PLANNING FOR RESILIENCE

PAGE 6

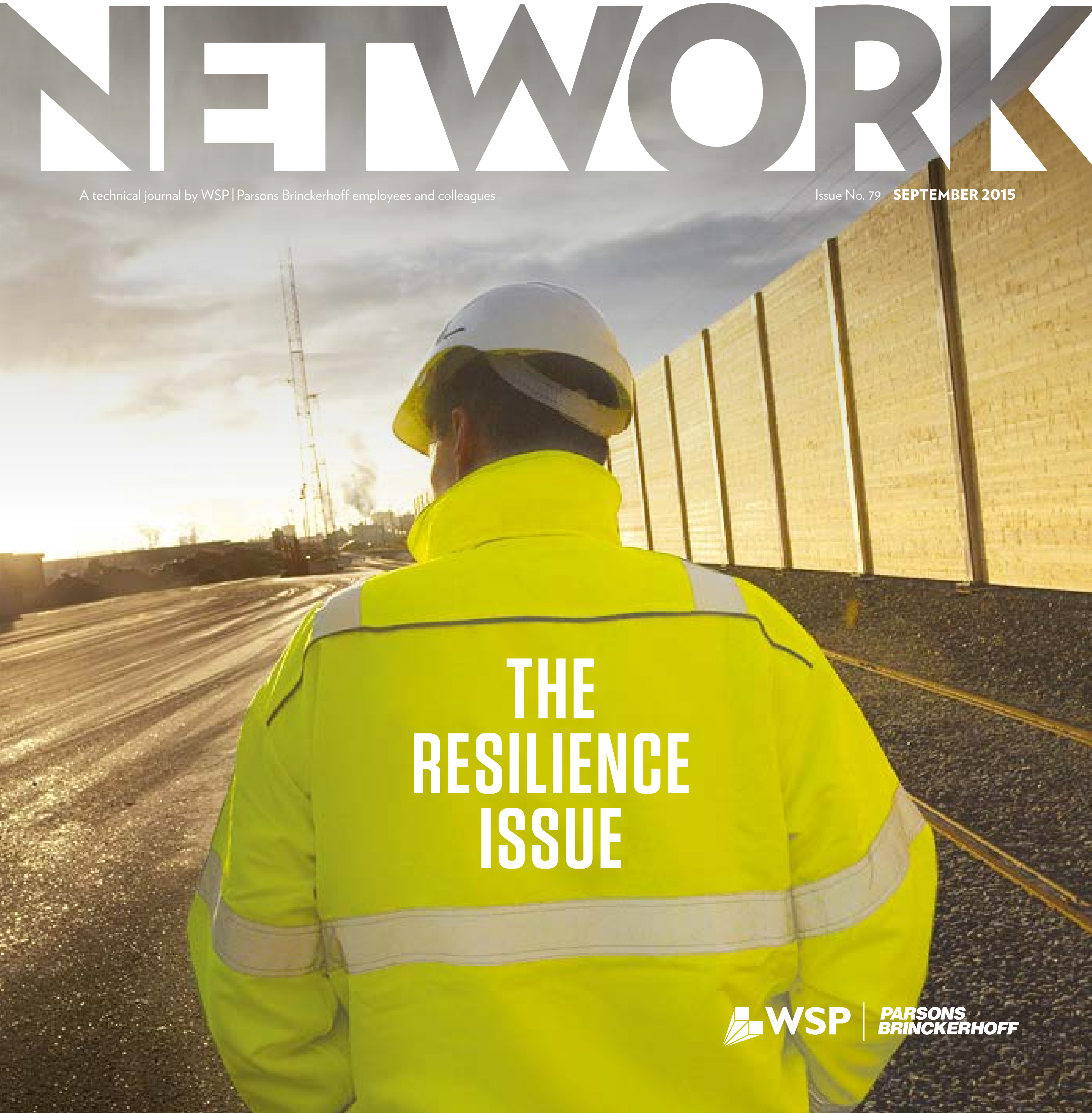
CENTRAL PARK: SUSTAINABLE, LIVEABLE, RESILIENT, AND FUTURE READY

PAGE 28

U.K. INFRASTRUCTURE: CAN WE COPE WITH FLOODING?

PAGE 84

# NETWORK



A technical journal by WSP | Parsons Brinckerhoff employees and colleagues

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# THE RESILIENCE ISSUE

WSP | PARSONS BRINCKERHOFF

NETWORK

**NETWORK** is the technical journal of WSP | Parsons Brinckerhoff. The publication presents unique technical solutions applied to real-world problems. Each issue discusses a specific theme and its application in our various sectors and specializations, on a global scale. **NETWORK** is also available online: network.wsp-pbworld.com.

## THE RESILIENCE ISSUE

WSP | Parsons Brinckerhoff is helping communities build or improve their ability to "bounce back" after hazardous events, extreme weather, climate change, blasts, flooding, and other shocks. This "resilience" publication contains over 30 articles and case studies about improving the resilience of our built environment against a variety of disruptions.

## INTRODUCTION



## CONCEPTS



## PROPERTY AND BUILDINGS



## TRANSPORTATION AND INFRASTRUCTURE

### BRIDGES/TUNNELS

# PLANNING FOR RESILIENCE

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EFFECTIVE RESILIENCE PLANNING CAN ENSURE THAT THE WORK WE DO CONTINUES TO FUNCTION WELL INTO THE FUTURE.

## OVERVIEW

Resilience is the capacity to withstand stress and catastrophe. This article gives an introduction and overview to resilience, and explores some of the potential resilience responses to impacts from change. It stresses that change at the macro level affects all of our projects and clients, and that with effective planning we can ensure the work that we carry out for our clients is resilient in a changing future.

## RESILIENCE PLANNING AND SYSTEMS THINKING

Resilience planning has its roots in systems thinking[1], risk reduction, and sustainability. A technical definition of resilience is "the ability of a system to absorb disturbances and still retain its basic function and structure" (Walker and Salt, 2006). Terms describing the opposite of resilience include fragility, vulnerability, and weakness, so clearly a resilient system is a desirable state.

Almost anything you can think of can be considered as a system. At its simplest, a system is a group of components, within a defined boundary that are interdependent and continually interact with each other to maintain the purpose of the system. Components include structures, processes, people, and policies, which are generally grouped into subsystems, effectively smaller systems with their own function. Systems nest like Russian dolls: a human (a system in its own right) controls a mechanical/electrical system (which relies on the human system functioning correctly), which is part of a building system, which is part of an organizational system, which is in turn part of a national economy – and so on (see Figure 1). A system is frequently disturbed (negatively or positively) by the outputs of another system which it cannot control.

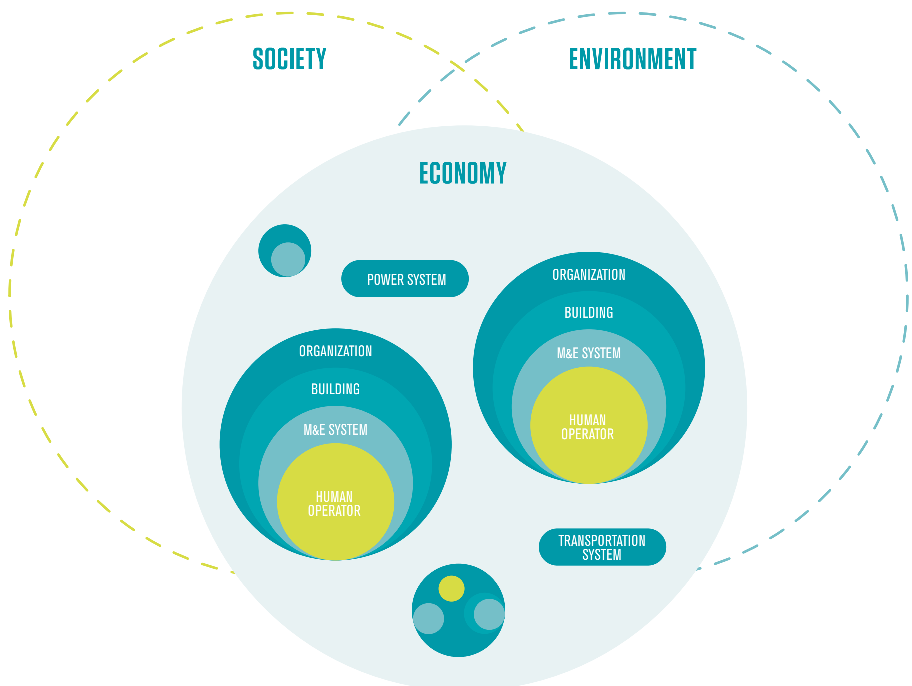


**FIGURE 1** - SYSTEMS NEST LIKE RUSSIAN DOLLS AS PART OF THE NATIONAL ECONOMY

In systems thinking, the boundary of the system is generally defined at a level suitable for the particular purpose under consideration. However problems arise when the system is defined at too low a level and subsystems get looked at in isolation, so-called silo thinking. Systems integration and collaborative working are accepted methods to ensure subsystems are properly integrated and mutually supportive to the overall system.

[1] Systems thinking is a discipline that helps build an understanding of how a system functions by determining what components make up the system, and then examining the links and interactions between the components. It helps to avoid unintended consequences when one part of the system is altered.

## USING SYSTEMS KNOWLEDGE TO BUILD RESILIENCE

As a professional services company, WSP | Parsons Brinckerhoff is focussed on systems involving buildings, infrastructure, and organisations. We are technical experts in many of the components and subsystems that make up these systems. We add value for our clients by helping them to design 'in' resilience through planning for the future, and we do this by sharing our understanding of trends in the social, natural, and political macro systems in which their projects and organisations sit. It is the disturbances caused by trends in these systems (which we can influence but not control) that impact the systems on which we work. We can summarise these macro trends as climate change, future resource availability, ecosystem services, social trends, and technological change.

As the case studies elsewhere in this publication show, WSP | Parsons Brinckerhoff works with clients to analyse the potential disturbances generated by these trends, and the positive and negative impacts these may have on the components and subsystems of the system on which we are working. We then prioritise the risks and opportunities identified, and propose technical, operational, and strategic approaches to manage them. In some of our more strategic projects, we then combine these into a resilience plan that is phased and prioritised as appropriate for their circumstances.

## RESILIENCE RESPONSES TO RISK

We can identify a number of typologies of possible responses to risk that will build resilience.

- Acceptance – usually where the severity of the disturbance grows slowly and where it is possible to monitor and review the vulnerability that ensues. This should not be confused with complacency – some trends such as climate change are nonlinear, and severe events can outstrip impact curve predictions. The tidal surge which disrupted the main London–West Country railway by washing out the line at Dawlish is an example of a nonlinear event (see "U.K. Infrastructure: Can We Cope with Flooding?" in this issue.)
- Protection – building defences like levees and polders. These have critical thresholds, and failures such as overtopping can be catastrophic (see "Lake Mälaren, Sweden: The Consequences of Flooding" in this issue.)
- Avoidance – where it is not possible to protect against the risk, or where the economic cost of protection is too high. Examples of this include managed retreat from coastal erosion zones which are too expensive to defend.
- Accommodation – designing a system so it can be recovered within an acceptable timescale after a disturbance – duplication of safety critical systems, or sacrificial ground floors which the system can cope without temporarily, but can be restored to use after a flood.
- Adaptation – temporary or permanent, doing things differently for the same result. Examples include introducing thermal mass into an existing building for cooling, or converting offices to dormitories when hospital staff cannot pass flooded roads.
- Multi-purposing and flexibility – having components that can do more than one thing, and (continued on page 9)

# EXPLORING RESILIENCE

We can explore resilience in more detail, and introduce some resilience planning terminology, using the analogy of two humans, each in their own right a system. A dancer and an author - each broke a leg on a winter skiing holiday. Each earns a living and satisfies creative instincts through their work - the particular **purpose** of the two human systems we are considering.

The potential for resilience or a catastrophic failure of a system after a disturbance is determined by a combination of four factors:

- Duration of the disturbance;
- Breadth of the disturbance – how many components in the system are disrupted;
- Severity of the disturbance – how much does it stop the system functioning; and
- Adaptive and /or transformative capacity of the system.

Both the dancer and author have disturbance to the same, single component (the leg), preventing them from walking for about 6 weeks – the **duration** of the disturbance. But the **breadth** and **severity** of the disturbance differs for each. For the author the breadth and severity are less, as they can work sitting down, communicate via IT, and be driven around by others. The impact is much broader for the dancer, who relies on mobility and agility to work, and for whom the overall significance of the disturbance is much more significant.

After the accident, **temporary adaptation** measures help the author to maintain mobility – plaster casts, crutches, and wheelchairs. This will suffice, the author can fulfil most main functions until the disturbance ends and the leg heals. The author's story ends here.

However the dancer, who can also maintain mobility using these adaptations, cannot use them to dance. The dancer is now a **component** with impaired performance in a larger system, the dance company. The company can accept this disturbance for a short period, as it has planned for resilience and has **redundant components** – the understudy in this case - that can fulfil the same role as a failed component, so the show goes on. The dancer undertakes another **temporary adaptation**, changing duties to teach students, so they still have some value in the wider system whilst recovering.

Sadly, after 3 months the dancer realises the leg has not regained sufficient strength for a professional career - **a critical threshold / tipping point** has been reached. The system cannot go on as before. The dance company's employment contract sets out **a service level threshold** –of three months as the acceptable limit for sick leave. So it cancels the dancer's contract, promotes the understudy, and its system purpose is maintained.

The dancer could make a **permanent adaptation**, accepting a lower wage but remaining in the same system by becoming a dance teacher. Alternatively, the dancer may take a **transformative** approach, spotting a niche opportunity to retrain as an artistic blacksmith, which makes use of strength and artistic skills and, after a considerable salary dip, it eventually delivers a higher income. Through **flexibility**, the former dancer has completely changed the way their system works and, after the disruption, has better achieved their purpose. And of course, had the dancer undertaken resilience planning for their career, a backup plan and savings may have been in place to avoid a **catastrophic system failure** in the ability to earn a living.

Could the disruption have been prevented in the first place? The author chose to **accept the risk** of disturbance as the potential impact of a broken leg was low. The dancer didn't think about it, and suboptimal decision-making resulted in the permanent change to the way they functioned. Undertaking a **risk evaluation** might have led them to **avoid** the risk by going on a different holiday. The dancer used **risk protection** – sophisticated bindings and a crash helmet. But this gave a false confidence, and the dancer did not understand the **level of risk**, instead deciding to have a quick attempt at some moguls on the first trip down a slope. The dancer also failed to consider the effects of **multiple disturbance interactions** – having a lot of schnapps the previous evening did not improve skill level or co-ordination!

