2g. Example case studies for design of permeable streets and hardscape for managing stormwater pollutants			

Route 3: Reduction of urban flooding risks

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Watershed and local flood control design concerns Objectives: 1. Fill gaps in information and develop models for flood control performance of permeable pavements 2. Produce and deliver guidance for designing permeable pavement to meet flood control requirements	Sufficient information regarding effects of permeable pavement on localized flood control	Gather existing information on permeable pavements on flood control in different contexts and over the life time, perform research to fill gaps, produce guidance and case studies	3a. Summary from the literature and available modeling of localized flood control for permeable pavement over its life cycle	24 months	$0.5 million	Consultants, Corps of Engineers
			3b. Investigation and guidelines for design for localized flood control using permeable pavement considering the full life cycle			
			3c. Example case studies of design for watershed flood control considering permeable streets and hardscape in land use planning and regulation			
	Sufficient information regarding effects of permeable pavement on watershed flood control	Gather existing information on permeable pavements on watershed flood control in different contexts and over the life time, perform research to fill gaps, produce	3d. Summary from the literature and available modeling of localized flood control for permeable pavement over its life cycle			
			3e. Investigation and guidelines for design for localized flood control using permeable pavement considering the full life cycle			

		guidance and case studies	3f. Examples of modeling for watershed flood control considering permeable streets and hardscape in planning and regulations, including life cycle cost and environmental impacts under climate change			

Route 4: Routine achievement of high quality construction

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Construction standards and issues Objectives: 1. Develop and distribute guidance for specifications, inspection, and traffic handling for permeable pavement 2. Develop and distribute guidance for pre-qualifying designers and contractors 3. Develop tests for construction quality control for permeable pavements	Representative specifications for obtaining quality in construction	Work with industry to consolidate existing specifications, and improve where needed, make widely available	4a. Example construction specifications for multi-functional permeable pavements	24 months	$0.6 million	Consultants
	Guidelines for pre-qualifying designers and contractors	Prepare guidelines working with experienced owners and industry, make available	4b. Guidelines for pre-qualification of designers and contractors for multi-functional permeable pavements			
	Guidance regarding construction sequencing and traffic management in urban areas	Prepare guidelines working with experienced owners and industry, make available	4c. Guidance for construction sequencing and traffic handling for urban permeable pavement systems			
	Training information for certification of permeable pavement inspectors	Prepare inspection training working with experienced owners and industry, make available	4d. Training for inspection of permeable pavement construction			

	Good tests to measure performance related properties during construction	Identify best practice for testing in the laboratory and in the field for materials and structures for construction quality control. Develop new tests if needed.	4e. Best practice and gaps for performance related laboratory and field tests for construction quality control of permeable pavement materials and structures.			
			4f. New laboratory and field tests for construction quality control of permeable pavement materials and structures			
			4g. Guidance for laboratory and field testing for construction quality control of permeable pavement materials and structures			

Route 5: Maintenance and rehabilitation costs and methods

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Maintenance Objectives: 1. Collect, summarize and distribute comprehensive information regarding best practices for maintenance 2. Develop and use system for collect cost information and performance 3. Develop tests for maintenance effectiveness 4. Develop and make available best practices for utility cuts in permeable pavements	Comprehensive information regarding maintenance schedules and typical costs	Database and ongoing data collection process for typical unit costs on regional basis, make available, best if tied to inclusion of permeable pavement systems in asset management cost data collection processes.	5a. Set up of initial database and ongoing data collection process for typical unit costs on regional basis for permeable pavement	18 months	$0.75 million	Consultants
			5b. Recommendations for inclusion of permeable pavement in standard cost data collections processes			
	Comprehensive guidance for best practices for maintenance and cleaning of permeable pavements	Gather existing information and prepare guidelines working with experienced owners and industry, make available	5c. Guidance for best practices for maintenance and cleaning of permeable pavement as part of low impact development infrastructure across climate types			
			5d. Tests and practice for rapid measurement of permeable pavement infiltration for quality control of maintenance			
			5e. Example standard specifications and contract language for contracting maintenance of permeable pavement			

			5f. Summary of permeable pavement surface cleaning technologies			
	Comprehensive guidance for restoration of utility cuts in permeable pavement	Develop comprehensive guidance for restoration of utility cuts in permeable pavement, make available and provide training	5g. Comprehensive guidance and example plans and specifications for restoration of utility cuts in permeable pavement			
			5h. Training for inspection of restoration of utility cuts in permeable pavement			

