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

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16. ABSTRACT

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 discussions were held with the National Ready Mixed Concrete Association (NRMCA), the National Asphalt Pavement Association (NAPA), and the Tongji University Sponge City Project (Shanghai, China). A workshop was organized in November 2017 based on those discussions with the goal of identifying knowledge, information, and communication barriers to adoption of permeable pavement 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 listen to presentations, exchange and discuss unanswered questions identified by the group, and then to discuss a proposed road map to fill the gaps in knowledge, processes, and guidance. This document is the result of that workshop and additional development of the road map. It presents the organization of the workshop, summaries of the presentations and the breakout and plenary discussions, and the final road map developed from the results of the workshop.

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# EXECUTIVE SUMMARY: OVERVIEW OF WORKSHOP AND PROPOSED ROAD MAP

In early 2017, the University of California Pavement Research Center (UCPRC) and the Interlocking Concrete Pavement Institute (ICPI), working with the National Center for Sustainable Transportation (NCST), 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 discussions were held with the National Ready Mixed Concrete Association (NRMCA), the National Asphalt Pavement Association (NAPA), and the Tongji University Sponge City Project (Shanghai, China). A workshop was organized based on those discussions 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 listen to presentations, exchange and discuss unanswered questions identified by the group, and then to discuss a proposed road map to fill the gaps in knowledge, processes, and guidance. The conference website is *www.ucprc.ucdavis.edu/permPvmt/*.

The result of the workshop is this final report on the workshop and the proposed road map. Presented in this report is a comprehensive discussion that identifies challenges to be solved and the road map with "routes" of proposed actions to remove technical and institutional barriers to realize the goal of making permeable pavements a fully viable alternative in standard practice. The road map includes the details of proposed projects to complete the journey, including expected durations and costs.

The following is a summary of the 10 proposed routes. Each route consists of set of projects to address a requirement for widespread implementation that has gaps that need to be filled to achieve the goal of making permeable pavements a choice that can be considered by planners, designers, and maintenance and water quality professionals with confidence.

**Route 1. 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

[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.

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 the 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 2. 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 the 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 3. 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 agency, 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 and including 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 4. Reduction of target pollutants to meet water quality requirements.** Develop design decision trees/menus for reduction of target pollutants from existing and additional research. Include runoff reduction as an integral part of water quality management objectives and pollutant reduction credits.

**Route 5. Reduction of urban flooding risks.** Develop approaches for considering permeable pavement in flood models for use in zoning, planning, land development codes, and flood control design.

**Route 6. Reliable pavement structural designs.** Complete the development of reliable structural design tables that account for long-term saturated soils typical to permeable pavements. This will likely require a significant

[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.

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 7. Routine achievement of high-quality construction.** Improve construction guide specifications, including improved construction methods, and quality control and quality assurance test methods and inspection protocols/checklists.

**Route 8. Maintenance and rehabilitation costs and methods.** Refine information regarding best practices for maintenance methods and their costs for different applications and make them widely available. Identify designs that minimize sediment transport and deposition to reduce required maintenance. Improve maintenance methods, including surface-cleaning techniques and equipment, and potential deicer use reduction. Identify best practices for hydrologic and structural rehabilitation and for reconstruction methods for aging permeable pavements.

**Route 9. Incorporation of permeable pavements into asset management systems.** Based on results from the five routes above, develop/refine asset management tools for stormwater agencies and road agencies. These should include inspection methods/standards, and maintenance costs. Concurrently, improve and, where possible, validate the quantitative performance models appropriate to each at the site scale, drainage system scale, and regional watershed (flood) scale.

**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 with practitioners, policy-makers, and other stakeholders. It also includes finding funding to execute this road map.

# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | Millimeters | mm |
| ft | feet | 0.305 | Meters | m |
| yd | yards | 0.914 | Meters | m |
| mi | miles | 1.61 | Kilometers | Km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | Square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | Square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | Square meters | $m^2$ |
| ac | acres | 0.405 | Hectares | ha |
| $mi^2$ | square miles | 2.59 | Square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | Milliliters | mL |
| gal | gallons | 3.785 | Liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | Grams | g |
| lb | pounds | 0.454 | Kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | Lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | Newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | Kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | Inches | in |
| m | meters | 3.28 | Feet | ft |
| m | meters | 1.09 | Yards | yd |
| km | kilometers | 0.621 | Miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | Hectares | 2.47 | Acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | Milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | Gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | Ounces | oz |
| kg | kilograms | 2.202 | Pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | Poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380 (Revised March 2003).

# 1 INTRODUCTION

In early 2017, the University of California Pavement Research Center (UCPRC) and the Interlocking Concrete Pavement Institute (ICPI), working with the National Center for Sustainable Transportation (NCST), 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 discussions were held with the National Ready Mixed Concrete Association (NRMCA), the National Asphalt Pavement Association (NAPA), and the Tongji University Sponge City Project (Shanghai, China). A workshop was organized based on those discussions with the goal of identifying knowledge, information, and communication barriers to adoption of permeable pavement[3] 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 listen to presentations, exchange and discuss unanswered questions identified by the group, and then to discuss a proposed road map to fill the gaps in knowledge, processes, and guidance.