## "AT THE HEART OF RESILIENCE THINKING IS A VERY SIMPLE NOTION - THINGS CHANGE - AND TO IGNORE OR RESIST THIS CHANGE IS TO INCREASE OUR VULNERABILITY AND FOREGO EMERGING OPPORTUNITIES."

- WALKER AND SALT

can stand in for another damaged component. An example would be a rail bridge that can also be used as a vehicle evacuation route (see "Adapting the Lower Deck of an Existing Bridge for Light Rail Operation and Typhoon Conditions" in this issue.)

- Transformation – repurposing the system as needs change. For example, using electric vehicles as mass batteries to balance grid demand, charging or discharging according to need.

## SEVEN KEY POINTS FOR RESILIENCE PLANNING

There are seven key points to consider when it comes to resilience planning:

1. 'Systems thinking' forms the basis for resilience planning.
2. It is necessary to define a system boundary at the right level and to make sure teams working on subsystems collaborate to get optimal functioning in any system.
3. Resilience planning requires a detailed technical, governance, and operational understanding of how a system works, together with an understanding of how macro systems are likely to disturb it.
4. Disturbances can interact, multiplying their impacts.
5. It is important to learn from previous disruptions and by looking at how others successfully managed risk. Innovation can be part of resilience, but is not always essential. However, the impact of the same disturbance in the same location varies depending on the system it affects. Therefore there is no "set" response to any disturbance, although a typology of responses is helpful.
6. Risk can be non-linear – gradual rises in disturbance have gradual effects until a tipping point occurs and the system cannot function as it did. The effects after tipping points reached are hard to predict.
7. The absolutely fundamental point – change in macro systems is a given, and resilience depends on being able to anticipate and cater for the impacts it causes. Trusting to luck is not the same as planning for resilience!

## IN CONCLUSION

As Walker and Salt note: "At the heart of resilience thinking is a very simple notion – things change – and to ignore or resist this change is to increase our vulnerability and forego emerging opportunities. In so doing, we limit our options. Sometimes changes are slow (…); sometimes they are fast (…). Humans are usually good at noticing and responding to rapid change. Unfortunately, we are not so good at responding to things that change slowly. In part this is because we don't notice them and in part it's because often there seems little we can do about them". (Walker and Salt, 2006, pp.9-10)

As later case studies in Network Issue 79 show, we can set out to understand and predict change, and we can help to plan for resilience. Our examples show that with the right combination of collaboration, systems understanding, trend and impact knowledge, and technical, operational and strategic expertise, we can plan effective responses to change and make current systems more resilient.

***Lynne Ceeney*** *is Global Head of Sustainability and is based in WSP | Parsons Brinckerhoff's London office. Her interest in systems thinking and resilience comes from her work on complex projects at the organisational, city, and regional scales, where ensuring their future well-being requires an expert understanding of trends that will impact current assets, projects, and objectives. She prefers resilience planning to reliance on luck.*

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# RESILIENCY PLANNING IN THE U.S. – AN OVERVIEW

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RESILIENCY: THE RESULT OF AGENCIES TAKING APPROPRIATE ACTION(S) TO ENSURE THAT A SOCIETY CAN CONTINUE TO FUNCTION EFFECTIVELY AFTER A SIGNIFICANT EVENT OR IN RESPONSE TO A LONG-TERM CHANGE OF CONDITIONS.

There is a heightened interest in ensuring the long-term resiliency of communities. Public agencies in the United States, particularly those in the most vulnerable areas, are paying closer attention to the impacts and risks posed by climate change, severe weather, and other natural disasters. They are focusing increased attention on questions of resiliency in the face of threats ranging from coastal sea level rise and storm surge to inland flooding and tornadic winds; from heat waves and drought conditions to dust storms and forest fires; from the slower but no less impactful effects of long-term climate change to the more immediate impacts of extreme weather and naturally occurring disasters.

Some areas (the New York region, Vermont, Colorado, coastal Louisiana and others) are still recovering from specific events that have reshaped entire communities and created a much heightened awareness of the vital importance of infrastructure to ensure long-term community resiliency. In California and Texas, off-the-charts weather conditions have caused many to re-think the assumptions that were the foundation for future-oriented planning, and to consider designing resilience into the infrastructure they depend upon. These realities are the same around the globe where significant weather events and longer-term climatic changes are reshaping approaches to a more resilient built environment.

While professionals seek to apply existing and new data-driven tools to identify the most appropriate responses to a changing environment, the entire resiliency field is experiencing rapid development, spurred by the dearth of accepted and approved technical approaches that incorporate future risk into planning and design.

It is also a reality of resiliency, looking forward to the future, that there are fairly large uncertainties associated with the likelihood of different system conditions occurring given the range of potential climate-related impacts. Any approach that addresses resiliency needs to therefore be based on a few principles that can help guide agency processes that recognize these uncertainties.

## ASSESSING THE IMPLICATIONS OF ASSET FAILURE

The methods used to assess the implications of asset failure, in terms of potential loss to a community or agency, need to address the impact of such losses in ways that rarely, if ever, drove decision-making in the past. These methods need to explicitly include the quantifiable impacts to economic vitality, natural and environmental resources, and quality of life. The long-term effects of recent extreme weather events extended beyond those most immediate and observable, suggesting that such broader impacts need to be an explicit part of resiliency planning for all projects moving forward.

Risk-based approaches to resiliency will vary by the contexts and character of communities, and by the relative importance of assets serving these communities. This must be considered when tailoring a risk assessment approach for particular projects. Tools exist that do this for transportation-related infrastructure, and other tools are emerging that better define and predict the broader economic, social, and environmental benefits of resiliency-related transportation infrastructure investment. Combining engineering knowledge with economic values of benefit or loss facilitates the quantification of risk. It is a useful direction in which resiliency planning is heading.

## INCORPORATING UNCERTAINTIES INTO APPROACHES

The range of projections of future climate conditions represents a significant challenge to resiliency planning. Disparities in forecasted sea level rise are well-known. Similar uncertainties are inherent in projections of other climactic conditions, extreme weather, and natural events. However, projections, when appropriately utilized, can provide a means to bound the range of future potential impacts (example – establish high, medium, and low potential sea level values). In areas where this range indicates significant potential effect, more sophisticated approaches (such as Monte Carlo simulations) provide a way to understand and address the implications of these uncertainties on crucial decisions that need to be made.

The use of these projections must recognize and reflect the inherent underlying uncertainties that stem from two key factors.

- The first is variability in future projections that stem from differing assumptions on future potential conditions (for example - greenhouse gas emissions scenarios), and
- The second reflects the inherent variability and uncertainty of the model outcomes themselves.

This broad range of uncertainty represents a key consideration in using future projected data and applying modeled future scenarios toward the goal of effective decision-making. Practitioners must incorporate this uncertainty into planning and design in ways that are rarely considered or applied in current practice.

## PLANNING FOR RESILIENCY

In sum, resiliency planning for better informed engineering and agency resource allocation is evolving rapidly and changing the way we develop and implement infrastructure plans and projects. While broad principles apply, there is currently no single accepted solution. Each context calls for a tailored approach. New methods and data sources are emerging for quantifying and incorporating a broader range of economic, environmental, and quality of life factors. But at the same time, significant questions remain about the variability of data and the forecasts which they influence.

In the end, even with state-of-the-art approaches to resiliency planning and design, there is no substitute for good judgment drawn from a rapidly expanding body of knowledge – a body of knowledge reflected in this volume by the array of individual articles by WSP | Parsons Brinckerhoff colleagues.

The articles that follow, based on leading edge thinking and professional experience, include approaches that reflect the key principles and practices that build resiliency. They are written by professionals who represent a range of backgrounds and professional interests and who provide varying perspectives on resilience - perspectives that consider risk, vulnerability, failure, and emerging changes in analysis and design methods.

***Michael Flood** is National Resiliency Lead for Parsons Brinckerhoff, now part of WSP | Parsons Brinckerhoff. His work, with a team of professionals from within the organization, is to help infrastructure agencies, facility managers, and communities achieve long-term resiliency.*

HURRICANE SANDY (ALSO KNOWN AS "SUPERSTORM SANDY") WAS A CATASTROPHIC EVENT FOR THE NEW YORK METROPOLITAN REGION IN OCTOBER 2012 RESULTING IN AN ESTIMATED U.S.$70 BILLION IN DAMAGE. IT DEVASTATED NEIGHBORHOODS, COASTLINES, AND CRITICAL INFRASTRUCTURE THROUGHOUT THE NY REGION AND HIGHLIGHTED THE REALITY THAT MANY CITIES ARE UNPREPARED FOR EXTREME WEATHER EVENTS AS THEY HAVE NOT FULLY DEFINED THE BROADER IMPLICATIONS OF SUCH EVENTS.

# INTEGRATED URBAN STRATEGIES IN THE RESILIENCE FRAMEWORK

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A PLANNING APPROACH THAT CONFRONTS THE CHALLENGES OF URBAN RESILIENCY BY INCORPORATING ENGINEERING EXPERTISE AT THE BEGINNING OF THE PLANNING PROCESS IS DISCUSSED, AND EXAMPLES OF PROJECTS IN NEW YORK CITY WHERE THIS APPROACH HAS BEEN USED ARE PRESENTED.

We live in an era of tremendous change and challenge. The past 50 years have witnessed both a doubling of the global population and a paradigm shift from rural to urban living. Global population is projected to surpass 9 billion by 2050, with 70 percent of the world living in urban locations. At the same time, consumption rates outpace the planet's natural resource production; our carbon footprint exceeds 330 parts per million, a level not seen on this planet in the past 10,000 years; climate change and the risk of extreme weather events are threatening economies; rising sea levels claim urban land area; and rising global temperatures increase the risk of drought and storm intensity. The political and financial power to effectuate change lies within vulnerable cities, as does the burden to move forward quickly.

Enhancing the resiliency of our cities needs to begin at the visioning stage, before individual projects are conceptualized. To confront the challenges of urban resiliency, Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) has seen success by embedding engineering and technical expertise into the planning process, a brand of planning we term Integrated Urban Strategies (IUS). Involving engineers at the beginning adds value to the development of visions. These visions are in turn grounded in sound engineering that helps progress projects through a more rigorous and connected feasibility analysis from the outset. Engineers and planners need to work side by side to solve the increasingly complex challenges faced by our cities. IUS represents a team of planners and engineers putting forth community-supported, actionable projects that achieve multiple-benefits for a community's resiliency and quality-of-life needs both today and in the future. IUS is a brand of planning well suited to resiliency planning in that it achieves risk-reduction benefits while at the same time viewing the community as an holistic series of inter-connected systems. IUS results in achievable projects that are feasible, implementable, value-laden, and resilient, designed to generate economic benefits and infuse communities with a higher quality-of-life.

## INFRASTRUCTURE + RESILIENCE PLANNING IN THE U.S.

There are three trends that inform the role of IUS in resiliency planning in its practice in the United States.

### 1. AGING INFRASTRUCTURE AND LIMITED FUNDING

Federal, state and local clients are faced with aging infrastructure and limited public funding resources. In Connecticut, for example, the average transportation structure is 81-years-old and vulnerable to the increasing risks of climate change. Consequently, we must think about infrastructure solutions that are integrated into economic and community goals. IUS helps clients think within this larger context and position infrastructure as a catalyst to larger reinvestment and financing strategies.

### 2. URBAN FOCUS –URBAN CENTERS ARE GROWING

Cities across the nation are growing. In the Northeast alone, New York City, Boston, and Washington, D.C. have experienced 10-year population increases of 2.1 percent, 4.8 percent,

and 5.2 percent, respectively. This heightens the responsibility of resiliency planning within urban centers, as well as the need for a planning strategy that considers a city's multiple aging systems and how they interact with and sustain one another.

### 3. A SHIFT IN INFRASTRUCTURE MANAGEMENT

More than ever, public funding and planning is focusing on climate change, sustainability, and resiliency planning not as specific goals but as frameworks within which to holistically plan for communities. As sustainable and resilient infrastructure becomes the focus for achieving vibrant communities, infrastructure management is at the forefront of this shift. With initiatives such as New York City's PlaNYC or the Federal Highway Administration's (FHWA's) Climate Change and Extreme Weather Vulnerability Assessment Framework, public agencies are working to understand how to connect infrastructure into the fabric of communities and tie it to urban systems so it may serve to enhance the sustainability and resiliency of the places they occupy, thereby achieving multiple benefits.

These trends are reshaping the environment in which clients are working to manage their infrastructure and grow their cities. IUS can help clients build infrastructure that generates economic growth, adapts to a changing environment, serves multiple purposes, and relates to the surrounding community context. ›

**70%**

OF THE WORLD WILL BE LIVING IN URBAN LOCATIONS BY 2050

# BECAUSE OF COLLABORATION, CANARSIE IS EQUIPPED WITH AN ACTIONABLE, VALUE-LADEN, AND COST-EFFECTIVE PROJECT THAT HAS COMMUNITY SUPPORT AND CLEAR NEXT STEPS.