Route 6: Incorporation of permeable pavements into asset management systems

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Asset management Objectives: 1. Develop best practices for organizational arrangements within local government for asset management for multi-functional low impact infrastructure 2. Develop best practices for inclusion of multi-functional low impact infrastructure in asset management systems 3. Develop guidance for rehabilitation and reconstruction of permeable pavements	Guidance regarding organizational arrangements within local governments for permeable pavements and other low impact development	Identify best practices and include in guidance, including examples of what works and what doesn't work, make available.	6a. Guidance on best practices for organizing local government to deliver and maintain permeable pavement and other multi-functional low impact infrastructure through its life cycle	24 months	$0.82 million	Consultants
			6b. Training for best practices for organizing local government to deliver and maintain permeable pavement and other multi-functional low impact infrastructure through its life cycle			
	Inclusion of permeable pavement and other low impact development in asset management systems	Develop recommendations for inclusion of permeable pavement and other low impact infrastructure in pavement or other asset management systems, make available	6c. Guidance for inclusion of permeable pavement and other multi-functional low impact infrastructure in infrastructure management systems			
			6d. Condition survey measures for asset management of multi-functional permeable pavement and other low impact infrastructure			
			6e. Test methods and practices for consideration of stormwater quality in asset management of permeable pavement and other low impact infrastructure to meet stormwater permit requirements			

			6f. Guidance for development of performance equations and decision trees for permeable pavement and other low impact infrastructure in asset management systems, with case studies 6g. Training for inclusion of permeable pavement and other low impact infrastructure in asset management systems			
	Comprehensive guidance for rehabilitation and reconstruction of permeable pavement	Develop comprehensive guidance for rehabilitation and reconstruction of permeable pavements, make available	6h. Guidance for rehabilitation and reconstruction of permeable pavement 6i. Training for rehabilitation and reconstruction of permeable pavement			

Route 7: Accurate life cycle cost analysis and environmental life cycle assessment tools

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Costing and decision support Objectives: 1. Produce and deliver framework, data and tools for initial and life cycle costing of permeable pavement as part of multi-functional systems 2. Establish practice for comparison of permeable and impermeable systems	Framework and tool for comprehensive life cycle cost analysis of permeable streets and hardscape considering stormwater, flood management and transportation	Develop a framework and then a tool for comprehensive life cycle cost analysis of permeable streets and hardscape	7a. Framework for comprehensive life cycle cost analysis of use of permeable streets and hardscape for transportation and stormwater functionality	18 months	$0.48 million	Consultants
			7b. Software tool for comprehensive life cycle cost analysis of use of permeable streets and hardscape for transportation and stormwater functionality (or inclusion of permeable pavement modules if there is an existing tool)			
			7c. Examples of life cycle cost analysis for use of permeable pavement for stormwater and transportation functionality			
	Stormwater and transportation performance and cost data for performing comprehensive LCCA	Develop processes for collecting and using data for LCCA of permeable pavement	7d. Guidelines and examples for developing performance and cost data for life cycle cost analysis of permeable pavements for stormwater and transportation functionality			

Route 8: Infrastructure management organizations that consider the full functionality of permeable pavements

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Integration of multi-functional priorities and responsibilities Objectives: 1. Reduce institutional barriers to use of permeable pavement Common understanding of multiple functions and their requirements 2. Solutions for roles, responsibilities, funding so that multiple functions addressed	High-level information identifying obstacles and recommended solutions for changes in project delivery to overcome obstacles in responsibilities and funding caused by multi-functionality	Survey typical obstacles and identify potential solutions, develop high-level summary	8a. Recommendations for overcoming obstacles to multi-functionality of streets and hardscape	18 months	$0.15 million	Academic or consultant; promotion by NACTO and others
	High-level information for domain areas identifying issues that other domain areas need considered for pavement and hardscape to meet stormwater and transportation requirements	Within each domain area (planning, design, construction, monitoring, etc.) identify what that domain area needs to do to consider other functions, develop high-level summary	8b. Considerations for multi-functional streets and hardscape for urban planning, stormwater, pavement and flood control design, construction, maintenance, and asset management			

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Planning and development codes Objectives: 1. Produce and distribute guidance for updating planning and design codes 2. Produce and deliver guidance for overall planning and project delivery	Information regarding updating local government planning, building, stormwater design and pavement design codes to facilitate use of streets and hardscape for both transportation and stormwater functionality	Use risk-assessment to evaluate codes for arbitrary and unnecessary items in codes that restrict use of permeable pavement.	8c. Risk assessment for common code obstacles to use of permeable pavement	18 months	$0.36 million	Consultants
			8d. Guidance for reviewing urban planning code and practice considerations for multi-functional streets and hardscape			
			8e. Guidance for reviewing stormwater design code and practice considerations for multi-functional streets and hardscape			
			8f. Pavement design code and practice considerations for multi-functional streets and hardscape			
			8g. Case studies of common obstacles and successful practices to deliver multi-functional streets and hardscape using permeable pavement			

	Guidance for the entire project delivery process, including all life cycle budget items, contracting expertise for successful delivery.	Develop guidance from both owner and industry experience. Include case studies showing consequences of both good and bad practice.	8h. Guidance and case study examples for the complete project delivery process for permeable pavements.			