The result of the workshop is this final report on the workshop and the proposed road map. Presented in this report is a comprehensive discussion that identifies challenges to be solved and the road map with "routes" of proposed actions to remove technical and institutional barriers to realize the goal of making permeable pavements a fully viable alternative in standard practice. The road map includes the details of proposed projects to complete the journey, including expected durations and costs.

All presentations, a list of the participants, information given to the breakout groups and their results, and additional information is included in the conference website at *www.ucprc.ucdavis.edu/permPvmt/*.

[3] 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.

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# 2 SUMMARY OF WORKSHOP PROGRAM

The workshop was held at the Oddfellows Hall in downtown Davis, California, 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 costs 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 limited funding and the size of the workshop meeting site. The result was a diverse, experienced group with expertise in pavements, stormwater quality, flood control, planning, and landscape architecture, and participants from academia and government, as well as from the consulting and construction and materials sectors. The expertise and the practice sectors of the 57 participants are shown in Table 2.1 below. The participant list is in Appendix A and on the website.[4] 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, and several of whom also helped organize the final workshop content for posting on the Internet and for use in this report. The staff and students were led by Ali Butt, Jeff Buscheck, and Arash Saboori.

[4] *www.ucprc.ucdavis.edu/permPvmt/Participants.aspx*

**Table 2.1: 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* |

## 2.2 Program

The program for the workshop, shown in Appendix 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.[5]

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 edited, combined where there was overlap, and organized by topic areas during the night between the first and second days by the workshop chair. The result was the 76 questions, shown in Appendix C and on the website.[6] These were grouped into the preliminary topic areas:

- 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, and 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 Appendix D) with diverse representation from the matrix of expertise areas and practice sectors, discussed the

[5] *www.ucprc.ucdavis.edu/permPvmt/Presentations.aspx*
[6] *www.ucprc.ucdavis.edu/permPvmt/PDF/Questions%20from%20Permeable%20Pavement%20Workshop%20Day%201.pdf*

questions and possible actions to answer them. UCPRC staff and students documented the discussions. Each group was instructed to address questions they selected from the three topic areas assigned to them in the first morning session (shown in Appendix D), as well as questions from another three topic areas in the second session.

All participants gathered 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 summarized in this report by topic area, and the presentations made by the groups summarizing their discussions can be seen on the workshop website.[7]

Based on the group reports the workshop chair then prepared an outline of the proposed road map for permeable pavements, and this was followed by a discussion that included all workshop participants. Included in the discussion were additions to the proposed road map, and suggestions for whom 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 suggest 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.

Following the workshop, the co-chairs reviewed and summarized the presentations, the group breakout discussions, and the final discussion for this report. The original categories for the 76 questions given to the breakout sessions were expanded and reorganized when summarizing the breakout discussions to better reflect the directions that the group discussions took and additional topic or subtopic areas that were identified in the discussions. The topic areas were rephrased a second time to reflect the goals for permeable pavements. The co-chairs then developed the road map as a series of "Routes" to complete the goals for each topic area through completion of a set of projects. The road map was sent for review by the workshop attendees and then finalized for this report.

### 2.3 Summary of the First-Day Presentations

After a brief welcome, the co-chairs and sponsors of the workshop gave a charge to the conference attendees: that they 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.

[7] *www.ucprc.ucdavis.edu/permPvmt/Breakouts.aspx*

John Harvey of the UCPRC presented a summary of a 2017 Caltrans-sponsored research survey[8] regarding obstacles to the implementation of permeable pavement *(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 of the survey 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, 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 an American Society of Civil Engineers (ASCE) standard for permeable interlocking concrete pavements (PICP) *(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 a lack of sufficient ownership of the technology to justify research for permeable pavements compared with conventional impermeable pavements. He also noted a high prioritization by state and municipal road agencies of safety for vehicle operators and a lower prioritization of stormwater concerns, as well as pavement engineers' concerns regarding maintenance and life cycle costs for permeable pavements. On the other hand, meeting National Pollutant Discharge Elimination System (NPDES) permit requirements is the priority for stormwater engineers and managers, and maintaining the safety and resilience of stormwater management infrastructure are also important. In this context, many practitioners sense a lack of sufficient information regarding permeable pavements. He suggested that a plan is needed for government, industry and academia to come together 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 its stormwater quality benefits *(www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Willis_Killingsworth_Industry_Perspectives.pdf).* He also summarized the extensive amount of information on pervious

[8] See *www.ucprc.ucdavis.edu/PDF/UCPRC-TM-2017-03.pdf.*

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 for owners regarding maintenance and operation of pervious concrete pavement.