## CANARSIE/FRESH CREEK - SHORELINE ACCESS AND RESTORATION PROPOSALS


**FIGURE 1** — FRESH CREEK SHORELINE ACCESS AND RESTORATION PROPOSALS

## CANARSIE/FRESH CREEK - 108TH ST WITH L AVENUE

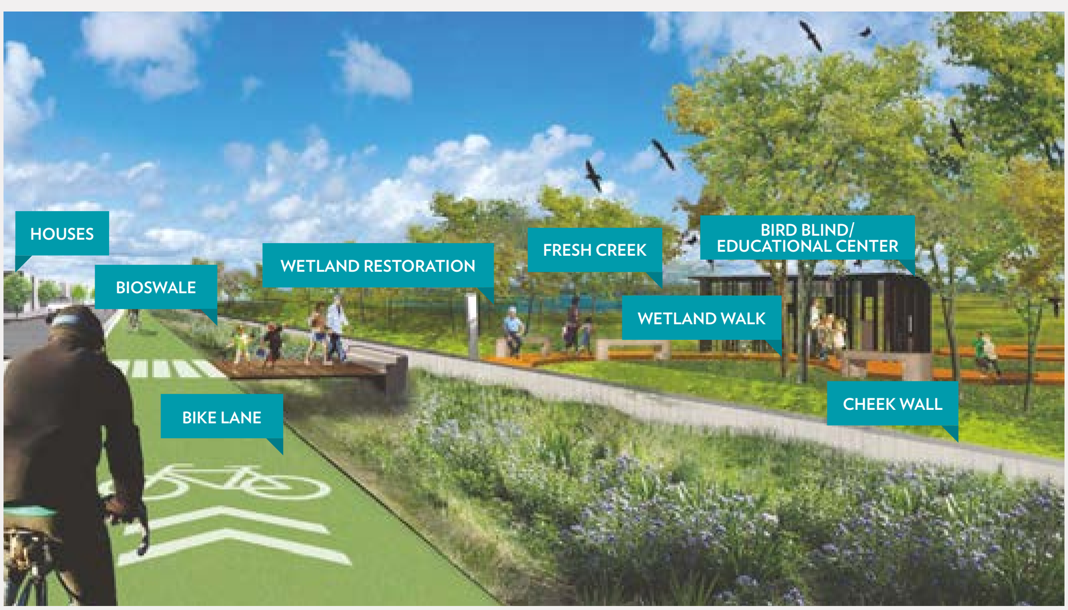


**FIGURE 2** — A BIKE LANE RUNS PARALLEL TO FRESH CREEK

## RESILIENCE PLANNING IN PRACTICE IN THE NORTHEAST REGION OF THE U.S.

In the aftermath of Superstorm Sandy, the federal, state, and city governments all enacted resiliency programs to reduce the risk of damage from climate-related events, and provide multiple benefits within communities. These programs relied primarily on federal funding from the Community Development Block Grant Disaster Recovery (CDBG-DR) Program. Beginning with the Mayor's Office's Special Initiative for Rebuilding and Resiliency (SIRR) and continuing with U.S. Department of Housing and Urban Development's (HUD's) Rebuild by Design and New York State's New York Rising programs, WSP | Parsons Brinckerhoff planners and engineers were involved in each of these efforts. Using IUS principles at the outset allowed us to plan feasible projects, which leads to financing of these projects and designing and implementing them on increasingly local scales. By improving how these projects are developed, we are involved in how they are built.

The New York Rising Community Reconstruction Program is an example of how IUS best serves the planning of resilient communities. The program was designed to allow communities most impacted by Superstorm Sandy to decide how to most effectively program federally allocated dollars to fulfill immediate needs, in line with a long-term community resiliency vision. WSP | Parsons Brinckerhoff was contracted to develop ten community resiliency plans in New York City, covering coastal communities in Jamaica Bay, the New York Inner Harbor, and the Long Island Sound.

## FRESH CREEK LONG-TERM RESTORATION AND RESILIENCY PROJECT

### IUS IN CONTEXT

One project of particular note was the Fresh Creek Long-Term Restoration and Resiliency Project for the Brooklyn community of Canarsie, a peninsular neighborhood flanked by water on three sides. During Superstorm Sandy, Canarsie experienced storm surge as high as 6-9 feet, particularly along Fresh Creek where homes line the water's edge. Given its low topography, properties upland from Fresh Creek are vulnerable to erosion, sea level rise, and less severe storms. Additionally, Fresh Creek has poor habitat quality, poor water quality due to combined sewer outflow (CSO) discharges, the presence of invasive species, and is a filled historic wetland. Despite these challenges, Fresh Creek is an important natural asset connecting the community to water and has been identified as a potential ecological restoration opportunity.

Only the collaborative expertise of planners, landscape architects, coastal engineers, and stormwater engineers could solve the challenges and realize the opportunities. Pooling resources and knowledge of the community, WSP | Parsons Brinckerhoff employed IUS principles to develop the plan which combines coastal protection, stormwater management, and ecological restoration strategies while at the same time enhancing community access along the shoreline (see Figure 1).

The project calls for construction of a floodwall along those areas of the shoreline that are at-risk to sea level rise and a 10-year storm surge return period, coupled with an inland bioswale large enough to capture stormwater from a 100-year rainfall event. This would address both daily stormwater management needs and needs that arise during storm conditions, besides reducing the risk of permanent tidal inundation of approximately 17.5 acres of land, including 300 buildings and more than 3,000 linear feet of city streets. On the water-side of the wall, proposed habitat restoration would address many of the ecological and environmental challenges the creek faces. To enhance community access, the project also includes a bike lane that runs parallel to the creek and water-connections from the adjacent roadway to the water's edge thereby improving quality of life for Canarsie residents (see Figure 2).

These quality of life benefits may have other secondary benefits as well, such as the economic benefits of increasing property values along the creek. Most importantly, by involving engineers at the planning stages, our team ensured that the project is not only beneficial, but technically feasible. Coastal engineers provided technical drawings and design heights, stormwater engineers provided catchment area calculations, and urban designers and landscape architects determined how to tie multiple infrastructure systems together in order to create a coherent resiliency project. Because of this collaboration, Canarsie is equipped with more than a plan. They are equipped with an actionable, value-laden, and cost-effective project that has community support and clear next steps.

## RESILIENT PLANNING REQUIRES INTEGRATED URBAN STRATEGIES

As evidenced by the Fresh Creek Long-Term Resiliency and Restoration Project, integrating multiple disciplines pulling from multiple areas of expertise and community input ensures that planned projects meet a community's needs and vision, are feasible from an engineering standpoint, and can adapt to changes in environment, socio-economics, and other unknowns. This method of integrated planning is essential to planning resiliency. When planning for an urban community's risks and vulnerabilities, we must consider that community as a comprehensive network of interacting infrastructure, economies, natural systems, and livelihoods. Extreme weather events impact these systems equally, and so we must consider them equally when planning resilient communities. Integrated Urban Strategies ensures a brand of planning that enhances a community's quality of life and at the same time sustains its way of life.

*__Tom Jost__ is a Senior Urban Strategist who has spent his professional career exploring the drivers that influence urban development. He has managed some of the most dynamic and transformative projects shaping the future of urban communities in the New York City metropolitan region.*

*__Samer Saliba__ is an Urban Strategist whose work is focused on bridging the gaps between planning, design, and engineering. He ensures that all the needs and opportunities of his projects are met at equal levels by using an integrated planning approach, resulting in balanced projects that go well beyond the basics of community planning.*

# A SYSTEMS APPROACH TO CLIMATE CHANGE ADAPTATION

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## AN ASSET ADAPTATION FRAMEWORK, DEVELOPED FOR APPLICATION ON TRANSPORTATION FACILITIES, COULD ALSO BE APPLIED TO COMMUNITY RESILIENCE PLANNING.

The effects of climate change are real. They influence many complex relationships within a community susceptible to changes in the various climate stressors. In addition to the physical infrastructure, the impacted elements include the environment, emergency management, economic vitality, and many social issues – in other words, the health, safety, and welfare of affected communities. Figure 1 illustrates the multi-faceted nature of community impacts that can be affected by the changing climate conditions. This article discusses a systems approach called ADAP (adaptation decision-making assessment process) which was developed by Parsons Brinckerhoff, now part of WSP | Parsons Brinckerhoff, for use on various types of transportation infrastructure but which can be applied to community resilience planning.

FIGURE 1 — COMMUNITY IMPACTS OF CLIMATE CHANGE


## NATIONAL DISASTER RESILIENCE COMPETITION

To emphasize the need and benefits of a holistic response to extreme weather events, the U.S. Department of Housing and Urban Development (HUD) in collaboration with the Rockefeller Foundation has broadened awareness of the non-infrastructure impacts by providing significant resources and support to communities to help them become more resilient. The National Disaster Resilience Competition is a competitive program to award nearly $1 billion in HUD Disaster Recovery funds to eligible communities. The purpose of this competition is to aid not only infrastructure resilience but strengthen the fabric of the community so that it is better prepared to “bounce back” when a disaster strikes.

## A SYSTEMS APPROACH

Climate change adaptation is complex enough to warrant a complex approach. A systems engineering approach can provide the framework for dealing with this complex set of issues. Systems engineering is an interdisciplinary branch of engineering that focuses on planning, designing, and managing complex engineering systems over their life cycles. However, systems engineering is usually not broad enough to deal with the impacts of climate change on an entire community. What is needed is a “systems approach” - an approach that requires engineers, planners, maintenance and operations personnel, policy makers, financial experts, funding source managers, and the public to work together from the beginning to address the issues of the entire community over a long-term planning horizon. Involving the public early in the process is essential because the impacts of climate change do not respect community boundaries and it is likely that any approach will need to involve the entire region. This level of cooperation among so many stakeholders is not typical and will require lead agencies to implement strategies that remove barriers to communication and cooperation among these various interests.

## THE ADAPTATION DECISION-MAKING PROCESS (ADAP)

As part of the work performed for the Federal Highway Administration (FHWA) to address infrastructure adaptation, WSP | Parsons Brinckerhoff in collaboration with ICF International developed a systems approach called ADAP (adaptation decision-making assessment process). This 11-step process to address the impact of severe climate on various types of transportation infrastructure matches adaptation actions with the varying levels of impact and risk (see Figure 2). ›

## THIS 11-STEP PROCESS TO ADDRESS THE IMPACT OF SEVERE CLIMATE ON VARIOUS TYPES OF TRANSPORTATION INFRASTRUCTURE MATCHES ADAPTATION ACTIONS WITH THE VARYING LEVELS OF IMPACT AND RISK

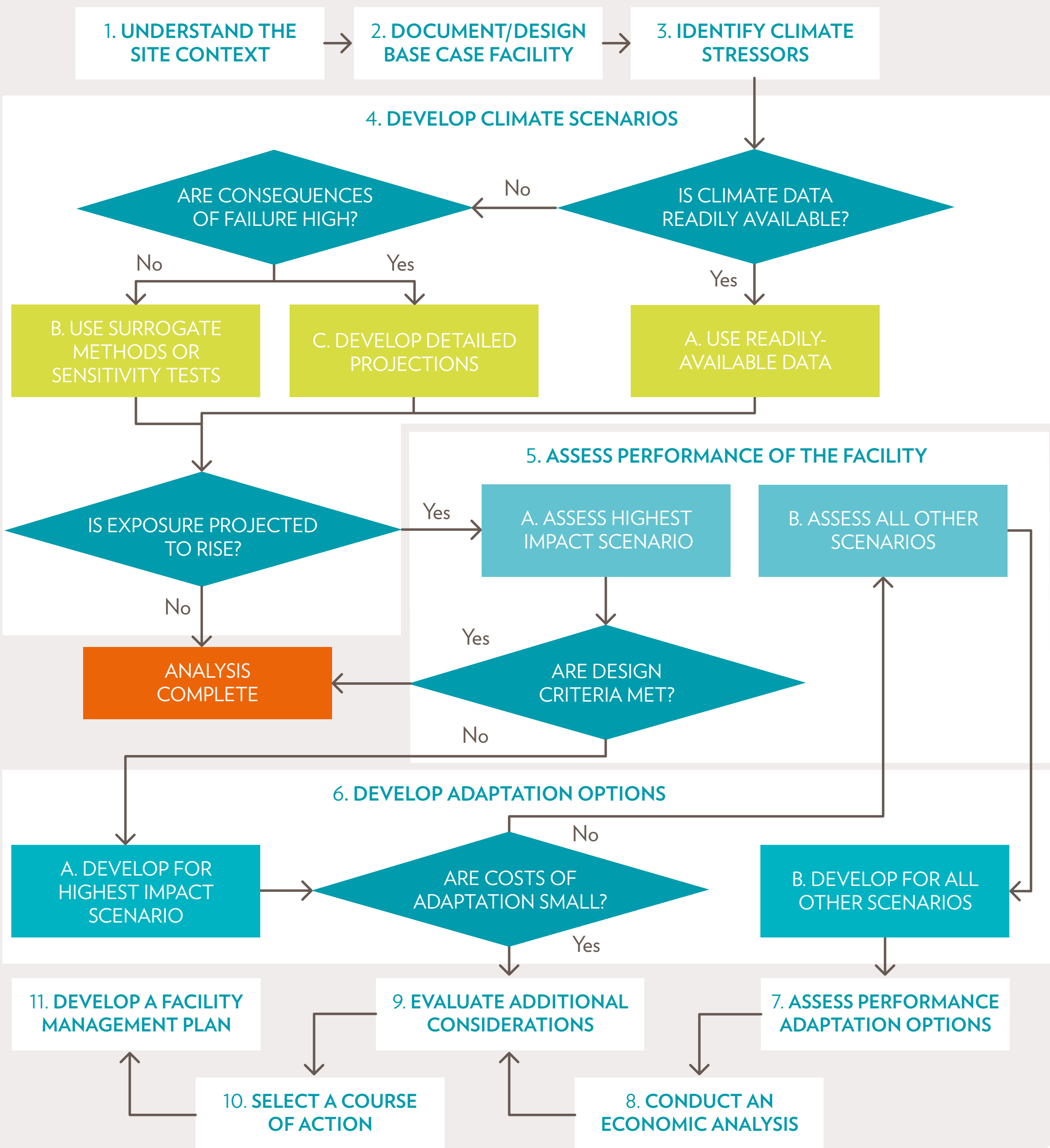


FIGURE 2 — ADAPTATION DECISION-MAKING ASSESSMENT PROCESS (ADAP)


**FIGURE 3** – THE ELEMENTS OF ADDRESSING CLIMATE IMPACTS TO THE WHOLE COMMUNITY

Although the process was developed for application on individual transportation facilities, it can be applied to other assets as well, including community resilience planning. Total community concerns are addressed in step 6 of the ADAP process, Develop Adaptation Options; these options include both structural and non-structural strategies.

## A SYSTEMS APPROACH TO RESILIENCE FOR THE WHOLE COMMUNITY

The ultimate goal of a systems approach to resilience planning is to deliver feasible, flexible, and fundable solutions based on a defensible decision-making process that is built on a foundation of community support and considers much more than individual assets. That means an approach that addresses rebuilding physically resilient assets and also, where possible, rebuilding so as to benefit the community by bettering housing, businesses, the economic health, and the social fabric of the affected area.

Community support must begin with an educational campaign to improve the level of understanding of climate change and its threats and possible negative outcome. Community leaders should identify a neutral lead agency (perhaps a local educational institution or a metropolitan planning organization) that can bring people from the region together to develop a detailed approach to resilience planning. Involving the community beyond the government agencies can be an effective way to bring the localities into regional alignment. Besides addressing the practicality of coordinating adaptation responses across community boundaries, a central agency that represents a unified community response will be a favorable influence on potential funding source decision-makers.

Widespread public engagement is necessary to the process. As potential resiliency solutions develop, a vigorous outreach campaign that involves the public in developing and refining approaches will help build community consensus. Figure 3 indicates the elements of a comprehensive approach all of which require public dialogue.