Route 9: Planning guidance that considers the multi-functionality of permeable pavements

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Comprehensive planning Objectives: 1. Produce and distribute guidance planning processes that consider permeable pavements	Guidance to identify potential obstacles and opportunities for use of permeable streets and hardscape in the planning process, and who needs to be involved	Develop information with good information regarding opportunities and obstacles for using permeable pavement, including use and maintenance through the life cycle of the infrastructure	9a. Guidance for consideration of permeable streets and hardscape in urban infrastructure planning, including use and maintenance through the life cycle of the infrastructure	18 months	$0.38 million	Consultants
			9b. Case studies of consideration of permeable streets and hardscape in urban infrastructure planning, including use and maintenance through the life cycle of the infrastructure			
	Guidance for producing planning maps for use of multi-functional permeable pavement considering soils, existing infrastructure, storm events	Develop information for producing maps and use it in guidance	9c. Integrating climate change projections into transportation and stormwater handling plans, considering use of permeable hardscape			
			9d. Use of modeling to create and update planning maps for stormwater quality and flood management considering use of permeable hardscape			

			9e. Guidance for creating planning maps and checklists for use of permeable pavement for stormwater and transportation functionality			
			9f. Case studies of creating planning maps and checklists for use of permeable pavement for stormwater and transportation functionality			

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Designing for additional benefits and impacts Objectives: 1. Provide guidance for identifying full system multi-functionality benefits and impacts of systems with permeable pavement	Summary guidance for identifying additional benefits and impacts	Summarize existing information into comprehensive guidance for benefits beyond transportation, stormwater quality and flood control	9g. Guidance for designing maximum benefits into projects using permeable pavements	18 months	$0.48 million	University or consultants
			9h. Case studies for designing maximum benefits into projects using permeable pavements			
	Long-term performance of environmental benefits	Review older existing projects to see how long environmental benefits have continued	9i. Long-term environmental benefits performance of permeable pavement systems			

2. Information regarding long-term performance of environmental benefits 3. Provide design sketch books for systems capturing maximum functionality and long-term performance	Guidance regarding design of permeable pavements optimized for active transportation	Review existing information and perform new research as needed regarding active transportation benefits of permeable pavements	9j. Effects of pavement design and maintenance on human comfort during active transportation under different conditions			
			9k. Guidance for design and maintenance of pavements to maximize human comfort during active transportation under different conditions			
	Idea books (design sketch books) and case studies for systems using permeable pavements for multiple benefits	Develop sketch book for use of permeable pavements for multiple benefits including aesthetics	9l. Design sketch book for use of permeable pavements to create better places			

Route 10: Efficient and comprehensive access to the best information

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Communication among industries and users Objectives: 1. Create a communications and publications plan for permeable pavement information and execute it 2. Create and operate a clearinghouse for information on permeable pavement	Create a clearing house and an integrated communication and publication program, working with other existing organizations	Develop a communications and publication strategy working with existing organizations, fill gaps in existing information, make information widely available	10a.Communications and publications strategy for permeable pavement and other multi-functional low impact infrastructure, filling the gaps and expanding the work of existing organizations 10b.Set up clearing house and operate publication program, including information for different audiences from elected officials, non-governmental stakeholders, management in different functional areas, engineers, technicians, asset managers, permitting organizations	12 months	$0.25 million	University

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Education and training Objectives: 1. Create and operate a professional training and certification program for permeable pavement 2. Produce and maintain information on permeable pavements as part of multi-functional infrastructure for use in university classes across all relevant disciplines	Professional certificate in permeable pavements	Set up and deliver web-based with some in-person training program leading to professional certificate in permeable pavement, covering the topic areas for all functions	10c.Curricula and program for obtaining a professional certificate in multi-functional permeable pavements (planning, design, construction, maintenance, asset management), covering topics across all functional areas and how to organize to deliver and maintain permeable pavement and other low impact infrastructure 10d.Develop and deliver two years of web-based and some in-person classes to complete certificate, including new classes where needed and existing classes where available	12 months	$0.35 million	Universities with pavement & stormwater expertise

	Information for use in university classes	Develop quality information regarding permeable pavements for use in environmental engineering, environmental science, pavement engineering, asset management, hydrology classes at undergraduate level	10e.Instructional information regarding permeable pavement for: environmental engineering, environmental science, pavement engineering, asset management, hydrology			

Road Map Area and Objectives	Gap	Approach to Fill Gap	Proposed Projects	Timeline	Estimated Cost	Who Should Do It
Funding for research, development, implementation Objectives: 1. Produce and communicate a comprehensive road map for achieving full implementation	Comprehensive technical and funding plan for focused, intense program to move permeable pavement to full market potential	Create and communicate road map, identify and develop funding opportunities, execute program	10f.Create with stakeholders and communicate road map (this document) 10g.Identify and organize stakeholders and potential funding organizations to develop funding plan to deliver program in road map 10h.Develop funding	48 months Notes: 10f. done 10g., 10h. 1 year	$0.75 million Notes: 10f. already paid by industry	Universities

potential for permeable pavement 2. Identify and organize stakeholders to fund execution of the road map 3. Establish a center, consortium or other organization to deliver the program with a short, intense and focused effort, followed by a long-term implementation effort	There is no organization to deliver the program laid out in the road map		10i.Establish center, consortium or other organization to deliver program over three years			

3.2 Next steps

The proposed way forward involves the following tasks and timeline:

- Summer 2018:
  - Use existing resources from the funding of the workshop.
  - Finalize the road map based on stakeholder input and distribute. Set up a site to identify and organize existing information for the items identified in the road map.
  - Identify potential partners and existing groups
  - Update road map as new information appears
  - Apply for an Every Day Counts grant through FHWA
- Fall 2018:
  - Identify a Technical Working Group to guide implementation of this road map. This group should include government (transportation, stormwater, public works administration), industry (consulting designers, contractors, materials suppliers) and academia (pavement engineering, stormwater). The working group should be known to selected federal, state, and municipal transportation and stormwater agencies, as well as stakeholder non-profit organizations. The group would identify funding opportunities and prioritize expenditures.
- 2018 to 2025: Based on the symposium and road map, implement a comprehensive plan and funding mechanism for collecting, communicating, and distributing well-developed, technically sound, appropriately structured information for use by local government, consultants, private developers and state agencies.
- 2019 to 2021: Based on the workshop and resulting refined road map, complete a focused, intensive program of research, development and implementation tasks to fill the gaps. This will likely rely on state DOT funding, TRB/NCHRP sources, and perhaps private foundation funding.

Attachment A. Participant List

Invited Participants

First name	Last name	Organization
Mike	Adamow	San Francisco Public Utilities Commission
Janet	Attarian	City of Detroit - Planning and Development
Thomas	Baird, PE	Barton & Linguicide, D.P.C.
Simon	Bisrat	California Department of Transportation
John	Bolander	University of California, Davis
Robert	Bowers	Interlocking Concrete Pavement Institute
Jonathan	Buck	Engeo Incorporated
Ruijun	Cao	Hong Kong Polytechnic University
Michael	Carlson	Contra Costa County Flood Control District, Public Works
Bob	Cullen	Riverside County Flood Control and Water District
Brian	Currier	Office of Water Projects, Sacramento State University
Jason	Drew	NCE
Lifu	Duan	Sichuan Iglitter Road Technology Co., Ltd
Nathan	Forrest	California Nevada Cement Association
Kyle	Gallup	Riverside County Flood Control and Water District
David	Garcia	Riverside County Flood Control and Water District
Cornelis	Hakim	California Department of Transportation
John	Harvey	University of California Pavement Research Center
Liv	Haselbach	Lamar University
David	Hein	Applied Research Associates, Inc. (ARA)
Larry	Henry	City Berkeley Public Works Commission
Curtis	Hinman	Herrera Environmental Consultants
Joe	Holland	California Department of Transportation
Sonoko	Ichimaru	University of California, Davis
Michael	Irvine	City of Vancouver, British Columbia
Maria	Javier	City of Fremont
Bhaskar	Joshi	California Department of Transportation
Kenneth	Justice	National Ready Mixed Concrete Association
Mark	Keisler	California Department of Transportation
John	Kevern	University of Missouri-Kansas City
Brian	Killingsworth	National Ready Mixed Concrete Association
Jessica	Knickerbocker	City of Tacoma
Ken	Kortkamp	San Francisco Public Utilities Commission
Philip	Kresge	National Ready Mixed Concrete Association
Rico	Lardizabal	City of Fremont
Michael	Leacox	NCE
Hui	Li	Tongji Unviersity
Keith	Lichten	SF Bay Regional Water Board
David	Liguori	Bay Area Pervious Concrete

Brian	Lutey	Ozinga Ready Mix Concrete
Alejandro	Martinez	University of California, Davis
Deepak	Maskey	California Department of Transportation
Brandon	Milar	California Asphalt Pavement Association
Amir	Patrick	AECOM
Katherine	Petros	Federal Highway Administration
Anne	Quasarano	City of Fremont
Christine	Rice	Affinity Engineering Inc.
Shadi	Saadeh	CSU Long Beach
David	Smith	Interlocking Concrete Pavement Institute
Peter	Smith	The Fort Miller Co. Inc.
Samuel	Tyson	Federal Highway Administration
Frans	van der Meer	City of Fremont
Neil	Weinstein	The Low Impact Development Center
Pete	Weiss	Valparaiso University
J. Richard	Willis	National Asphalt Pavement Association
Guang	Yang	Harbin Institute of Technology
Ray	Yep	Berkeley Public Works Commission

University of California Pavement Research Center Staff and Graduate Students Assisting with Documentation

First name	Last name
Robel	Ayalew
Julian	Brotschi
Koral	Buch
Jeff	Buscheck
Ali	Butt*
Joseph	Hammond
Shawn	Hung
Liya	Jiao
Sampat	Kedarisetty
Yanlong	Liang
Stefan	Louw
Hesam	Nabizadeh Rafsanjani
Maryam	Ostovar
Christina	Pang
Julio	Paniagua
Fabian	Paniagua
Arash	Saboori*
Ashkan	Saboori
Weizhuo	Xiong