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 producers 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 San Francisco Bay Area, sometimes combined with bio-retention *(www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Ehsaei_Sweet_Thoughts_on_the_Future.pdf)*. He discussed good experiences 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 permeable pavement 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, the use of 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 *(www.detroitmi.gov)* discussed planning and conceptual design for permeable pavement *(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 the City of Chicago that are now being used for the City of Detroit: Complete Streets Guidelines, which provides guidance on modal hierarchy and mode sharing; the 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 the costs of "green build" streets are often less than projected and have costs of a similar order of magnitude as "business as usual" streets, but that this new street type has greater benefits, which results 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. Thus the notebook 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 the ongoing need to meet stormwater quality requirements, Detroit is charging property owners a fee for impervious surfaces that 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 adjacent 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 fulfill those approaches *(www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Lichten_Regulations_and_Codes.pdf)*.

The main regulatory drivers for stormwater management 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 of water, 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 rivers, lakes, bays, and oceans.

Keith Lichten identified permeable pavements as offering opportunities for significant co-benefits through hydro-modification 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 Americans with Disabilities (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 to ensure that these pavements 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 *(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. Moving to ME methods will require performance information 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 a move to ME design methods for permeable interlocking concrete pavements (PICP) began in 2014 at the UCPRC with APT that also produced information applicable to designs 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 be included in ME design is needed, as well as a 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 the resulting functional properties, and on the relationship of pervious concrete strength to structural design. In addition, little is understood about the structural benefits of using pervious concrete for soil subgrade reinforcement. Gaps were also identified regarding experience in constructing permeable pavements and how to bridge those gaps through education and certification. Other gaps identified were 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 *(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 *(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 the 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 that considers LCCA and feasibility ranking and is not overly complex and difficult to use.

Mike Carlson from the Contra Costa County Flood Control and Water Conservation District *(www.co.contra-costa.ca.us/5743/Flood-Control-District)* discussed communication between stormwater and pavement practitioners from planning through maintenance *(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 reconciling 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 infrastructure 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, Carlson 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 of the UCPRC *(www.ucprc.ucdavis.edu)* 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 (LCCA). 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 that 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[9] was conceived to resolve problems from lack of technology change in asphalt mix design, the need for improvements in concrete for pavement and bridges, improvements in operations, and lack of consistent and comprehensive information on long-term pavement performance *(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 that was not being made due to decades of often unfocused and incrementally funded work. 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, and operated by a temporary unit of the National Research Council. It was funded by states contributing 0.25 percent 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.[10]

Liv Haselbach of Lamar University (near recently flood-ravaged Houston) *(www.lamar.edu)* framed permeable pavement and other low-impact development (LID) as a flood control measure, particularly in watersheds that

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

[10] *www.trb.org/StrategicHighwayResearchProgram2SHRP2/Blank2.aspx*

include urban areas that exist in series within a watershed *(www.ucprc.ucdavis.edu/PDF/PermPvmt%202017/Haselbach_Stategic_Research_Program.pdf)*. An example of this type of watershed discussed was in east Texas along several major rivers going through urban areas. 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 stormwater flows increase for a given storm as the surfaces in urban areas geographically aligned within a watershed are paved and become impervious, while the stormwater facilities in each city along the river 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 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 in the 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 *(lowimpactdevelopment.org)* covered a range of topics. He noted that the same hydrologic performance metrics for bio-retention 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 having been 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.

Weinstein 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 a 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. The lowest lump sum bidding approach 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 does not 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 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 do not 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

The following is a summary of the breakout group discussions of the 76 questions shown in Appendix C. It is organized and expanded from the original topic areas of the 76 questions shown in Appendix C.

### *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 its successful use. At the site scale, guidance is needed on design practices for the civil engineers, hydraulic engineers, pavement/geotechnical engineers and landscape architects responsible for different aspects of permeable pavement implementation. Such information is available from ASCE and others, but knowledge of it is limited.

Additionally, ASCE needs to transcend the bifurcation of permeable pavements within two of its institutes—Transportation and Development—where pavement interests mostly lie, and Environment and 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. As a start, this guidance can be illustrated through successful permeable pavement case studies.

Permeable pavements require additional and different technical and administrative considerations than 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 identify where “corner cutting” results in problems.

This discussion was incorporated in the road map into Route 1.

### *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 within road agencies regarding performance and designs for low maintenance will help gain acceptance and reduce the 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 does not 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. The restrictions based on depth to groundwater table are an example of an obstacle that needs more scientific research regarding risk. 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, and information and practices to overcome those obstacles need to be developed. Documentation of how to successfully use permeable pavement as a BMP needs to be developed and made available. This information is available in diverse places but it has not been collected.

This discussion was incorporated in the road map into Route 1.