Examples of resilience planning to consider in addition to the engineering design of specific structural assets include:

- Zoning code revisions:
  - minimum floor elevations for houses, garages, and ancillary structures;
  - flood proofing at vulnerable elevations; and
  - foundation, structural and mechanical design requirements.
- New development site plan reviews that include addressing possible risks.
- Comprehensive master plan revisions:
  - policy documents;
  - land use; and
  - flood plain restrictions.
- Other major facility long-range plans (e.g., emergency services, public utilities, schools);
- Relationship to regional transportation plan; and
- Coordination with electric and gas utilities and communication providers.

## CONCLUSION

The potential threats posed by a changing climate cannot be attacked on only one front – they must be dealt with holistically, with an organized approach that considers all of the relevant ramifications. The ADEP approach can be used in any stage of response to the effects of climate change - from resiliency planning, to new project development, to responding to damages already incurred. This approach has been adopted by the FHWA in their guidelines for adapting infrastructure to the effects of climate change and is being used by the study team that developed it as the framework for continuing studies on asset adaptation nationwide.

## ACKNOWLEDGEMENTS

The material in this article is based on work developed by Chris Dorney, Mike Flood, Justin Lennon, Michael Meyer, and the author.

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# THOUGHTS ON THE NEED FOR 'CONTEXT-SENSITIVE' RESILIENCE

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## ISSUES AND CONSEQUENCES THAT EXTEND BEYOND JURISDICTIONAL OR FUNCTIONAL BOUNDARIES SHOULD BE CONSIDERED WHEN FORMULATING POLICIES, PROGRAMS, AND PRACTICES TO IMPROVE THE RESILIENCE OF TRANSPORTATION INFRASTRUCTURE.

Recent increases in planning activities to address the resilience of transportation infrastructure in withstanding extreme weather and adapting to the long-term impacts of changing climate are, indeed, welcome trends. Planning and decision-making for improving resilience fit well with asset management and risk management practices that are rapidly taking hold in the transportation community. These efforts typically employ systematic, rational approaches to weighing the risks and consequences associated with weather and climatic-related events and trends, and in assessing potential measures to mitigate impacts.

It is to be expected that the foremost concerns among transportation agencies will center upon the transportation assets and services for which they have primary responsibility. However, there are associated questions and concerns that are often afforded insufficient attention which involve whether resiliency planning and decision-making by an individual agency have adequately considered and vetted "external" issues - issues whose overall significance may well equate to, or potentially exceed, those involving an agency's own assets and services, but whose jurisdictional or functional limits extend beyond an agency's purview. Here are a few examples, posed as questions that deserve some degree of attention:

- Are communities or facilities whose vital access would be protected through investments in transportation resilience themselves likely to be survivable and sustainable given the severity of extreme weather and climatic impacts for which the transportation adaptive measures are designed?
- Where the resilience of transportation links (which are essential for access to developed areas) is involved, are commensurate measures being planned for other vital infrastructure serving those areas that are essential to the viability of these areas (stormwater management and flood controls, fresh water supply, sanitary sewer lines and wastewater treatment, electric power and telecommunications lines, internal roads and streets, etc.)?
- Are decisions on whether and how to invest in the resilience of strategically important facilities adequately considering the benefits and potential impacts to regions and locales beyond the jurisdiction of the transportation agency making those decisions? For example, for arterial highways traversing a small "corner" of a jurisdiction whose economy and well-being are only marginally affected by that facility, but where major impacts would occur in adjacent jurisdictions from any disruption in service, how is the "home jurisdiction" to consider the relative resilience priority of that facility when resources are scarce and the potential benefits accrue to "others"?
- Are more comprehensive solutions available when considered on a larger geographic scale which might obviate the need for a multitude of less efficient and less cost effective individual solutions? For example, could a Netherlands-scale system of levees and flood control systems protecting an entire region from sea level rise and storm surges, though very costly, turn out to be more cost effective than the multitude of measures by individual entities and jurisdictions that might otherwise be necessary?

These questions indicate the need for context-sensitivity when formulating policies, programs, and practices focused on improving the resilience of transportation infrastructure. Agencies must consider issues and consequences that extend beyond narrowly defined jurisdictional or functional boundaries, which the forces of nature do not respect.

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**PLANNING AND DECISION-MAKING FOR IMPROVING RESILIENCE FIT WELL WITH ASSET AND RISK MANAGEMENT PRACTICES THAT ARE RAPIDLY TAKING HOLD IN THE TRANSPORTATION COMMUNITY.**

# ENGINEERING RESILIENT SYSTEMS IN TIMES OF ACCELERATING TECHNOLOGICAL ADVANCEMENTS **MOVING TOWARDS ANTIFRAGILITY**

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WHEN A LEGACY SYSTEM ACTUALLY "GETS BROKEN" (E.G., BY HURRICANE SANDY), VAST TECHNICAL POSSIBILITIES OPEN FOR THE INTRODUCTION OF FAR SUPERIOR SYSTEMS.

Resilience is generally understood to be the capacity of systems, sub-systems, or their individual elements to recover from disturbances and continue to function successfully. The term resilience is also used to describe the capability to not just recover from disturbances, but to actually benefit from them – to evolve and become better suited to perform the same tasks or to adapt to handle additional tasks. This phenomenon is analyzed in a thought-provoking book "Antifragile: Things That Gain from Disorder" (2012, by Nassim Nicholas Taleb), which explains why the antonym of fragile is 'antifragile' (Taleb's neologism, due to the absence of an existing precise antonym) and not any of the following: resilient, elastic, strong, hardened, rigid, robust, solid, unbreakable, or "something-proof". For this article, the broader meaning of the term resiliency is used - one that includes antifragility.

In the past it was not understood that a system could become stronger or better when exposed to stress (i.e., antifragile). However, developments and standardization that occurred over the past decades in the fields of micro-electronics, material science, communication technologies, along with advancements in software development tools and techniques have made the engineering of antifragile systems possible.

Traditional design techniques use predetermined design criteria while antifragile systems are built to additionally take into account unknowns. The ever-increasing rate of knowledge accumulation and technological advancements is experienced through an increased frequency of life-changing technological improvements. Nevertheless, the way these systems are used, the risks and environment in which they are used, or how they develop in the future is becoming increasingly unpredictable (e.g., electricity, DNA, the Internet).

In the face of certain yet unpredictable changes, two mutually exclusive engineering approaches are available:

- Using traditional engineering methods to build hardened systems whose life cycle may nevertheless become progressively shorter due to their inability to adjust to changed environment and/or need for higher level of performance; or
- Acknowledging the fact that both the environment and functional requirements will change over time, and accommodating for the unknown by intentionally building innovative and flexible systems that can evolve when needed.

Technologies that allow inclusion of flexibility and future-proof (anti-fragility) criteria into a system's functional requirements (design criteria) have been around for at least two decades and are considered proven (e.g., microprocessor-based hardware, object-oriented software, standardized sensors, routable protocols, fiber-optic communication). Therefore, as it is possible to build new systems or upgrade the existing in a manner that would enable their easier evolution in the future (minimizing downtime), engineering of contemporary systems should include a full set of universally applicable resilience measures. The following engineering and organizational concepts, measures, and features should be specified and applied to systems expected to be resilient:

## 1. THOROUGH UNDERSTANDING OF A SYSTEM'S FUNCTIONAL REQUIREMENTS

A system's functional requirements can often be satisfied far better using a thorough, open, and educated brainstorming process with all stakeholders. Experience teaches that thinking outside of the box and having

a diverse, multidiscipline approach (fresh-eye perspectives on goals and issues from different angles, problem solving skills outside the established line of engineering thought, etc.) – while not assuming the design methods and solutions even for traditional and routine engineering tasks are known in advance – provide for creativity and lead to simpler, lower cost, yet superior, modern, and future-proof systems and solutions that are developed faster in a less risky way.

## 2. DEFINING FAILURE CRITERIA

Designing a system with "no single point of failure" and components "fail-safe" criteria is essential for its future resilience. Additionally, consideration of effects (and cost) of redundancy options shall be based on the system's actual functional requirements, and should include all of the following:

- the utilization of diverse sub-components to prevent common mode failures;
- possible swarming strategies (allowing a certain percentage of components to fail without affecting the operation outcome);
- evaluation of hardening vs. strategic sacrificing of individual components or sub-systems (partial reduction of service operation);
- determination of an acceptable level of the system's temporary degradation and the maximum recovery time taking into account user and public safety and other relevant issues; and
- volume and distribution of spare parts, etc.

## 3. MODULARITY AND STANDARDIZATION

Another feature that should be incorporated into a resilient system is ensuring that system performance issues or failures are localized and manageable. To achieve this, it is essential that subsystems and/or individual components are functionally segregated and that their internal operation, external interfaces, and communication method(s) are well-defined, documented, and standardized.

Functional, performance-based specifications that rule out proprietary methods and components are necessary for ensuring the very basis for the system's flexibility. Gradual modification of a system is more easily accomplished if it is modular, consisting of standardized, interoperable, commercial off-the-shelf (COTS) components. The system's fault tolerance, hence resiliency, is also improved and redundancy accomplished with fewer additional components when they are intelligently organized to take over the role of a failed component.

## 4. ACTIVE CONTINUOUS MONITORING

Resiliency is also supported by continuous monitoring of a system's state, including active self-diagnostics – to the lowest replaceable system component level. This allows for early identification, timely intervention, and accurate management of potential issues and emerging problems.

The benefits of accurate feedback about the system's state, data mining, trending, asset management, intelligent preventive maintenance, when combined with built-in modularity and standardization, bring one important additional benefit with each identified issue: opportunity to re-evaluate the system and improve it accordingly. In other words, what causes one component to break, as long as it does not break the system, should also contribute to the system's overall resilience (antifragility) – that is, if the system is capable of evolving. Even if a disruptive event breaks a particular system, it can still contribute to improving the resilience of similar systems (e.g., aircraft manufacturing and maintenance).

Building state of the art systems that achieve resiliency through well-thought-out design provides both direct and indirect benefits to the designer and the stakeholders alike, as well as to the general public. Those benefits include higher system capability, reliability, safety, and quality, with reduced developmental and operational risks and costs.

While new infrastructure projects are good candidates for implementing novelty features including resilience, repairing and upgrading older infrastructure often present opportunities for dramatic qualitative improvements. And when a legacy system actually does "get broken" (e.g., by Hurricane Sandy), vast technical possibilities open for the introduction of far superior systems (easier implementation, simplification/consolidation, advanced and flexible features, etc.).

With its great engineering legacy and knowledge of modern technologies in this time of accelerating technological changes, WSP | Parsons Brinckerhoff is able to provide expert assistance to our global infrastructure clients, and offer them resilient, state of the art economical systems and solutions that will serve them well in the foreseeable future.

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# THE INTERSECTION OF RESILIENCE, SUSTAINABILITY, AND LIVABILITY

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FOR A LIVABLE FUTURE, RESILIENT TO DISRUPTIONS, SUSTAINABILITY IS THE WAY TO GET THERE. US CITIES ARE COMBINING THESE CONCEPTS IN THEIR URBAN PLANNING.

Municipalities and agencies are struggling with terminology. An average local transportation staff or elected official, depending upon what has been in the news of late (the weather, the cost of energy, the need for jobs) will sit up with attention when you use the words: resilient, livable, sustainable. But these words can carry political baggage; it may be acceptable to say livable, but not sustainable, and four years ago most people would not have really understood what resiliency was, though 'disaster preparedness' was a regular topic. Now communities recognize those 100-year storms seem to happen every year, and the capacity to bounce back is crucial to maintaining quality of life and economic viability.

The terms resiliency, sustainability, and livability are sometimes used interchangeably, though at the cost of achieving necessary outcomes for communities and agencies, and with the price of weakening these concepts. If a livable present and future, resilient to disruptions, is the desired outcome, sustainability is a lens to get there.

## SUSTAINABILITY

Sustainability is a lens through which the planning, project delivery, and development processes focus to achieve the needs of the communities today without sacrificing capacity for future generations. A sustainability lens always includes balancing priorities across several areas, including the economy, community needs, and environmental quality, but also equity, health and well-being, energy, water and materials resources, and transportation and mobility needs. In the United States, resilience and livability are outcomes sought through planning and design processes.

If you really have used a sustainability lens on a process, have been honest and smart about your priorities, you will have assessed risk and resilience. And if you are diligent about sustainability, you would have incorporated community value, quality of life, and that characteristic which makes engineers very nervous – beauty - by making livability a priority.

## LIVABILITY

Livability has long been a priority of communities seeking to improve the quality and attractiveness of urban and rural communities. Livability initiatives come from local priorities as well as federal leadership from agencies such as the U.S. Environmental Protection Agency (EPA), the Department of Housing and Development (HUD), and the Department of Transportation (DOT) sustainable livable communities divisions.

Washington, DC carried out the Anacostia Waterfront Initiative, a 'great streets' initiative and a livability study more than a decade ago, which focused on how the public right-of-way and infrastructure could better serve the communities, residents, and business owners along some of Washington, DC's famous waterways and boulevards, transforming infrastructure barriers, such as the South Capitol Street viaduct, into a walkable, bikeable urban boulevard that furthered economic development. The city also led the way on studies of low-impact development stormwater management techniques to improve water quality and minimize combined sewer outfall events, while providing co-benefits to neighborhood residents and businesses by improving access to greenspace, shade, and habitat. This approach to livability used a sustainability lens to focus on and realize the city's priorities.

## RESILIENCE

Resilience has taken on new urgency around the world as coastal cities adjust to more frequent and severe storm events; communities in arid regions struggle to recover from wildfires; and inland communities deal with flooding they have never before experienced. The objective of resilience is for a community and its economic functions to recover quickly, and soundly, after a major disaster event. This is sometimes achieved through distributing key infrastructure services, such as power generation and distribution, or water treatment, as well as ensuring some level of redundancy, so that key systems are backed up. If one considers the intersection of resilience with sustainability and livability, some curious possibilities are revealed.

- You can have resilience without sustainability, odd though that would be. A solution could enable a city to recover quickly, but would not be able to be maintained in the long-run or would sacrifice too many resources to accomplish. A resilient solution that requires extensive capital and maintenance, or that causes ecological side effects, would be short-sighted, a prospect which is fundamentally un-resilient. However, most of us have witnessed how poorly managed processes can mangle objectives.
- You can, also, have resilience without livability. While this would be survival, it would also probably not provide the quality of life which is often a hallmark of livability.