*Organized final session content and website information

Attachment B. Workshop Program

Tuesday November 14 **Start at 1 pm**		
Welcome	Co-chairs and sponsors	1 to 1.10 (10)
Charge to the workshop	Co-chairs and sponsors	1.10 to 1.20 (10)
Overview	Where are we and what is missing? Summary of survey results; Workshop goals, deliverables and structure *John Harvey*	1.20 to 1.35 (10 present, 5 questions)
Pavement industry perspectives	Thoughts on the future of permeable pavement from materials producer and contractor perspectives, meeting pavement and stormwater needs. *Richard Willis (NAPA), David Smith(ICPI), Brian Killingsworth (NRMCA)*	1.35 to 1.55 (5, 5, 5 present, 5 questions)
Stormwater and pavement, thoughts on the future from recent experience	Thoughts on the future of permeable pavement from a stormwater perspective, what kind of future do permeable pavements have meeting pavement and stormwater needs. *Amir Ehsaei (speaking)/Tom Sweet, AECOM*	1.55 to 2.10 (10 present, 5 question)
Planning and conceptual design	How and where do decisions about permeable pavement occur in planning and conceptual design, what is working, what is not, what is missing? *Janet Attarian, City of Detroit*	2.10 to 2.25 (10 present, 5 question)
Stormwater regulation and codes	What do pavement people need to know about stormwater regulation, codes and basic stormwater considerations? *Keith Lichten, California Water Board*	2.25 to 2.40 (10 present, 5 question)
Design, maintenance and performance	What are gaps regarding permeable pavement design, maintenance and performance, for vehicle traveled ways and other urban hardscapes? *Dave Hein, ARA*	2.40 to 2.55 (10 present, 5 question)
Break		2.55 to 3.15
Specifications and Construction	What are gaps regarding permeable pavement specifications and construction, and are specs and other technical information enough to overcome pre-conceived notions, fears, the status quo, and the personal bias of civil engineers who are permeable pavement skeptics? *Mike Adamow, San Francisco Public Utilities Commission*	3.15 to 3.30 (10 present, 5 question)
Life cycle cost analysis	Is the framework correct (just pavement or does it capture off-site benefits and costs?) Do	3.30 to 3.45 (10 present, 5 question)

	we have the numbers for both permeable pavement and other BMPs? *Dave Hein, ARA*	
Life cycle assessment and other demand on streets	What are the new demands on pavement besides safety and structural capacity and how does permeable fit in or not? What is an LCA framework to look at these new pavement demands and stormwater? *John Harvey*	3.45 to 4.00 (10 present, 5 question)
Communication between stormwater and pavement people from planning to maintenance	What are common communications gaps between the knowledge domains and goals of stormwater and pavement, and ideas on fixing them? *Mike Carlson, Contra Costa County Flood Control and Water Conservation District*	4.00 to 4.15 (10 present, 5 question)
What about a Strategic Permeable Pavement Research Program	What was SHRP and SHRP2? First cut: what are the biggest questions? Pavements and Stormwater *John Harvey, Liv Haselbach and Neil Weinstein*	4.15 to 4.35 (5-5 5, 5 question)
Get ready for next day	Follow up questions and review activities for next day	4.35 to 4.50
Evening get together; Dinner on your own	Appetizers and drinks	5.00 to 6.30
Wednesday November 15 Start breakfast at 7.15 am		
Breakfast		7.15 to 8.15
Morning sessions, what do we have and what is missing (same subjects plus a what did we miss)	Small groups with facilitator, student scribe for each subject area	8.15 to 10.00 (get organized then 3 x 30-minute sessions for each group)
Break		10.00 to 10.30
Second morning sessions, same subject (how to get to solutions, who, what, when, where, how)	Small groups with facilitator, student scribe for each subject area	10.30 to 12.00 (3 x 30 minutes sessions
Lunch		12.00 to 1.00
Reports back	Facilitator, student scribe	1.00 to 2.30 (10 reports x 10 minutes)
Break		2.30 to 2.50
Outline of draft road map	Discuss	2.50 to 3.30
Participants, funding and schedule	Discuss	3.30 to 4.15
Additional ideas for road map	Open discussion	4.15 to 4.45
Next steps and schedule	Organizers	4.45 to 5.00

Attachment C. Questions for Discussion Groups

#	Category	Question	Asked by
1	Costing and cost decision support	What should be included in a framework for initial and life cycle cost comparisons for permeable pavement versus impermeable pavement?	KJ, AB, HL
2	Costing and cost decision support	How can life cycle cost analysis be made to be more widely used when comparing alternative stormwater systems including permeable pavement?	DH
3	Costing and cost decision support	Is there sufficient information regarding initial costs and life cycle costs available to practitioners? If not, how can it be gathered? How can it be communicated for practical use?	JH, DH, PW, MI, HL
4	Costing and cost decision support	How can the costs of permeable pavement be reduced?	HL
5	Materials and pavement performance	How do we address damage from de-icing agents, plowing, frost effects and other cold weather pavement and hardscape safety management?	KJ, BJ
6	Materials and pavement performance	Can pervious concrete mix designs and performance be improved through better consideration of mix design approaches, construction processes, fibers, admixtures?	DH, JB, NF
7	Materials and pavement performance	How can more pilot projects be done to demonstrate and improve industry and owner experience with permeable pavements?	DH
8	Materials and pavement performance	Can materials design processes be improved for balancing strength and durability versus permeability for porous asphalt, pervious concrete, permeable pavers and permeable pre-cast concrete for different structural capacity and hydrological design situations? Is there sufficient information available regarding concrete and asphalt materials design?	PS, JH
9	Materials and pavement performance	Can materials design processes be improved for reservoir, sub-base and bedding layers for different design situations? Including materials selection, consideration of construction	JH, JBuck
10	Materials and pavement performance	Is there guidance for selection of PG grade for porous asphalt mixes that includes consideration of sealing of the surface under traffic and dust capture? Do we know if warm mix can be used beneficially for porous asphalt?	BC, JK
11	Education and training	How do we get this type of pavement/system into college curricula? For engineers, for planners, for architects? Who else should be on this list?	KJ, AQ