### *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, and it may double or triple 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 a 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 individuals 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 models for stormwater flow and water quality that identify areas with constraints on permeable pavement use as well as areas where it should be considered as an alternative to increasing the extent of 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 processes. These maps might identify land use and the 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 solution 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.

This discussion was incorporated in the road map into Route 1.

### *2.4.4 Planning and 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 any 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 the borders of parking areas at low points. The idea books should be backed up by documentation of multibenefit 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.

This discussion was incorporated in the road map into Route 2.

### *2.4.5 Costing and Cost-Decision Support*

Compared to conventional pavements, there a paucity of information available regarding initial and life cycle costs for permeable pavements 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 cost 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 that 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.[11] 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 was not.

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) *(www.bmpdatabase.org)*. Contributions to

[11] According to the 2018 Local Roads Needs Survey, the most commonly used pavement management systems in California are the following: StreetSaver (51%), MicroPaver (19%), no PMS (14%), Cartegraph (13%,) and other systems (13%).

this database are voluntary. It covers all BMPs, 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 US and Canada. As a result, performance data have been collected and published by the US EPA, state and local stormwater agencies, academia, ASCE, and industry.

This discussion was incorporated in the road map into Route 3.

#### *2.4.6 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 lifetime 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.

This discussion was incorporated in the road map into Route 4.

#### *2.4.7 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 these are capable of considering permeable pavements, the use of permeable pavements and their effects on flood management, and discharges to receiving waters, case studies should be undertaken to determine how permeable pavements can help to meet permit conditions and reduce flooding. Guidance should be developed for using these models when considering permeable pavements.

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

This discussion was incorporated in the road map into Route 5.

#### *2.4.8 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 comes from a few well-documented field studies that cover a range of applications. However, there is a pressing need for accelerated pavement testing (APT) and mechanistic modeling that will result 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 climate-region and subgrade permeability specific estimates of the time that the subgrade has a standing head above it, is saturated with no standing head, and is wet. They must also include the properties of different compacted soil types 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 APT. 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, are needed. Validation study results should be used to further improve the designs. This can be further improved with well-documented pilot demonstration projects in relatively low-risk locations as a start (rest stops, ramps, etc.).

This discussion was incorporated in the road map into Route 6.

#### *2.4.9 Materials and Pavement Performance*

Tests are needed to characterize the strength, stiffness, fatigue, permanent deformation properties of subgrades and permeable pavement materials for mechanistic-empirical (ME) 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.

This discussion was incorporated in the road map into Route 6.

#### *2.4.10 Construction Standards and Issues*

Continued contractor training and construction QC/QA are essential, as are 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 for enforcing the specifications. More training for material producers and contractors is needed, and consideration of the qualifications when selecting contractors is important.

In developing guidance for construction specifications, consideration should be given to including requirements that material manufacturers be involved with the contractor during construction until sufficient experience has been developed within the construction 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.

This discussion was incorporated in the road map into Route 7.

### *2.4.11 Maintenance*

Systematic collection of maintenance data and costs is needed, especially for surface cleaning, as well as for 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. In the breakout groups there was some disagreement as to whether existing information is insufficient, or if it is sufficient but has not been 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 surfaces (permeable pavers, pervious concrete, porous asphalt, pre-cast pervious concrete slabs).

Identification of best practices for restoring permeable pavement after accessing utilities is needed, as is 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. 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.

This discussion was incorporated in the road map into Route 8.

### 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 practices. 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 with 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, monitoring for stormwater quality to meet stormwater quality permit requirements where applicable, and monitoring of the 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 of permeable pavements is also needed to restrict storage of clogging materials, such as landscape debris and soil, on permeable pavements, as is identification of permeable pavements for street cleaning staff since permeable and impermeable pavements require different equipment and treatments.

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 judgment. Performance models can be improved once measurements of both become part of a standardized periodic condition data collection process for asset management. Most local governments do not currently have impermeable pavement performance models based on their own local data.

This discussion was incorporated in the road map into Route 9.

#### *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.

There is a need for training materials that can be given to combined audiences with different expertise areas. The materials should cover considerations related to the full multi-functionality of permeable pavement. Documented examples of permeable pavement successes are needed to illustrate the steps in planning, design, construction, and maintenance necessary to achieve success, and where possible to show 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.

This discussion was incorporated in the road map into Route 10.

### 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 are scattered training offerings 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 and include 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, both self-paced and live ones, 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.

This discussion was incorporated in the road map into Route 10.

### 2.4.15 Funding for Research, Development, Implementation

Funding sources for research to model and measure the performance of stormwater management infrastructure and practices have been uncoordinated and are scattered across industry, municipal, state, and federal sources. 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 clearinghouse 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 (NACTO), 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 relying on 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 does not 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.

This discussion was incorporated in the road map into Route 10.