## OTHER EXAMPLES OF CITIES COMBINING RESILIENCE, SUSTAINABILITY, AND LIVABILITY

### CHICAGO, ILLINOIS

- The city of Chicago embarked on a process of revising their approach to delivering projects in the public realm. They created a set of interlinked documents to address complete streets, sustainability, and livability (Streets for People). As they set about creating a set of new requirements for all infrastructure projects, they made livability a cornerstone. However, resilience and climate adaptation, resources conservation, and sustainable construction methods were included as key requirements in project delivery, for all projects.

- Chicago Department of Transportation (CDOT) is looking to create urban infrastructure that is resilient to future climate change. Also, CDOT is looking to reduce greenhouse gas emissions by making walking and biking easily accessible throughout the city. Specifically, implementing its new complete streets guidance and focusing efforts on incorporating placemaking into more projects brings active transportation facilities to the forefront of capital projects. The focus on livability results in more community engagement in shaping and programming the public realm, such as through the Make Way for People initiative and other small-scale placemaking programs.
- At the same time, CDOT has placed emphasis on restoring ecological service functions in the public right-of-way through innovative and award-winning green infrastructure pilot projects such as the Green Alley pilot projects, now a city program. The Green Alley program retrofits alleyways with permeable pavement, asphalt, concrete or pavers, so stormwater is infiltrated and does not collect on hard surfaces and drain into storm sewers, or cause flooding. The alleyways are re-graded and pitched to facilitate drainage. High-albedo (most reflective) pavements which reduce urban heat gain are used, as well as recycled material. The program helps with resiliency goals by lessening the impact of frequent storm events and distributing stormwater management throughout the city. Retrofitted alleys also include new light fixtures that reduce light pollution while maintaining safe light levels.

### SEATTLE, WASHINGTON

- The city of Seattle, a coastal seaport city in the state of Washington, is actively working to increase its resiliency through climate protection initiatives that apply to all of the city's policies, programs, and planning efforts. Seattle was one of the first cities in the nation to adopt a climate action plan (CAP), which includes steps to monitor and report on targets and actions through climate action outcome indicators. Currently 25 indicators are being tracked; they range from livability goals, like the amount of open space, to modal share goals.
- Adaptation planning is one of the key climate change initiatives within Seattle. For example, the city is working hard at increasing the use of green stormwater infrastructure (GSI) within the public right-of-way. All city projects are required to implement GSI to the maximum extent feasible for flow control. This means that GSI must be incorporated throughout the project site wherever feasible, constrained only by the physical limitations of the site, practical considerations of engineering design and necessary business practices, and reasonable financial considerations of costs and benefits. Additionally, the city has an executive order that establishes a citywide goal of 700 million gallons of stormwater managed annually with GSI by 2025.
- Another example from the city of Seattle is the recently added Seattle Green Factor requirement, which is administered by the Department of Planning and Development. Green Factor is a score-based code requirement that increases the amount of quality landscaping in new development. It applies to all new development in neighborhood business districts with more than four dwelling units, more than 4000 square feet of commercial uses, or more than 20 new parking spaces. To help developers comply with this program, the city offers a 'menu' of landscape credits for various features like green roofs, trees, shrubs, etc. These requirements benefit the city's livability and resiliency goals.

## CONCLUSION

Respecting and balancing local environmental, social, economic, and climate risk priorities through a robust planning and data-driven design process should achieve livability and resiliency outcomes. Resilience is important to our communities, as we recognize the need to be ever more dynamic and creative in how we anticipate and plan for the challenges delivered by a changing climate, as well as the standard severe weather events we have always had to address. If a livable present and future, resilient to disruptions, is the desired outcome, sustainability is a lens to get there.

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*__Stephanie Brown__ has over a decade of experience managing and preparing documentation compliant with NEPA for a variety of transportation projects. In addition, she has experience in the development of sustainable infrastructure policies and guidelines and leading the alternatives development process for a variety of roadway projects.*

# DESIGNING BUILDINGS FOR FUTURE CLIMATES IN THE U.K.

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THROUGH A STUDY OF FOUR BUILDING PROJECTS, THIS ARTICLE EXPLORES HOW IMPACTS FROM CLIMATE CHANGE AFFECT THE WAY WE THINK ABOUT DESIGNING BUILDINGS.

As global environmental policy focuses on minimizing greenhouse gas emissions and the extent of anthropogenic (human-caused) climate change, there is a growing realization that at least part of the anticipated change in climate is unavoidable. Consequently, policies and strategies need to be in place to allow our buildings to adapt to a warmer climate, thereby making them more resilient.

The Design for Future Climate (D4FC) initiative by the U.K.'s Technology Strategy Board (TSB)[1] enabled project teams to consider climate change impacts in the design of new construction and building refurbishment projects in the U.K. It allocated £5 million to approximately 50 projects. WSP (now part of WSP | Parsons Brinckerhoff) formed a team for the purpose of generating a climate change adaptation strategy for four building design projects already in the WSP | Parsons Brinckerhoff portfolio and chosen for the competition:

- Trowbridge County Hall: an office renovation project;
- Great Ormond Street Hospital Phase 2B: a new wing of an inner city hospital;
- London Bridge Station Redevelopment: the revitalization of a major London train station; and
- Westbrook Primary School: a new school.

The TSB report entitled, 'Design for Future Climate' explores a number of impacts from climate change and how they might affect the way we think about designing buildings. The report classifies the identified climate change adaptation risks into three categories: comfort, construction, and water (see Figure 1). It is by these categories that the four projects were assessed.

In order to generate a climate change adaptation strategy, the primary objective was to process general information about the changing climate, apply a variety of climate scenarios to each project and its unique set of characteristics, and evaluate what the effect might be on the building's ability to perform its function. UKCP09[2] future climate data was used on all projects, as was a synthesis of this data into building thermal simulation weather files (available under the Prometheus project[3]) which present a range of future climate scenarios that vary based on expected global emissions (medium, high, very high), the future date (2030s, 2050s, 2080s), as well as a range of probabilistic determinations (10 percent, 33 percent, 50 percent, 66 percent, 90 percent). For thermal analysis, WSP | Parsons Brinckerhoff chose to show all three future dates, typically under the 'high' scenario, and 10 percent, 50 percent, and 90 percent probabilistic determinations.

## FIRST STAGE – RISKS AND OPPORTUNITIES

The first step was to determine what climate change risk categories were actual issues for the project in question. To achieve this, a fundamental risk review was undertaken with the client's involvement in this process. Risks were evaluated to determine their likely impact and the probability of them occurring, given what we understood to be the range of future climates (see Figure 2).

For those risks considered important, a list of design responses or approaches were developed. The scope of these responses/approaches included: design modifications to the existing design process, management solutions, ideas for which implementation can be delayed, or simply

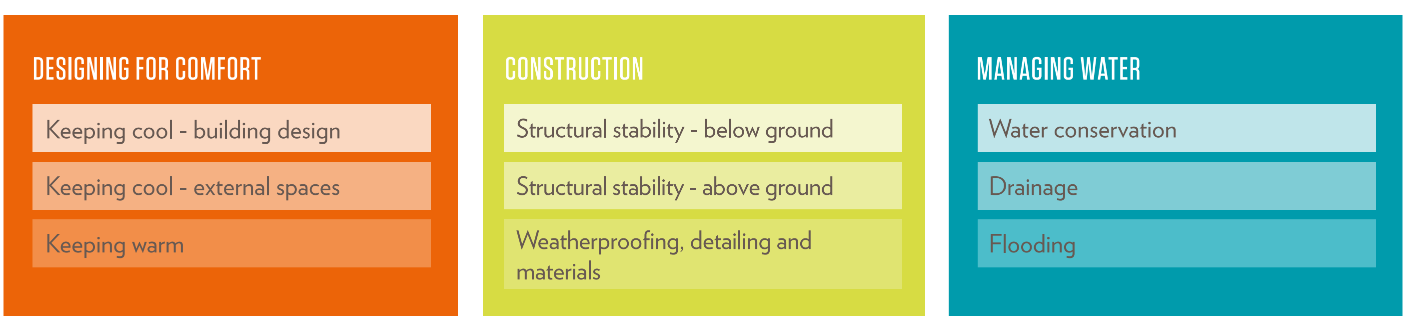


**FIGURE 1** – CLIMATE CHANGE ADAPTATION RISK CATEGORIES

[1] In August 2014 the Technology Strategy Board changed its name to Innovate U.K., to better express its role and purpose. Innovate U.K. is the U.K.'s innovation agency. It funds, supports and connects innovative British businesses through a unique mix of people and programmes to accelerate sustainable economic growth.

[2] http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/index.html

[3] http://emps.exeter.ac.uk/engineering/research/cee/

a suggestion to monitor certain building-specific or climate-based parameters as a warning sign for action or trigger point for implementation.

This initial stage process was documented in a Climate Change Risk and Opportunities Report, which was intended to give the client and the TSB an understanding of:

- all risks that climate change poses to the building and site;
- the severity of the risks, from the most extreme that may require design changes, to those that only require monitoring; and
- opportunities to reduce or eliminate risk, the pros and cons of these opportunities, and the timeframe to implement them.

### SECOND STAGE – TECHNICAL FEASIBILITY

The subsequent stage was a technical feasibility assessment. The purpose of this stage was to evaluate the benefit of each initiative and to assign a capital and life cycle cost to give the client enough information to determine whether to make an investment in the suggested design initiatives or whether it might be more fiscally prudent to delay intervention. From this feasibility assessment and cost benefit analysis, a climate change adaptation strategy was developed and presented to the client for their consideration.

## GENERAL THOUGHTS ON THE CLIMATE CHANGE ADAPTATION RISKS TO THE FOUR PROJECTS

***Comfort*** *– We need to adapt our buildings so that people can live and work in comfort as the temperatures rise. Innovations in design are essential to meet the challenges of hotter summers and warmer winters, while reducing the amount of energy we use. ('Design for Future Climate', Bill Gething, page 12)*

- When designing for future climate, it is important to avoid relying on air temperature as the sole determinant for thermal comfort and to consider alternative measures which include:
  - Resultant temperature which is essentially an average between the air temperature and the mean radiant temperature, and is a better indicator of how a person will feel in a space, given the impact of the temperatures of surrounding surfaces.
  - Predicted mean vote which is a mathematical model defined in ASHRAE[4] 55 that considers not only air temperature and mean radiant temperature but also humidity, clothing, activity and air speed.
  - Adaptive thermal comfort is specifically designed for testing natural ventilation designs where opening windows is the primary source of comfort modulation. The model varies the acceptable resultant temperature based upon the external conditions and hence allows for the intuitive phenomenon that "people get used to" higher temperatures and over the years will acclimatize to a warming environment.
- Initiatives such as façade shading, glazing performance, exposed thermal mass, and alternative HVAC strategies that feature radiant chilled elements will reduce energy usage and limit radiant heat and/or provide additional radiant cooling and limit the comfort impact on a warming climate.
- When initially reviewing a building's climate change risk profile, consideration of building loading is an early indicator of likely climate change risk exposure. Buildings that are externally loaded (i.e., the majority of their heat gains come from the building fabric, either because the floor plate is thin or because the space is sparsely occupied) are much more susceptible to the effects of climate change on comfort.

***Construction*** *– Although the effect of climate change on wind speeds and soil stability is not yet clear, we need to review our techniques, materials and fixings to ensure that new buildings are weatherproof and robust. ('Design for Future Climate', Bill Gething, page 20)*

- UKCP09 provides average wind speed increases, but the real risk to building structure is peak wind. The team was able to determine what peak wind speeds would create a problem and provide that information as a trigger point for action, should peak wind speed data be available in future. Current U.K. design practice allows for a 50 percent increase in peak wind speed, demonstrating there is some wiggle room for extreme events.
- UKCP09 guidance suggests an increase in mean winter rainfall leading the team to typically suggest an elevation in the exposure category for wind driven rain intensity (using the Building Research Establishment scale).
- Lightning strikes per annum are expected to increase potentially changing a project's risk category and the required lightning protection regime.
- Typically, temperature impacts on the performance of structural elements (e.g., increased thermal expansion) was found to be negligible. Likewise, the consequences of increased UV exposure on the performance and durability of exposed building elements was found to be insignificant since modern materials do usually have a good resistance to UV.

***Water*** *– With the prospect of summer droughts, more frequent extreme rainfall and increased flooding, water management is becoming a serious challenge for the building industry. ('Design for Future Climate', Bill Gething, page 30)*

- In the U.K. as elsewhere, flood modelling for climate change scenarios is still generally subject to assumptions. Government guidance recommends designing stormwater attenuation assuming a 20-30 percent increase ›

| | | IMPACT | | | | |
|---|---|---|---|---|---|---|
| | | Insignificant | Minor | Moderate | Significant | Severe |
| PROBABILITY | Negligible | LOW | LOW | LOW | MEDIUM | MEDIUM |
| | Rare | LOW | LOW | MEDIUM | MEDIUM | HIGH |
| | Unlikely | LOW | MEDIUM | MEDIUM | HIGH | HIGH |
| | Possible | MEDIUM | MEDIUM | HIGH | HIGH | EXTREME |
| | Probable | MEDIUM | HIGH | HIGH | EXTREME | EXTREME |

**FIGURE 2** - RISK CATEGORIZATION

[4] ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) is a global society advancing human well-being through sustainable technology for the built environment. ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) is a standard that provides minimum requirements for acceptable thermal indoor environments.

in the design rainfall event. A 20 percent increase is also generally used for river flows. Generally though, those allowances cannot reflect local variability and the science is still under development which makes it difficult to precisely quantify future flood risk and the appropriate level of future flood protection.

- The future availability of fresh water for building use is difficult to predict and affected by multiple variables including future population, technological improvement and behavioral change; combined with the current low cost of water this means that it is very difficult to demonstrate the financial viability of options like rainwater harvesting. More robust future water cost modeling would be a valuable addition to the cost-benefit analysis helping to promote the use of these initiatives, though existing water stress assessments along with general climate forecasts from UKCP09 do help to highlight geographically where water stress is likely in future.

In considering climate change adaptation decisions, conversations primarily focused on both uncertainty and impact of risk. Overall, the category with the most readily usable quantitative information - comfort - is perhaps the least important. Whereas issues of structural stability and flooding, which have general but not specific climate guidance, are potentially catastrophic if proper precautions or strategies are not implemented.

## CONCLUSION

Expected changes in the climate over the next 100 years mean that we will need to adapt the design of our existing and new buildings to prepare them for the anticipated but as yet unknown extent of climate change impacts. By providing project specific advice considering building typology, location, climate and function, WSP | Parsons Brinckerhoff can prepare clients to tackle the challenges of climate change adaptation with the latest in climate forecast data and sensible risk mitigation techniques.