12	Education and training	What is best approach to get proper information into the hands of engineers (design, specifications, maintenance), owners (selection of contractors, maintenance, construction inspection, specifications), contractors (construction)? How to move a risk-averse engineer from no to yes?	PK, BM, AQ
13	Education and training	Should there be a training and certificate program for permeable pavement designers? If yes, how to set up?	JBuck
14	Education and training	What is best approach to get stormwater quality and flooding onto the performance criteria for public works and road agencies? What is best approach for communicating permeable pavement, multi-BMP systems including permeable pavement and other LID treatments to public works directors and their staff who must sign off on them?	JH
15	Education and training	What advances have been made in advancing permeable pavement technology, and are they being adequately communicated? Do people know what previous problems have been solved? If not, how to communicate?	HN
16	Communication	What is best approach to communicate awareness and valid information about permeable pavements to public works staff, the public and elected and appointed decision-makers? Who needs to be involved? Are permeable pavements just not ready yet?	DH, JA, ML
17	Communication	Why is permeable pavement being widely used in other countries for many years, more than in the US? What is different? Can this be changed?	AB
18	Communication	How can hardscape effects on quality of life be brought into competition for funding, in addition to stormwater and transportation benefits?	JA
19	Communication	How can public road funding decision processes be made to consider other functionalities of roads? In some places being used for simultaneous conversion to complete streets, can stormwater considerations in use of funding be included? If yes, how? If not, why?	JA
20	Communication	Is there adequate information regarding probabilities of different types of failures of permeable pavements to be considered in conceptual and project level design? If not, how could it be developed?	RL
21	Communication	How best to gather information regarding successes with permeable pavement and present to decision makers? Including good information regarding LCA and LCCA?	KP

22	Project-level design issues	How to handle design of permeable pavement next to buildings with basements, pavement shoulders next to impermeable pavements and other structures vulnerable to infiltrated water? Is there adequate information available regarding how to do these correctly?	KJ, JH, PW
23	Project-level design issues	What else is needed to be able to do mechanistic-empirical design of permeable pavements? Including consideration of lightly compacted saturated soils?	DH, JH, BJ, BM
24	Project-level design issues	Do we have sufficient information regarding effects of geo-grids on structural capacity?	DH
25	Project-level design issues	Do we have sufficient example standard specifications that designers can use, and how to train them to use them properly? If not, how to improve them? Where are most used specifications coming from (stormwater boards?) and are they being reviewed by permeable pavement experts?	DH, KL, JBuck
26	Project-level design issues	Is there a potential market for pre-cast permeable pavements? What applications?	PS
27	Project-level design issues	Is there adequate information and guidance regarding compaction of subgrades to balance permeability and structural capacity? Is there adequate information and guidance regarding characterization of subgrades, slopes, etc. for permeable pavement suitability and design?	CH, JH, MI, Hess, JBuck
28	Project-level design issues	What is holding back applications for shoulder retrofits of highways?	PW
29	Project-level design issues	How can geotechnical investigations for selecting appropriate places for permeable pavements and their design be made better, faster, cheaper? Is there adequate guidance and standards for geotechnical investigations? If not, how to develop? If yes, how to understand and communicate and to communicate scope vs risk?	JK, MI,
30	Project-level design issues	What is experience and design guidance with check dams and other designs for internal slopes, spills, horizontal flows, slope stability and other considerations besides vertical flow?	JK, AM, BJ
31	Project-level design issues	Is there adequate guidance regarding retrofitting impermeable pavement and hardscape to become fully permeable? If not, what needs to be done to develop it?	MI
32	Project-level design issues	Do we have sufficient field and/or accelerated pavement testing data to design pavements for critical distresses (cracking, rutting, raveling, clogging)? For pervious concrete subbases for confinement of reservoir aggregate? And if not, how can it be gotten?	DH, JH