## 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, including these two examples:
  - Integrated Stormwater Pavement Systems
  - Combined Stormwater Transportation Systems
- From the questions and group discussions in the workshop, it is clear that enough technical information for all the topic areas is available for practitioners to move ahead, while efforts are underway to fill gaps and update 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 usable 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 since invested in webinars and training materials. However, a larger effort that reaches users outside of ASCE spheres is required.
- 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.
- There is a need for a communications strategy to address all the audiences who require information for their work and that covers 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 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, development, and implementation work 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, which mandated technology transfer of permeable pavements within LTAP. Legislation in 2018 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.

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# 3 ROAD MAP

## 3.1 Routes, Projects, Estimated Costs and Durations

The road map developed by the Permeable Pavement Road Map Workshop is shown in the following tables. The road map is organized by the routes, which consist of a set of projects. Each route is intended to complete the goal for each topic area. The routes are presented roughly in the sequence of project delivery from organizational frameworks, planning, design, construction, maintenance, and asset management, followed by development and access to information and communication. Estimated cost and duration are provided for each project.

**Route 1. 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 2. 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 the 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 3. 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 agency, 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 and including 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 4. Reduction of target pollutants to meet water quality requirements.** Develop design decision trees/menus for reduction of target pollutants from existing and additional research. Include runoff reduction as an integral part of water quality management objectives and pollutant reduction credits.

**Route 5. Reduction of urban flooding risks.** Develop approaches for considering permeable pavement in flood models for use in zoning, planning, land development codes, and flood control design.

**Route 6. Reliable pavement structural designs.** Complete the 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 7. Routine achievement of high-quality construction.** Improve construction guide specifications, including improved construction methods, and quality control and quality assurance test methods and inspection protocols/checklists.

**Route 8. Maintenance and rehabilitation costs and methods.** Refine information regarding best practices for maintenance methods and their costs for different applications and make them widely available. Identify designs that minimize sediment transport and deposition to reduce required maintenance. Improve maintenance methods, including surface-cleaning techniques and equipment, and potential deicer use reduction. Identify best practices for hydrologic and structural rehabilitation and for reconstruction methods for aging permeable pavements.

**Route 9. Incorporation of permeable pavements into asset management systems.** Based on results from the five routes above, develop/refine asset management tools for stormwater agencies and road agencies. These should include inspection methods/standards, and maintenance costs. Concurrently, improve and, where possible, validate the quantitative performance models appropriate to each at the site scale, drainage system scale, and regional watershed (flood) scale.

**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 with practitioners, policy-makers, and other stakeholders. It also includes finding funding to execute this road map.

*Route 1: Infrastructure Management Organizations that Consider the Full Functionality of Permeable Pavements*

<u>Integration of Multi-Functional Priorities and Responsibilities</u>

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Reduce institutional barriers to use of permeable pavement<br><br>2. Common understanding of multiple functions and their requirements<br><br>3. Frameworks for roles, responsibilities, funding across different internal and external organizations 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 | 1a. 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 | 1b. Considerations for multi-functional streets and hardscape for urban planning, stormwater, pavement and flood control design, construction, maintenance, and asset management | | | |

Planning and Development Codes

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Produce and distribute guidance for updating planning and design codes<br><br>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 | 1c. Risk assessment for common code obstacles to use of permeable pavement | 18 months | $0.36 million | Consultants |
| | | | 1d. Guidance for reviewing urban planning code and practice considerations for multi-functional streets and hardscape | | | |
| | | | 1e. Guidance for reviewing stormwater design code and practice considerations for multi-functional streets and hardscape | | | |
| | | | 1f. Pavement design code and practice considerations for multi-functional streets and hardscape | | | |
| | | | 1g. 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. | 1h. Guidance and case study examples for the complete project delivery process for permeable pavements | | | |

*Route 2: Planning Guidance that Considers the Multi-Functionality of Permeable Pavements*

<u>Comprehensive Planning</u>

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 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 regarding opportunities and obstacles for using permeable pavement, including use and maintenance through the life cycle of the infrastructure | 2a. 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 |
| | | | 2b. 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 | 2c. Integration of climate change projections into transportation and stormwater-handling plans, considering use of permeable hardscape | | | |
| | | | 2d. Use of modeling to create and update planning maps for stormwater quality and flood management, considering use of permeable hardscape | | | |
| | | | 2e. Guidance for creating planning maps and checklists for use of permeable pavement for stormwater and transportation functionality | | | |
| | | | 2f. Case studies of creating planning maps and checklists for use of permeable pavement for stormwater and transportation functionality | | | |