Part of the contract with the TSB was that the design for future climate activities, projects, and learning be disseminated to the industry externally as well as to peers internally. WSP | Parsons Brinckerhoff has provided a number of presentations and webinars, and contributed to a book and a documentary about the projects.

***Matthew Payne**, Vice President, leads the WSP | Parsons Brinckerhoff Built Ecology team on the east coast of the U.S., having previously done the same in the London and Sydney offices. His expertise includes climate specific building design advice, with a focus on energy, water and indoor environment quality.*

***Meike Borchers**, Associate Director at WSP | Parsons Brinckerhoff in the U.K., has expertise in structural design and the built environment. She is a qualified BREEAM and Code for Sustainable Homes assessor and her expertise also includes performance analysis, energy efficient technologies, energy strategies and sustainable building materials.*

***Enrico Isnenghi**, Associate Director, is a water engineer and leads the WSP | Parsons Brinckerhoff water team in London. His expertise includes flood risk assessment and management and water resources in general, climate change adaptation and emergency planning.*

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- CIWEM Conference – the Chartered Institute of Water and Environmental Management event where Enrico Isnenghi presented specific water focus for Great Ormond Street Hospital.
- RIBA Design for Future Climate Book by Bill Gething - a book that summarises the first 26 projects in the D4FC competition that features WSP | Parsons Brinckerhoff's work from Trowbridge and Great Ormond Street Hospital.

EXPECTED CHANGES IN THE CLIMATE OVER THE NEXT 100 YEARS MEAN THAT WE WILL NEED TO ADAPT THE DESIGN OF OUR EXISTING AND NEW BUILDINGS TO PREPARE THEM FOR THE ANTICIPATED BUT AS YET UNKNOWN EXTENT OF CLIMATE CHANGE IMPACTS.

AERIAL VIEW: LONDON

# CENTRAL PARK: SUSTAINABLE, LIVEABLE, RESILIENT, AND FUTURE READY

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THE UTILITIES INFRASTRUCTURE OF THIS NEW MIXED-USE URBAN RENEWAL PROJECT IN SYDNEY IS A COMPLEX INTEGRATION OF SYSTEMS THAT PROVIDES AFFORDABLE LOW-CARBON ENERGY AND A RELIABLE AND SUSTAINABLE SOURCE OF WATER.

THE CENTRAL THERMAL PLANT IS THE ENGINEERING HEART OF CENTRAL PARK AND A PRIME EXAMPLE OF A PROJECT THAT PROVIDES STRONG BENEFITS IN THREE AREAS: SUSTAINABILITY, LIVEABILITY, AND RESILIENCE.

Australian cities are among the world's most sprawling and least affordable cities. Our continent is water scarce, and our grid one of the most carbon intensive in the world. Affordability – Density – Resource Efficiency – Amenity – these are interconnected foundational elements of successful cities of the 21st century. Cities must become more resilient to the physical, social, and economic challenges that are a growing part of the 21st century; they must incorporate a view of resilience that includes not just the disasters – floods, earthquakes, fires – but the stresses that weaken the fabric of a city on a day-to-day basis.

While liveability in Sydney is rated one of the highest globally, the challenges of increasing density and maintaining amenity are substantial. Furthermore, our city utilities were never envisioned for the compact cities now required to remain globally competitive. As a nation and a city, new models of urban innovation are needed to enable the kind of renewal that will keep Sydney at the pinnacle of global cities.

The Central Park Project in Sydney seeks to provide a blue-print for addressing these challenges for urban Australia, servicing increased density with low-impact energy and water systems while improving public amenity and liveability. The new model for urban infrastructure implemented at Central Park, a mixed-use urban renewal project comprised of residential, student accommodation, commercial office, retail and public space components, can be a crucial enabler in addressing the scale and nature of urban renewal development needed across Sydney.

WSP (now part of WSP | Parsons Brinckerhoff) was involved from the project's conception and provided integrated services (with an environmentally sustainable design focus) that included: mechanical, electrical, hydraulics/plumbing, vertical transportation, fire safety and fire protection, and energy and water assessments.

## THE PROJECT

Central Park (the former Carlton and United Brewery heritage site) is in the central business district (CBD) of Sydney, anchoring a broader development site with the University of Technology, Sydney (UTS). Delivered by Frasers Property Australia and Sekisui House Australia, the project demonstrates the developers' aspirations to create an environmentally sustainable urban precinct through a combination of certified green buildings, green public domain, and sustainable district utilities infrastructure.

The Central Thermal Plant is the engineering heart of Central Park and a prime example of a project that provides strong benefits in three areas: sustainability, liveability, and resilience. It is a fully integrated thermal energy, electricity and water utility system, enabled by a ground-breaking precinct governance framework and financed by one of the first low-carbon environmental upgrade agreements (EUA) in New South Wales (NSW), and it has pioneered the delivery of district infrastructure in an urban regeneration context.

The precinct utility provides affordable, low-carbon energy and a reliable and sustainable source of non-potable water through a 20MW central thermal plant, 2MW tri-generation and 1ML/day district water recycling and re-use system.

## PROJECT INNOVATION

The Central Park utilities infrastructure is a complex engineering feat of electrical, gas, and thermal energy and potable, recycled and stormwater management. The integration of these systems with a complex, multi-user community is a first, and it has required collaborative innovation by the design, construction, and commercial teams:

- **Technical Innovation:** The phased delivery of precinct thermal energy systems and the first low-carbon 'green transformer' tri-generation system in Sydney has developed new expertise in the design and construction sectors in Australia. Furthermore, constructing a utility hub within a spatially constrained urban precinct has proven an enabler for similar systems to be delivered more efficiently across the Australian market.
- **Governance Innovation:** The implementation of shared thermal services has required innovation in governance frameworks to create a functional market for thermal energy between disparate ownership and stakeholder profiles including the developers, Department of Planning and Infrastructure, residents, and tenants (residential, commercial, and retail). Central Park provides for reform in the broader energy market to allow both thermal energy retailing and embedded generation.
- **Commercial/Financial Innovation:** The financial innovation of the environmental upgrade agreement (EUA) process for infrastructure finance servicing multiple buildings (including complex ownership

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and heritage considerations) is a first and has revolutionized the urban infrastructure market in Australia. It has led to a much broader uptake of low-carbon energy funds from major financial institutions.

## RESILIENCE ASPECTS

The project has been designed with resilient features which include the following benefits and mitigation aspects:

- Delivery of affordable, low-carbon energy: this provides mitigation against climate change and it offers resilience to the economic cost-of-living pressures on its residents and commercial businesses.
- Central thermal plant: the CTP remains as a standalone autonomous "box", minimising reliance on the local electrical grid. This arrangement requires careful thought into the system arrangement and system drivers to ensure that the tri-generation plant will be fully utilised and all outputs balanced.
- Thermal energy storage: this process of storing redundant thermal energy that is generated by the tri-generation system and thermal plant to use at a later time reduces the need and size of energy infrastructure normally designed to satisfy peak demand, for example, it reduced the number of required electric chillers from 32 to 8; the number of boilers from 24 to 5; and the number of cooling towers from 24 to 12. For resilience, a back-up emergency power system is provided for the plant room.
- Separating thermal and electrical networks: this principle long established in Nordic countries, global leaders in urban sustainability, enables both the improved feasibility of renewable energy on the electrical network side (by reduced demand and improved load consistency) and the opportunities for waste-heat capture for thermal networks. Both these approaches are front-line strategies in reducing reliance on fossil fuels and reforming the energy sector. Large-scale energy sector reform is a crucial element in successfully addressing climate change. The outputs of the CTP fall under the categories of electrical and thermal output:
  - Electrical output – utilised to supply the conventional electrical chillers, pumping equipment, cooling towers and plantroom lighting; and
  - Thermal output – utilised for space heating, domestic hot water and for the generation of chilled water by the absorption chiller plant.
- Cooling/heat rejection: the water-cooled electric chiller plant has been optimally configured to achieve a high operational efficiency through effective load matching with the cooling demand profile of the precinct. The modularity of the electric chiller plant ensures sufficient resilience in case of breakdown and routine maintenance, inclusive of the absorption chiller plant configuration.
- Recycled Water Treatment Plant (RWTP): low total dissolved solids (TDS) make-up water will be sourced from the RWTP to serve the cooling towers, which will be backed up by the Sydney water mains.

## SUMMARY

The Central Park CTP is an exemplar project for urban utilities, changing the paradigm for our management of urban energy and water networks.

- It integrates cutting edge technology across energy and water systems; shared thermal services, tri-generation, private electricity networks, waste-water treatment and sewer mining to deliver low-carbon energy and low-impact water to residents, commercial tenants, building owners and the public domain.
- The CTP is a highly complex industrial-scale utility delivered in a dense urban precinct without compromising visual or environmental amenity.
- It has tested the governance structures of energy market regulation, and broken new ground in the reticulation and commercialisation of thermal energy networks in Australia.
- It has leveraged innovative finance mechanisms – the first environmental upgrade agreement and first low-carbon fund in Australia – to be wholly privately funded.
- It has delivered on the triple-bottom line, engineering that serves people, profit, and planet.

***Richard Palmer** is Associate Director for the WSP | Parsons Brinckerhoff Sustainability team in NSW and has played a leading role in the sustainability advisory and analysis services for district utilities in Australia.*

# FLOODING OF HOSPITALS DUE TO EXTREME WEATHER CONDITIONS

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AFTER A MASSIVE STORM CAUSED MAJOR FLOODING IN THE CITY OF MALMÖ IN SWEDEN, A METHOD WAS DEVELOPED TO EVALUATE THE RESILIENCE OF THE CITY'S HOSPITALS TO FLOODING AND DETERMINE WHICH HOSPITALS WERE MOST VULNERABLE.

On the morning of August 31, 2014, the southwestern area of Sweden was hit by a massive storm and Malmö, one of the largest cities in Sweden, was severely struck by the storm which brought heavy rainfall and flash flooding. Roads were flooded, basements filled with water, and public transport was disrupted.

The Swedish Meteorological and Hydrological Institute (SMHI) had issued a 'level 1' warning, meaning that the weather could cause certain risks to the public and disruption for some civil functions. However, the hospital in Malmö was not prepared for the large amounts of surface water flooding due to the storm and consequences were severe at the hospital site. Surgical procedures were canceled, patients were evacuated, and equipment had to be replaced due to contamination.

As a consequence of the storm, Region Skåne, the healthcare organization responsible for the operation and maintenance of major hospitals in the area, contracted WSP (now part of WSP | Parsons Brinckerhoff) to investigate and evaluate the ability of hospitals in Skåne County to withstand future flooding events.

## DEFINING THE METHOD

Hospital disaster resilience can be defined as a hospital's ability to respond to the shock of disasters while maintaining critical functions, and then to recover to its original state or adapt to a new one.

WSP | Parsons Brinckerhoff Fire & Risk group developed a method to evaluate the hospitals' resilience related to flooding, determine which hospitals were most vulnerable, and suggest risk reducing actions to be implemented.

Nine hospitals in Skåne were visited and inspected, and maintenance personnel and other relevant staff were interviewed to acquire the necessary information.

Hospitals were evaluated to assess both the likelihood and the consequences of the flooding event. To determine the likelihood of flooding (high likelihood or low likelihood), key factors were analyzed such as:

- past records of surface water penetrating the building;
- building placement and orientation (e.g., on a slope, low ground, a hill); and
- condition of the surrounding area (e.g., surface water, asphalt).

Depending on the answers, the investigated hospitals were put in either the "high likelihood" category or the "low likelihood" category.

To determine the consequences of a flooding event, a number of criteria were defined to determine the extent that medical care would be affected. These criteria included, amongst other effects, investigations regarding the type of equipment that would be affected if the hospital was flooded. Hospitals would then be placed in one of three categories of consequences –

## TO DETERMINE THE CONSEQUENCES OF A FLOODING EVENT, A NUMBER OF CRITERIA WERE DEFINED TO DETERMINE THE EXTENT THAT MEDICAL CARE WOULD BE AFFECTED.

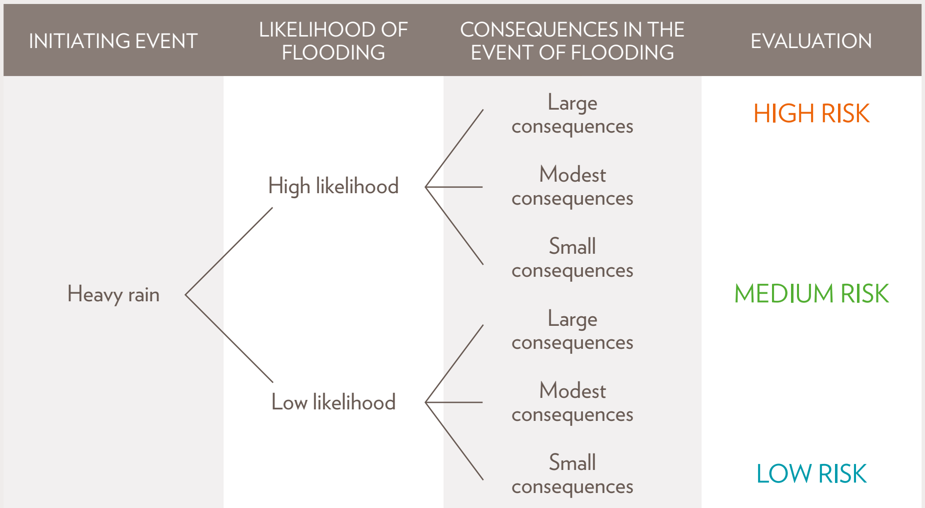


**FIGURE 2** - EVALUATION OF RISK

"small" consequences, "modest" consequences, and "large" consequences.

After determining the likelihood and consequences of a flood event, a schematic assessment of the overall risk value was wqperformed.

## RESULT

After applying the method to the investigated hospitals (see Figure 2), the results were:

- Four hospitals were categorized as "High risk";
- Two hospitals were categorized as "Medium risk"; and
- Three hospitals were categorized as "Low risk".

## CONCLUSION

The method developed by WSP | Parsons Brinckerhoff to investigate and evaluate the ability of hospitals to withstand future flooding events provided the client, Region Skåne, with results that will enable them to prioritize future resilience work so that a focus can be on the hospitals in most need of risk-reducing measures.

The Swedish Meteorological and Hydrological Institute states that due to climate change, heavy rains will be more and more common in the future. This method can help counties, not only Skåne but also in other parts of Sweden, to evaluate current conditions and develop future resilience strategies.