33	Project-level design issues	Is load transfer possible or useful for pervious concrete and pre-cast applications? Is there adequate design guidance regarding jointing and slab sizes? If not, how can it be developed?	PS, JH
34	Project-level design issues	Is there adequate guidance regarding design of full-width versus partial width alternatives? If not, how can it be developed?	KK
35	Project-level design issues	Do we have good tests to characterize strength, stiffness, fatigue, permanent deformation properties of subgrades and permeable pavement materials for mechanistic-empirical pavement design?	DH, JH, NF
36	Project-level design issues	Do we have adequate information about hybrid permeable pavements, such as concrete and asphalt bases for pavers, waste pavers as subbases, bound bedding layers, etc.?	JH
37	Project-level design issues	Is there adequate information regarding the upper speed limit above which permeable pavements are no longer the right choice? If not, how to get it? If yes, how to communicate it?	MV
38	Project-level design issues	Can deflection testing be used to evaluate permeable pavements? If yes, is there guidance?	JBuck
39	Watershed and flood control design issues	Are there good mechanistic watershed hydrological data/models/tools that can capture the effects of permeable pavement and multi-BMP systems including permeable pavement on flood control and groundwater replenishment? Are they well calibrated with field data?	JB, KG, KL
40	Watershed and flood control design issues	Are there good mechanistic data/models/tools that can capture the effects of permeable pavement and multi-BMP systems including permeable pavement on stormwater quality? Including separated and combined sewer and stormwater systems	JH, MJ
41	Watershed and flood control design issues	Is there adequate guidance regarding selection of storm events for design? If no, how can it be developed and what needs to be considered? What about climate change? If yes, how can it be communicated?	BC, MI, ML
42	Designing for additional benefits and impacts	How can additional off-road and non-stormwater retention/detention benefits of permeable pavements be quantified and be included in design selection process? Examples are local heat island, noise, de-icing, active transportation suitability. Can these be included in life cycle assessment?	KJ, DH, JB, PW, AB, MI, JH
43	Designing for additional benefits and impacts	What are the roles of permeable pavements besides functioning as pavement, stormwater quality and stormwater flow, and how can they be quantified and brought into design/decision making process	JH

44	Designing for additional benefits and impacts	What are the chemical and biological processes that occur in a permeable pavement system? Can they be developed and incorporated to obtain greater benefits for water quality?	PW, JH
45	Designing for additional benefits and impacts	Is there adequate planning and design guidance for ratio of impervious to pervious surfaces for water quality and stormwater flow management? If no, how can it be developed? If yes, how can it be communicated?	BC
46	Designing for additional benefits and impacts	Do cities and counties have good groundwater and sub-surface flow and storage models to evaluate unintended consequences, benefits and risks? If not, how can they be developed? If yes, how can they be brought into decision-making easily?	JK, MJ
47	Designing for additional benefits and impacts	Is there an adequate life cycle assessment framework for permeable pavement to consider environmental impacts? How should permeable pavements be compared to other LID and impermeable systems?	RL
48	Construction standards and issues	How can industry standard specifications be better enforced?	KJ
49	Construction standards and issues	Do we have sufficient tests for construction quality control and assurance?	DH, JK
50	Construction standards and issues	How can qualifications for contractors and their personnel be made more rigorously enforced? How can contractor experience and understanding be improved?	KJ, DH
51	Construction standards and issues	How can owners get better at selecting designers and contractors, inspection, quality assurance?	DH
52	Construction standards and issues	What information is available regarding design of construction productivity, scheduling, traffic handling, selection of alternatives in traffic congestion or business access situations?	KK, JH
53	Maintenance	Do we have sufficient information regarding maintenance of permeable pavements? If not, how can it be gotten? How can it be best communicated? Does it consider high trash and pollutant load areas like loading bays? How can information be made available to small and large private permeable pavement owners regarding maintenance?	DH, SI, MJ, KJ
54	Maintenance	Do we have sufficient information regarding localized repairs, handling of utility repairs and other localized work on permeable pavements? If not, how can it be gotten? How can it be best communicated?	DH, JH
55	Maintenance	Are there regulatory drivers that could be used to support funding for operation and maintenance of permeable pavement, multi-BMP and other LID systems? If yes, what are they?	JH

56	Maintenance	What are the obstacles to effective operations and maintenance of permeable pavement, multi-BMP and other LID systems?	JH
57	Maintenance	Why aren't there more innovations in development of permeable pavement cleaning equipment for large and small-scale applications?	CH
58	Maintenance	What is guidance regarding maintenance debris from cleaning permeable pavements? Are there special considerations? Are the costs included in life cycle cost framework?	AB
59	Maintenance	Is there adequate guidance regarding operations and maintenance for different permeable pavement systems for different rainfall environments (types of storms, frequencies of storm events)?	BC
60	Maintenance	Is there adequate guidance for utility repairs under permeable pavements of different types? If not, how to develop? If yes, how to communicate better?	MI
61	Asset management	Do we have adequate information to bring permeable pavement into pavement management systems? Whose asset is a permeable road?	DH, JH, AB, JK
62	Asset management	Are there stormwater asset management systems and LID asset management systems in place? If not, how to develop them? How to communicate them and their benefits? How to mandate them?	JH, AB
63	Asset management	Is there sufficient information regarding how long environmental benefits last? If not, how to develop?	PW
64	Asset management	Is there adequate information regarding end of life for permeable pavements? Can they be rehabilitated to restore benefits? Do they need to be reconstructed?	PW
65	Asset management	Is there a standard for condition survey of permeable pavements and other permeable hardscapes? If not, how can one be developed?	MJ, JH
66	Funding for research, development, implementation	Do funding sources exist at state and federal levels to support research, development and implementation support for permeable pavements? If not, what can be done to create a pipeline and process for efficient RD&I? Consortia?	BK, RW, HL
67	Funding for research, development, implementation	What are top priorities for academic research on permeable pavements, LID, and their uses? What are top priorities for piloting of permeable pavement concepts coming from research and development?	SI
68	Funding for research, development, implementation	What would it take to get additional funding for stormwater flood control?	JH, MC
69	Funding for research, development, implementation	What university transportation center exists or should be created that should include permeable pavement and urban hardscape in its scope?	RW