Planning and Designing for Additional Benefits and Impacts

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Provide guidance for identifying full-system multi-functionality benefits and impacts of systems with permeable pavement<br><br>2. Information regarding long-term performance of environmental benefits<br><br>3. Provide design sketch books for systems capturing maximum functionality and long-term performance. | Summary guidance for identifying additional benefits and impacts | Summarize existing information into comprehensive guidance for benefits beyond transportation, stormwater quality and flood control | 2g. Guidance for designing maximum benefits into projects using permeable pavements | 18 months | $0.48 million | University or consultants |
| | | | 2h. 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 | 2i. Long-term environmental benefits performance of permeable pavement systems | | | |
| | 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 | 2j. Effects of pavement design and maintenance on human comfort during active transportation under different conditions | | | |
| | | | 2k. 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 | 2l. Design sketch book for use of permeable pavements to create better places | | | |

*Route 3: Accurate Life Cycle Cost Analysis and Environmental Life Cycle Assessment Tools*

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Produce and deliver framework, data and tools for initial and life cycle costing of permeable pavement as part of multi-functional systems<br><br>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 | 3a. 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 |
| | | | 3b. 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) | | | |
| | | | 3c. 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 | 3d. Guidelines and examples for developing performance and cost data for life cycle cost analysis of permeable pavements for stormwater and transportation functionality | | | |

*Route 4: Reduction of Target Pollutants to Meet Water Quality Requirements*

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Fill gaps in information and develop models for stormwater quality performance of permeable pavements<br><br>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 | 4a. 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 |
| | | | 4b. Investigation of transport and fate of regulated stormwater pollutants for permeable pavement over its life cycle based on modeling | | | |
| | | | 4c. 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 | 4d. Design models and tool for use of permeable pavement to manage stormwater pollutants | | | |
| | | | 4e. Example case studies of modeling of transport and fate of stormwater pollutants for permeable streets and hardscape | | | |
| | Guidance for designing permeable pavements to meet stormwater quality permit requirements | Develop guidance for use in design practice for effects of permeable pavement on transport and fate of stormwater pollutants | 4f. Guidance for use of permeable pavement to manage stormwater pollutants | | | |
| | | | 4g. Example case studies for design of permeable streets and hardscape for managing stormwater pollutants | | | |

*Route 5: Reduction of Urban Flooding Risks*

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Fill gaps in information and develop models for flood control performance of permeable pavements<br><br>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 lifetime, perform research to fill gaps, produce guidance and case studies | 5a. 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 |
| | | | 5b. Investigation and guidelines for design for localized flood control using permeable pavement considering the full life cycle | | | |
| | | | 5c. 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 lifetime, perform research to fill gaps, produce guidance and case studies | 5d. Summary from the literature and available modeling of localized flood control for permeable pavement over its life cycle | | | |
| | | | 5e. Investigation and guidelines for design for localized flood control using permeable pavement considering the full life cycle | | | |
| | | | 5f. 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 6: Reliable Pavement Structural Designs*

<u>Pavement Structural Design Approaches</u>

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Fill gaps, validate mechanistic-empirical models, designs and tools<br><br>2. Produce and distribute for information and tests for site investigations for new pavement and multi-functional performance evaluations for existing pavements<br><br>3. Produce new or improved materials and structure designs<br><br>4. Develop and distribute information about design considering the existing built environment<br><br>5. Provide guidance and case studies for the overall design and delivery process | Mechanistic-empirical (ME) 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) | 6a. 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 |

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| | Sufficient validation of ME models of permeable pavements for structural capacity under heavy loads | Identify pavement types and features needing validation and perform comprehensive evaluation including accelerated pavement testing and field monitoring | 6b. 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 | | | |
| | | | 6c. Long-term field validation of permeable pavement types and design features | | | |
| | | | 6d. 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 | 6e. Guidance for site investigations for design of permeable pavements, with examples | | | |
| | Guidance for structural and stormwater evaluation for existing permeable pavements | Develop test methods and processes for evaluation of existing permeable pavements, guidance, and examples | 6f. Test methods and processes for evaluation of stormwater functionality for permeable pavements | | | |
| | | | 6g. Guidance for evaluation of stormwater functionality of permeable pavements | | | |
| | | | 6h. 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 | 6i. 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 | | | |

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| | 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 | 6j. Performance of interaction of permeable pavements and underground structures | | | |
| | | | 6k. Performance of designs for combined permeable and impermeable pavements, including shoulder retrofits | | | |
| | | | 6l. Performance of permeable pavements containing underground utilities | | | |
| | | | 6m. Guidance on design of permeable pavements near underground structures and impermeable pavements, and permeable pavements containing underground utilities | | | |
| | | | 6n. Long-term field performance of permeable pavements near underground structures and impermeable pavements, and permeable pavements 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 | 6o. Comprehensive design guidance for permeable pavements | | | |
| | | | 6p. Examples of good and bad practice for design of permeable pavement | | | |