***Johannes Lärkner** is a Project Manager with the WSP | Parsons Brinckerhoff Fire and Risk group in Sweden. He holds a M.Sc. in Sociotechnical Systems Engineering and has been working with the concept of risk from different perspectives for almost ten years.*

# RESILIENCE FOR HIGH-END RESIDENTIAL PROPERTIES

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NEW FLOOD MITIGATION MEASURES WERE INCORPORATED INTO THE DESIGN OF A LUXURY RESIDENTIAL BUILDING IN MANHATTAN AFTER HURRICANE SANDY TO MAKE IT MORE RESILIENT TO FUTURE STORMS.

FIGURE 1 – PROJECT SITE AT 150 CHARLES STREET AFTER HURRICANE SANDY (OCTOBER 2012)

For the building design community, the impact of Hurricane Sandy didn't just stop with the clean-up. It has influenced the way we design buildings in New York City today and for the future. Regardless of the phase of a project, after Sandy, the design team had to reconsider their design to accommodate flood mitigation measures. One such project was a high-end (or luxury) residential building project at 150 Charles Street in the West Village neighborhood of Manhattan.

The 15-story residential building, designed by CookFox Architects with the Witkoff Group as the developer, is 240,000 square feet and includes over 90 apartments, extensive green terraces, a swimming pool, gym, and parking garage. WSP (now part of WSP | Parsons Brinckerhoff) provided MEP (mechanical, electrical, and plumbing) engineering services as well as fire protection engineering. Excavation was completed and construction documents were at 90 percent complete when the project site was partially flooded by the hurricane. An adjacent building exterior wall collapsed into the project site and the area was without power for one week (see Figure 1).

After Hurricane Sandy, the developer had its team of architects and engineers rethink the building design. A list of items was proposed to be incorporated into the project design to make the building resilient in the event of future storms. All resiliency suggestions were implemented. However, the efforts delayed the project by six weeks and added as much as $3 million to its cost.

## RESILIENCE MEASURES

The first major concern was the loss of power to the area. The installation of two natural gas emergency generators that would accommodate basic building operations was incorporated into the design. Finding a location for the generators was a challenge in itself. As the project was already 90 percent designed, the team was tasked with finding an additional 760 square feet of available roof space. Through several iterations and brainstorming sessions, it was decided to install the two generators above the elevators. In addition to the roof space, riser space for emergency generator conduits was required throughout the project. Both obstacles were overcome by the design team through collaboration.

In the event of a blackout, the two natural gas generators would run building services such as the fire alarm system, elevators, sewage ejector pumps, domestic water pumps, water heaters, and emergency egress lighting. Also, each apartment would be equipped with at least one electrical outlet connected to the emergency generator. WSP | Parsons Brinckerhoff designed for a large current draw in the individual apartment outlets, assuming that a power strip will be plugged into the single emergency outlet for multiple electrical devices. A 20 amp breaker was added per apartment, capable of handling 1.92 kW, whereas a normal convenience receptacle would draw 0.18 kW.

Other resiliency tactics implemented were for flood control. The subcellar level has a recessed swimming pool, with a bottom elevation 46 feet below the 100 year floodplain. Hurricane Sandy's storm surge raised the water level an additional 9.4 feet above the predicted astronomical tide levels[1] for Battery Park City (approximately 2 miles south west of the project site). The following measures were taken to keep the building dry in the event of another superstorm:

- Floodgates have been designed to encircle the building at the perimeter of the project site. Posts installed at regular intervals with designed locking flood panels can be assembled in a matter of hours. These panels extend 5 feet above the lowest point of the adjacent sidewalk to mitigate the effects of future flooding. The flood panels and posts are stored in the basement of the building. Permanent footings and anchor plates were installed at the sidewalk, into which these posts would be placed if a flood event is predicted. Structural consideration had to be given to the location and the design of the post support system.
- A flood mat was designed by the structural engineer to resist external groundwater pres-

[1] NOAA Water Level and Meteorological Data Report, Hurricane Sandy, January 24, 2013, page 9, Table 1b; http://www.tidesandcurrents.noaa.gov/publications/Hurricane_Sandy_2012_Water_Level_and_Meteorological_Data_Report.pdf

sure up to that of a flood level. Due to the depth of the subcellar pool, water pressure at 50 feet below the surface of the flood surge can be large.

- Backflow prevention valves were added to the sanitary and stormwater outlet of the facility which is approximately 20 feet below the 100 year floodplain. The backwater valves were designed to withstand the pressure, keeping the flood water out of the sanitary piping system and from backing into floor drains and plumbing fixtures.
- The sanitary distribution system was redesigned for the project as well. Originally, the cellar and subcellar sanitary system was piped to a sump pump located in the subcellar level. It was designed for a 100 year flood event. To address water levels experienced during Hurricane Sandy, the ground floor plumbing fixtures and floor drains were included in piping to the sump pump. The size of the sump pumps was increased from two pumps with a 500 GPM capacity to three pumps with a 700 GPM capacity. This increased the capacity 40 percent and created more redundancy.
- Specific rooms identified as critical spaces - electrical switch gear room, boiler rooms, gas meter and water meter rooms, telecommunications room - were designed with cast-in-place concrete walls for flood mitigation. In addition, the doors in the flood control walls were designed with anchors for demountable flood panels.

The 150 Charles Street project is an example of how residential units are now being designed to higher standards (see Figure 2). The market for luxury apartments almost demands these kinds of services and amenities for their buildings with one broker saying he was instructed to bring up flood planning before buyers did. "The last thing we wanted was for people to fall in love with the building and then go home and say to themselves, 'But what about flooding?'"[2] said a broker at the real estate firm that oversaw sales at 150 Charles Street. Future projects will need to be "Hurricane Sandy ready" as a marketable feature.

*Manda Magee is a Mechanical Engineer working in WSP | Parsons Brinckerhoff Building Systems for 9 years in the New York office, and for 15 years in the field. Her experience is in various building project types including academia, healthcare, corporate, government, residential and retail.*

[2] http://www.wsj.com/articles/SB10001424052702303759604579095620022672240

FIGURE 2 – RENDERING OF 150 CHARLES STREET

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# RESILIENCE IN ADOPTING GREEN BUILDING DESIGN – NATURAL LIGHTING FOR INDOOR SWIMMING POOLS

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'VEIL REFLECTION' IN INDOOR SWIMMING POOLS CAN IMPAIR THE VISION OF LIFEGUARDS AND AFFECT LIFE-RESCUE. THE AUTHOR ILLUSTRATES THE USE OF 'RESILIENCE AND ADAPTIVE CYCLE THEORY' IN A STUDY TO DEVELOP NEW DESIGN GUIDELINES FOR INDOOR SWIMMING POOLS IN HONG KONG.

## INTRODUCTION

Under the aegis of environmental protection and corporate responsibility, there are concerns being raised on different sustainable design concepts in buildings. In the last decade, there have been green building tools/assessment schemes made available which set standard protocols for green buildings. These protocols are good for building professionals and enable building designers to follow concrete guidelines instead of abstract concepts. However, such guidelines have their limits and once the limits are exceeded, a sequence of unexpected events may be the outcome.

In this article, the author illustrates the use of 'resilience and adaptive cycle theory' on a project studying the natural light design practices for indoor swimming pools in Hong Kong to improve the sustainable design process. Applying adaptive cycle theory, Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) was able to identify points of weakness and to develop comprehensive design guidelines.

## SAFETY IN SWIMMING POOL

Swimming is one of the most popular recreational activities and an important survival skill, and swimming pools have existed for centuries. Safety is of primary concern for most stakeholders, and many of the safety aspects of indoor pools, such as the filtration systems, non-slippery floors, and appropriate water temperature, are related to building design. It has been well documented that safety measures are useful in minimizing fatal accidents.

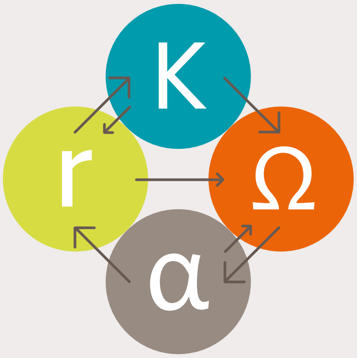
The adoption of 'green' building design introduced new challenges to safety in swimming pools by promoting large openings and windows for light and ventilation, which in some cases result in 'veil reflection' on the water surface of the swimming pool. These reflections may impair the vision of lifeguards and affect life-rescue.

## RISK ASSESSMENT THROUGH 'RESILIENCE AND THE ADAPTIVE CYCLE' CONCEPT

WSP | Parsons Brinckerhoff utilized the 'resilience and adaptive cycle' framework for their study on veil reflection, and to develop new design guidelines. There are four phases in an adaptive cycle: growth or exploration (r), conservation (K), release or collapse (Ω), and reorganization (α). As systems move along the adaptive cycle they gain and lose connectivity, capacity, and resilience to disturbance (see Figure 1).

### GROWTH OR EXPLORATION (r) PHASE

In the early stage of 'green' building design, large openings and windows for admitting more daylight and providing natural ventilation were promoted. Experienced designers and specialists spent time investigating the possible impact of adding such features. In this phase, project teams tend to take precautionary measures and to use prototype design as well as limiting the area of application. There is no major report on the occurrence of veiling reflection (reflected glare on the water surface of the swimming pool which can impair the vision of the lifeguard). The shortcomings are that highly intensive coordination and mature understanding of theory are required and the




**K - CONSERVATION**
Things change slowly; resources 'locked up'

**Ω - RELEASE**
Things change very rapidly 'locked up' resources suddenly released

**α - RE-ORGANIZATION/RENEWAL**
System boundaries tenuous; innovations are possible

**r - GROWTH/EXPLORATION**
Resources readily available

**FIGURE 1** – RESILIENCE AND THE ADAPTIVE CYCLE CONCEPT, SHOWING POSSIBLE CHANGES BETWEEN PHASES

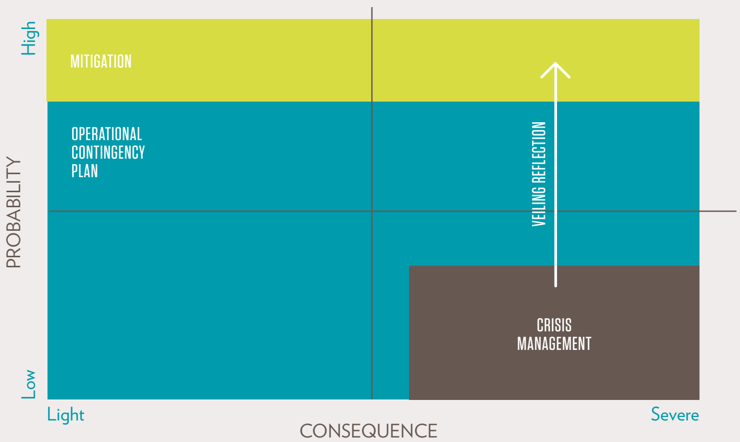



**FIGURE 2** – VULNERABILITY STUDY ON EFFECT OF GREEN BUILDING DESIGN ON VEILING REFLECTION IN SWIMMING POOLS


efficiency of the design process is relatively low and not able to satisfy all best practices and guidelines.

## CONSERVATION (K) PHASE

After sufficient experiences were gained from various projects, several design practices and rules of thumb were established. In this phase, most professionals can carry out the design. The design processes become smooth and mature. Each component, such as the use of openings for natural lighting and ventilation, is well integrated into different design considerations and responds to various local code requirements and is accredited with several green building certifications. The stakeholders benefit from the high efficiency of the design process in the meantime; and the different authorities and certification bodies are familiar with the design approach. The trade-offs are the reduction in flexibility of design and less room to identify and solve project-specific problems by an alternative method. After the mass production of "green" swimming pools, dramatic increases in the observation of veiling reflection were reported by the operation teams. Worse still, veiling reflection becomes one of the reasons for delay in several life-rescue cases.

## RELEASE OR COLLAPSE (Ω) PHASE

Drowning is one of the top three leading causes of unintentional death worldwide[1]. In Hong Kong, approximately seven fatal incidents of drowning in swimming pools are reported per annum. The increase in delay of rescue and near-miss rescue cases raised the concern of the public and government operating authorities. Furthermore, lifeguard associations have sometimes refused to staff these "green" swimming pools due to an unacceptable level of veiling reflection. Hence, abortive work and delay in handover is found in new swimming pools.

Expressed in terms of vulnerability (see Figure 2), new green building design raised veiling reflection from crisis management (rarely occurs but serious consequence) to a challenge that must be mitigated (veiling reflection occurs several hours a day). Since veiling reflection might cause drowning and death, and "green" swimming pools increase the occurrence of veiling reflection, its consequence is considered to be severe. When relevant government authorities gave serious consideration to veiling reflection in project implementation, many ideas were generated by stakeholders such as: using ›

[1] World Health Organization, 2004, The World Health Report: 2004: Changing History, World Health Organization, Geneva, Switzerland.

CCTV instead of lifeguards, using high-quality (low-e) glazing, adding shading devices to the pool area, installing more underwater lighting, and providing polarized sunglasses to lifeguards.

### REORGANIZATION (α) PHASE

In the release or collapse phase (Ω), many new ideas were proposed and applied to new swimming pools. As these innovative ideas were tested, it enabled stakeholders to sort out major key factors and constrain the dynamic. A series of studies were conducted to identify the key design parameters, the challenges of natural and artificial lighting design in swimming pool design, and major mitigation measures. The first design guidelines worldwide on this specific topic were developed and the arrangement specifically addressed the weakness of the design process in the growth or exploration (r) and conservation (K) phases.