70	Planning and development codes	Are there built in obstacles to permeable pavement in development codes or other policies and regulations? If yes, where? If yes, how can they be changed to get better results for their goals?	JH, BM
71	Planning and development codes	Is there sufficient information regarding permeable pavements or multi-BMP systems including permeable pavement in the typical stormwater BMP selection/design process? Can credits for handling stormwater be included in development systems?	JH, JBuck
72	Planning and development codes	What is the total potential market for permeable pavements? Retrofit of roadways, other hard scape, in multi-BMP systems? In terms of numbers of cities, counties, private owners; in terms of surface area of urban areas	PS, JH
73	Planning and development codes	Are cities and counties communicating effectively about permeable pavements to the development community and vice versa? What can be done to improve the development process to better consider permeable surfaces (pavement and other LID)?	JK
74	Planning and development codes	Is there adequate guidance regarding use of permeable hardscape for other than roads (sidewalks, etc.) and including permeable hardscape/pavement into active transportation and complete street projects? If not, how to develop?	BL, AQ
75	Planning and development codes	Can maps be developed identifying suitable candidate areas for permeable pavements and other permeable hardscape for planning and conceptual design purposes? What would need to be in those maps?	MJ
76	Planning and development codes	Are there incentives available for permeable pavement for private applications? If not, should there be? How would they get funded?	JH

Attachment D. Day 2 Discussion Groups

First Name	Last Name	Organization	Group	Q1	Q2	Q3	Q4	Q5	Q6
Alejandro	Martinez	UC Davis	1	cost	proj des	wat des	asset man	free	free
Brandon	Minto	UC Davis	1						
Frans	van der Meer	City of Fremont	1						
Mike	Adamow	San Francisco Public Utilities Commission	1						
Kyle	Gallup	RCFC&WCD	1						
Anne	Quasarano	City of Fremont	1						
Carlson	Michael	Contra Costa County	1						
Hui	Li	Tongji Unviersity	2	mat des	constr	wat des	planning	free	free
Brian	Killingsworth	NRMCA	2						
Michael	Irvine	City of Vancouver	2						
Ray	Yep	Berkeley Public Works Commission	2						
Brian	Lutey	Ozinga RMC	2						
Bob	Cullen	RCFC&WCD	2						
Yaming	Pan	University of California, Davis	3	comm	planning	asset man	add ben	free	free
Brandon	Milar	CalAPA	3						
Peter	Smith	The Fort Miller Co. Inc.	3						
Thomas	Baird, PE	Barton & Loguidice, D.P.C.	3						
Maria	Javier	City of Fremont	3						
Bhaskar	Joshi	CALTRANS	3						
Kenneth	Justice	National Ready Mixed Concrete Association	4	mat des	educ	comm	maint	free	free
John	Bolander	University of California, Davis	4						
John	Kevern	University of Missouri-Kansas City	4						
Pete	Weiss	Valparaiso University	4						
J. Richard	Willis	National Asphalt Pavement Association	4						
Jason	Drew	NCE	4						
Michael	Leacox	NCE	5	planning	educ	wat des	add ben	free	free
Deepak	Maskey	Caltrans	5						

Katherine	Petros	Federal Highway Administration	5						
Mark	Keisler	Caltrans	5						
Ken	Kortkamp	San Francisco Public Utilities Commission	5						
Keith	Lichten	SF Bay Regional Water Board	5						
David	Hein	Applied Research Associates, Inc. (ARA)	6	cost	proj des	maint	funding	free	free
David	Liguori	Bay Area Pervious Concrete	6						
Jessica	Knickerbocker	City of Tacoma	6						
Rico	Lardizabal	City of Fremont	6						
Brian	Currier	OWP @ Sacramento State	6						
Liv	Haselbach	Lamar University	7	comm	add ben	funding	proj des	free	free
Robert	Bowers	Interlocking Concrete Pavement Institute	7						
Amir	Ehsaei	AECOM	7						
Neil	Weinstein	The Low Impact Development Center	7						
Larry	Henry	City Berkeley Public Works Commission	7						
Cornelis	Hakim	CALTRANS	7						
Sonoko	Ichimaru	UC Davis	8	funding	constr	proj des	asset man	free	free
Nathan	Forrest	CNCA	8						
David	Smith	ICPI	8						
Jonathan	Buck	Engeo Incorporated	8						
Samuel	Tyson	Federal Highway Administration	8						
Robin	Welter	City of San Francisco	8						