Materials and Pavement Performance

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Identify and improve tests for materials and pavement<br><br>2. Identify and improve best practices for materials design | Good tests to characterize strength, stiffness, fatigue, permanent deformation properties of subgrades and permeable pavement materials for ME design | Identify best practice for testing in the laboratory and in the field for materials and structures. Develop new tests if needed. | 6q. Best practice and gaps for performance related laboratory and field tests for permeable pavement materials and structures | 24 months | $1.6 million | University research |
| | | | 6r. New laboratory and field tests for permeable pavement materials and structures | | | |
| | | | 6s. 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 | 6t. Optimization of asphalt mix designs for permeable pavement under different conditions. | | | |
| | | | 6u. Optimization of pervious concrete mix designs for permeable pavement under different conditions | | | |
| | | | 6v. Optimization of surface layers for permeable pavers under different conditions | | | |
| | | | 6w. 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 | 6x. Guidance for permeable pavement design and operations under snow and ice conditions | | | |

*Route 7: Routine Achievement of High-Quality Construction*

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Develop and distribute guidance for specifications, inspection, and traffic-handling for permeable pavement<br><br>2. Develop and distribute guidance for pre-qualifying designers and contractors<br><br>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 | 7a. Example construction specifications for multi-functional permeable pavements | 24 months | $0.6 million | Consultants |
| | Guidelines for pre-qualifying designers and contractors | Work with experienced owners and industry to prepare guidelines, make available | 7b. Guidelines for pre-qualification of designers and contractors for multi-functional permeable pavements | | | |
| | Guidance regarding construction sequencing and traffic management in urban areas | Work with experienced owners and industry to prepare guidelines, make available | 7c. Guidance for construction sequencing and traffic-handling for urban permeable pavement systems | | | |
| | Training information for certification of permeable pavement inspectors | Work with experienced owners and industry to prepare inspection training, make available | 7d. 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. | 7e. Best practice and gaps for performance-related laboratory and field tests for construction quality control of permeable pavement materials and structures | | | |
| | | | 7f. New laboratory and field tests for construction quality control of permeable pavement materials and structures | | | |
| | | | 7g. Guidance for laboratory and field testing for construction quality control of permeable pavement materials and structures | | | |

*Route 8: Maintenance and Rehabilitation Costs and Methods*

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Collect, summarize and distribute comprehensive information regarding best practices for maintenance<br><br>2. Develop and use system for collecting cost and performance information<br><br>3. Develop tests for maintenance effectiveness<br><br>4. Develop and make available best practices for utility cuts in permeable pavements | Comprehensive information regarding maintenance schedules and typical costs | Establish 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. | 8a. 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 |
| | | | 8b. Recommendations for inclusion of permeable pavement in standard cost data collection processes | | | |
| | Comprehensive guidance for best practices for maintenance and cleaning of permeable pavements | Work with experienced owners and industry to gather existing information, prepare guidelines, make available | 8c. Guidance for best practices for maintenance and cleaning of permeable pavement as part of low-impact development infrastructure across climate types | | | |
| | | | 8d. Tests and practice for rapid measurement of permeable pavement infiltration for quality control of maintenance | | | |
| | | | 8e. Example standard specifications and contract language for contracting maintenance of permeable pavement | | | |
| | | | 8f. Summary of permeable pavement surface cleaning technologies | | | |

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| | 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 | 8g. Comprehensive guidance and example plans and specifications for restoration of utility cuts in permeable pavement | | | |
| | | | 8h. Training for inspection of restoration of utility cuts in permeable pavement | | | |

*Route 9: Incorporation of Permeable Pavements into Asset Management Systems*

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Develop best practices for organizational arrangements within local government for asset management for multi-functional low impact infrastructure<br><br>2. Develop best practices for inclusion of multi-functional low impact infrastructure in asset management systems<br><br>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 does not work, make available. | 9a. 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 |
| | | | 9b. 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 | 9c. Guidance for inclusion of permeable pavement and other multi-functional low-impact infrastructure in asset management systems | | | |
| | | | 9d. Condition survey measures for asset management of multi-functional permeable pavement and other low-impact infrastructure | | | |
| | | | 9e. 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 | | | |
| | | | 9f. Guidance for development of performance equations and decision trees for permeable pavement and other low-impact infrastructure in asset management systems, with case studies | | | |

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| | | | 9g. 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 | 9h. Guidance for rehabilitation and reconstruction of permeable pavement | | | |
| | | | 9i. Training for rehabilitation and reconstruction of permeable pavement | | | |

*Route 10: Efficient and Comprehensive Access to the Best Information*

<u>Communication between Industries and Users</u>

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Create a communications and publications plan for permeable pavement information, and execute it<br><br>2. Create and operate a clearinghouse for information on permeable pavement | Create a clearinghouse and an integrated communications and publications program, working with other existing organizations | Develop a communications and publications 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<br><br>10b. Set up clearinghouse and operate publications 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 |

Education and Training

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Create and operate a professional training and certification program for permeable pavement<br><br>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, a 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). This should cover topics across all functional areas and explain how to organize resources to deliver and maintain permeable pavement and other low-impact infrastructure | 12 months | $0.35 million | Universities with pavement and stormwater expertise |
| | | | 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 | | | |
| | 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 | | | |

Funding for Research, Development, Implementation

| Objectives | Gap | Approach to Fill Gap | Proposed Projects | Timeline | Estimated Cost | Who Should Do It |
|---|---|---|---|---|---|---|
| 1. Produce and communicate a comprehensive road map for achieving full implementation potential for permeable pavement<br><br>2. Identify and organize stakeholders to fund execution of the road map<br><br>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 | 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) | 48 months<br><br>Notes:<br>10f. done<br>10g., 10h. 1 year | \$0.75 million<br><br>Notes:<br>10f. already paid by industry | Universities |
| | | | 10g. Identify and organize stakeholders and potential funding organizations to develop funding plan to deliver program in road map | | | |
| | | | 10h. Develop funding | | | |
| | 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 website 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 communicate extensively with 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.

# APPENDIX 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 | Barton & Loguidice, 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 lglitter 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 University |
| Keith | Lichten | SF Bay Regional Water Board |
| David | Liguori | Bay Area Pervious Concrete |

| First name | Last name | Organization |
|---|---|---|
| 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

# APPENDIX B: WORKSHOP PROGRAM

| **Tuesday November 14**<br>**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<br>*John Harvey* | 1.20 to 1.35 |
| Pavement industry perspectives | Thoughts on the future of permeable pavement from materials producer and contractor perspectives, meeting pavement and stormwater needs<br>*Richard Willis (NAPA), David Smith(ICPI), Brian Killingsworth (NRMCA)* | 1.35 to 1.55 |
| 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?<br>*Amir Ehsaei (speaking)/Tom Sweet, AECOM* | 1.55 to 2.10 |
| 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?<br>*Janet Attarian, City of Detroit* | 2.10 to 2.25 |
| Stormwater regulation and codes | What do pavement people need to know about stormwater regulation, codes, and basic stormwater considerations?<br>*Keith Lichten, California Water Board* | 2.25 to 2.40 |
| Design, maintenance and performance | What are gaps regarding permeable pavement design, maintenance, and performance, for vehicle traveled ways and other urban hardscapes?<br>*Dave Hein, ARA* | 2.40 to 2.55 |
| 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?<br>*Mike Adamow, San Francisco Public Utilities Commission* | 3.15 to 3.30 |

| | | |
|---|---|---|
| Life cycle cost analysis | Is the framework correct (just pavement or does it capture off-site benefits and costs)? Do we have the numbers for both permeable pavement and other BMPs?<br>*Dave Hein, ARA* | |
| Life cycle assessment (LCA) and other demands 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?<br>*John Harvey* | 3.45 to 4.00 |
| 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?<br>*Mike Carlson, Contra Costa County Flood Control and Water Conservation District* | 4.00 to 4.15 |
| What about a Strategic Permeable Pavement Research Program | What was SHRP and SHRP2? First cut: what are the biggest questions? Pavements and stormwater<br>*John Harvey, Liv Haselbach, and Neil Weinstein* | 4.15 to 4.35 |
| 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**<br>**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 what did we miss)? | Small groups with facilitator, student scribe for each subject area | 8.15 to 10.00 (get organized then 3 × 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 minute sessions | | |
| Lunch | | 12.00 to 1.00 |
| Reports back | Facilitator, student scribe | 1.00 to 2.30 (10 reports × 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 |

# APPENDIX 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 deicing 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, and 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), and 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 into 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 has permeable pavement been widely used in other countries for many years, more than in the US? What is different? Can this be changed? | AB |

| # | Category | Question | Asked by |
|---|---|---|---|
| 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 be included in considerations about use of funding? If yes, how? If not, why? | JA |
| 20 | Communication | Is there adequate information regarding the probabilities of different types of failures of permeable pavements that can 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 it 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 perform 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 geogrids 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 the specifications 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? Are there adequate guidance and standards for geotechnical investigations? If not, how to develop? If yes, how to understand and communicate and to communicate scope versus 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 |

| # | Category | Question | Asked by |
|---|---|---|---|
| 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 not, 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, deicing, 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 the ratio of impervious to pervious surfaces for water quality and stormwater flow management? If not, 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 subsurface 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, and 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 |

| # | Category | Question | Asked by |
|---|---|---|---|
| 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 are there not 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 research, development, and information? 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 | JH, JBuck |

| # | Category | Question | Asked by |
|---|---|---|---|
| | | BMP selection/design process? Can credits for handling stormwater be included in development systems? | |
| 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 |

## APPENDIX 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 | Riverside County Flood Control and Water District | 1 | | | | | | |
| Anne | Quasarano | City of Fremont | 1 | | | | | | |
| Carlson | Michael | Contra Costa County | 1 | | | | | | |
| Hui | Li | Tongji University | 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 | Riverside County Flood Control and Water District | 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 | 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 | | | | | | |