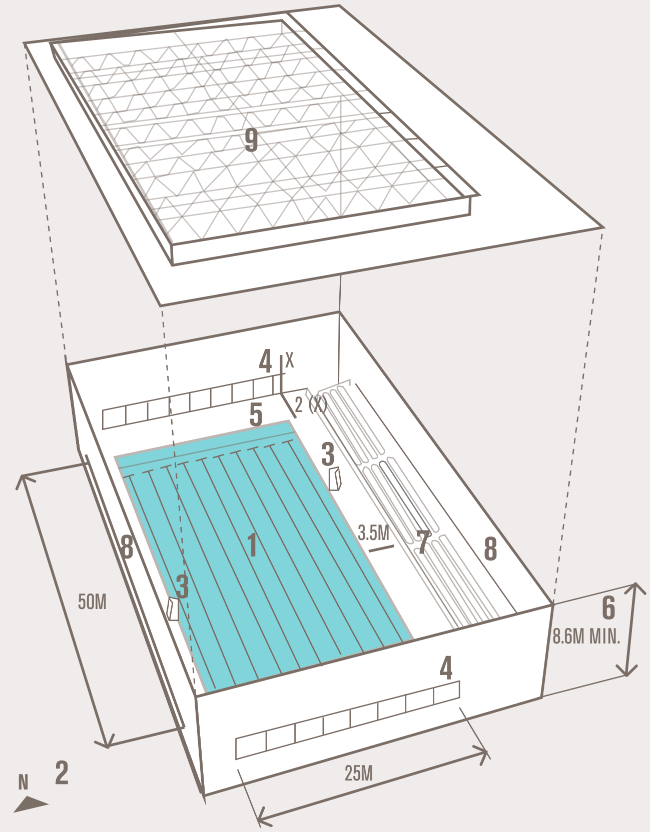
## WSP | PARSONS BRINCKERHOFF'S ROLE

WSP | Parsons Brinckerhoff was appointed by the government of Hong Kong as lead consultant in reviewing the existing design and developing a new design practice of natural and artificial light in indoor swimming pools in the reorganization (α) phase.

Apart from research study, the team also needed to identify the point of weakness through different tools, including the adaptive cycle framework. The major objective is to absorb disturbances (green building design practices, etc.) and still retain the basic function and structure (a safe and enjoyable swimming environment).

In the development of these guidelines, a study based on resilience and the adaptive cycle theory found the following:

- There is no principle on the design for swimming pools related to lighting and water body in existing documents [growth or exploration (r) phase].
- There is no conceptual guidance outlining the relationship between different design criteria and veiling reflection [growth or exploration (r) phase].
- There is a need to demonstrate how the above principles and theories can be applied in building design to prevent a misunderstanding of principles [conservation (K) phase].




IDEAL MODEL OF 25M X 50M INDOOR SWIMMING POOL WITH ROOFLIGHTS

## DESIGN EXAMPLES

### CASE 2 - WITH ROOFLIGHT

1 **Pool Basin** finish to have min. reflectance of 0.7.

2 **Swimming Pool** to be north /south oriented. 25m short sides facing north & south. 50m long sides facing east & west.

3 **Lookout Post for Lifeguards**

- At middle 1/3 zone of pool length
- Not to be opposite windows

4 **Window** at north & south ends of pool to reduce exposure to low altitude sunlight.

5 **Pool Deck Width and Window Height** - Pool deck width to be twice the window height to reduce veiling reflection.

6 **Building Height** - The height of ceiling is governed by artificial lighting system.

7 **Spectator Stand** not to directly face windows and the resultant veiling reflection.

8 **Ventilation Consideration** - Louvres recommended for natural ventilation.

9 **Rooflight**

- Area should be at least 50% of the pool deck area.
- Internal shading recommended to block out direct glare by sunlight.
- Light transmittance value of the glazing should be greater than that of the glazing for the windows by at least 0.2.

FIGURE 3 – ARRANGEMENT OF THE IDEAL SWIMMING POOL

The design guidelines shall do the following:

- Highlight the induced lighting problems in swimming pools and bridge the missing link between artificial and natural lighting design for swimming pools.
- Transform the physical/biological rules and conceptual relationships into concrete design guidelines that most building professionals can follow.
- Provide work examples (Figure 3) with renderings (Figure 4) for building professionals to study in order to avoid any misunderstanding of the proposed guidelines.

## CONCLUSION

New design concepts create new opportunities for design professionals but can also create challenges. Developing a system that can accommodate any change in design practices without deviating from the original principle is not easy. Using resilience assessments in different new sustainable designs help to identify potential problems at an early stage but, due to the one-off nature of building projects, applying complete assessments is not yet affordable. This project illustrates that several weaknesses in the design process can be identified through applying the concept of resilience and the adaptive cycle, and innovative measures were proposed to handle these issues. The first design guidelines would undergo other resilience and adaptive cycles, but the uncertainties between veiling reflection and other design practices have been reduced.

***Ernest Tsang**, Sustainability Specialist based in Hong Kong, has been involved in projects which included a study in code and guideline development, design and study of combined heat and power plants, energy analysis of various types of buildings and green building certification. He has a PhD in Daylighting and Building Energy.*

FIGURE 4 – THE RENDERINGS OF AN IDEAL SWIMMING POOL USED AS A REFERENCE BY STAKEHOLDERS

# RESILIENCY PUT TO THE TEST: ST. PATRICK'S BRIDGE

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THE NEW BRIDGE WAS DESIGNED TO WITHSTAND BOTH HIGH FLOOD WATERS AND HIGH ICE FLOES, BUT A 1-IN-100-YEAR FLOOD CAME AT A VULNERABLE PHASE IN THE CONSTRUCTION PROCESS.

The planning, design, and construction of the iconic St. Patrick's Bridge in Calgary, Alberta, Canada had been underway for more than four years when, only three months away from expected completion, a record flood threatened to wipe out the bridge in June 2013.

The bridge passes over the Bow River which is fed by glaciers and snowpack from the Rocky Mountains. Rapidly melting snow and ice combined with heavy rainfall upriver from Calgary and sent torrents of water past the bridge and flooded the city and the surrounding region, causing nearly CAD$5 billion in damage throughout the province of Alberta, the most expensive natural disaster in Canadian history. The bridge designers, RFR (Paris, France), in partnership with Parsons Brinckerhoff-Halsall (now part of WSP | Parsons Brinckerhoff) had anticipated and designed for this and other hazards. However, the design of the temporary works did not account for such a hazard, and the flood came at a vulnerable phase in the construction process.

## BRIDGE DESIGN AND CONSTRUCTION

St. Patrick's Bridge consists of a 182 meter (597 foot) continuous three-span network tied-arch, with a main span length of 99 meters (325 feet). The network arch form combines the arch ribs and deck in a truss-like structure, where the ensemble is stronger than the parts (see Figure 1). The arch ribs are each composed of twin steel tubes joined by welded top and bottom plates forming oblong cross-sections, and they run continuous between the sliding bearings on the two abutments.

The arch rib cross-sections, which are only 400 millimeters (16 inches) tall but vary in width from 1130 millimeters (45 inches) to 1550 millimeters (60 inches), give the arches significant out-of-plane strength to resist lateral loads from wind, water, ice, and earthquakes, and eliminate the need for bracing between the arches except for one bracing point at the peak of the main span, all while maintaining a slender profile.

The slender 320 millimeter (12 inches) thick cast-in-place concrete deck, with longitudinal post-tensioning, acts as a tension tie to hold the ends of the arches together, while minimizing the grade with its minimal profile. Over the majority of the two river channels, the only connections between the arches and the deck are the hangers by which the deck is suspended from the arches (see Figure 2). Slender steel struts support the deck from below over the island span. ›

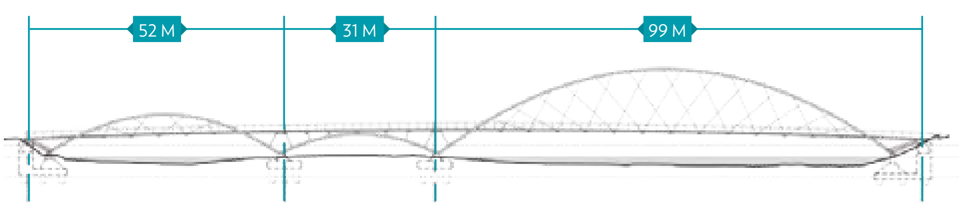



FIGURE 1 – PROFILE OF ST. PATRICK'S BRIDGE

FIGURE 2 – CONCEPTUAL ISOMETRIC CROSS-SECTION OF ARCH RIBS AND DECK (IMAGE COURTESY OF RFR)


FIGURE 3 — AERIAL IMAGE OF BRIDGE CONSTRUCTION JUST PRIOR TO FLOOD (NOTE GRAVEL BERMS PARTIALLY BLOCKING RIVER CHANNELS)

In order to construct the deck, rebar was placed and concrete was poured on forms that were set on a series of closely spaced falsework towers (temporary support towers). The towers were supported by temporary gravel berms that partially blocked the river and on temporary steel girders that spanned the openings in the berms (see Figure 3).

## THE FLOOD

When the flood waters rose in June 2013 (see Figure 4), the deck had only recently been completed and was not yet suspended from the arches, in part because the prefabricated steel arch sections were still in the process of being assembled and welded together. The floodwater and the debris that it carried overtopped the berms, washing them away and knocking out significant portions of the falsework (see Figure 5). This forced the deck to span distances for which it was never designed. A post-flood investigation revealed that the deck was severely cracked with permanent yielding of the steel reinforcing bars and steel post-tensioning tendons inside the deck. Consequently, the new deck had to be demolished and reconstructed, setting back the project completion date by a year.

Some good news came from the flood event; before the bridge was even completed, it had experienced a 1-in-100-year flood and survived with no serious consequences to the permanently fixed structure, which includes the piers, abutments, and the steel arches, whose lower sections were in place and were inundated by the flood waters. This demonstrated the benefit of having designed the bridge to be resilient from the beginning. Furthermore, the water never overtopped the deck, validating the design freeboard requirement.

## DESIGN FOR RESILIENCE

St. Patrick's Bridge was initiated by an international design competition launched in August 2009. The owner, Calgary Municipal Land Corporation (CMLC), recognized early on that the wild Bow River posed a risk to the future bridge and so a robust set of design criteria was established from the outset. The design criteria, communicated as part of the design competition Request for Submissions, included specific seismic, hydraulic, geotechnical, and geometric criteria to ensure resiliency against natural hazards. These criteria included the following:

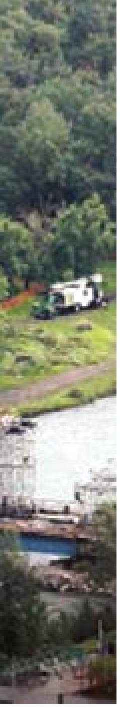
- Seismic design per the Canadian Highway Bridge Design Code;
- All piers and abutments to be founded on driven piles or drilled caissons;
- Eliminate or minimize the number of bridge piers located in the river;
- Design for a 1:100 flood event with a water velocity of 2.8 meters/second and mandatory calculation of pier scour;
- Bridge deck soffit to be a minimum of 1 meter (3 feet) above the 1:100 year flood elevation;
- Maximum ice level of elevation 1042 meters, slightly higher than the 1:100 flood elevation, with an ice crushing strength of 700 kiloPascals (100 psi);
- Minimum bridge freeboard of 1.5 meters (5 feet) over maximum ice level; and
- Mandatory involvement of the client's river hydrology specialist.

After CMLC selected the concept put forth by the RFR/Parsons Brinckerhoff-Halsall (now part of WSP | Parsons Brinckerhoff) team, the detailed design began in the summer of 2010. As the design progressed, the river ice was studied in more detail by the client's hydrology specialist and the design loads were clarified.

Because the Bow River is a fast moving river, ice buildup is typically composed of frazil ice, which is an accumulation of floating ice crystals created by super-cooled moving water. The frazil ice buildup can be up to 3 meters (10 feet) thick when it forms at the bridge site, especially where the water overtops land such as the island, but with little to no internal strength. At the time of the seasonal spring breakup when the river starts moving again, the ice in the river channel is typically about 0.5 meter (1.6 feet) thick and is substantially disintegrated, so the design ice crushing strength was reduced to the corresponding code value of 400 kiloPascals (60 psi). This ice pressure and thickness was applied to the arch and strut members present at the maximum ice elevation to maximize its effects on the design. All of the criteria to protect against natural hazards were incorporated in the design without any exceptions.

One of the goals of the bridge project was to link St. Patrick's Island, located in the middle of the Bow River, with both river banks. However, the island surface is below the 1:100 year flood elevation, so the criteria did not permit the bridge deck to touch down on the island. Instead, a secondary ramp links the island span of the main bridge with the ground surface of the island. A slender elevated ramp was used as opposed to an earthen embankment to avoid adding fill to the floodplain.

Despite the strict design criteria for natural hazards, the designers succeeded in creating a graceful structure that will be a Calgary landmark for years to come. This was made possible by



# 182 M

CONTINUOUS THREE-SPAN NETWORK TIED-ARCH

# 99 M

MAIN SPAN LENGTH

design choices for the structure type, member cross-sections, and material selections, all of which contributed to the slender but strong design. And, thanks to the early test put forth by Mother Nature, the owner and the designers know without a doubt that the bridge is resilient.

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**FIGURE 4** — HIGH WATER DURING THE FLOOD

**FIGURE 5** — AFTER THE FLOOD, BERM AND FALSEWORK WERE WASHED AWAY

# ADAPTING THE LOWER DECK OF AN EXISTING BRIDGE FOR LIGHT RAIL OPERATION AND TYPHOON CONDITIONS

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THE NORTHWESTERN PACIFIC BASIN REGION IN WHICH THIS BRIDGE IS LOCATED IS THE MOST ACTIVE CYCLONE BASIN IN THE WORLD AND ALMOST ONE-THIRD OF THE WORLD'S TROPICAL CYCLONES OCCUR HERE EACH YEAR.

## INTRODUCTION

The lower deck of a bridge in China is being made ready for future light rail transit (LRT) operation. The 2 kilometre (1.2 mile) cable-stayed bridge with double-deck design has an upper deck with three traffic lanes in each direction, and an enclosed lower deck which will accommodate light rail transit operation and a vehicle traffic lane only to be used in the event of a strong typhoon, i.e., when for safety reasons the upper deck is closed to traffic.

This Northwestern Pacific Basin region, in which this bridge is located, is the most active cyclone basin in the world and almost one-third of the world's tropical cyclones occur here each year. Tropical cyclone warning signals in Hong Kong/Macau are a set of signals used to indicate the threat or effects of a tropical cyclone. Signal 8 indicates that gale or storm force winds are expected, with a sustained wind speed of 63-117 kilometres per hour (39-73 miles per hour) from the quarter indicated and gusts that may exceed 180 kilometres per hour (112 miles per hour). In the past, the signals were physically hoisted, and the term "hoisted" is still in common usage. When typhoon signal No.8 is hoisted, LRT operations will be suspended and the lower deck of the bridge will be used for vehicle traffic only.

Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) is responsible for the design and upgrade of the mechanical and electrical (M&E) system of the lower deck of the bridge to cope with the future light rail transit (LRT) operation under normal circumstances and the vehicle traffic when typhoon signal No. 8 is hoisted.

The enclosed lower deck level of the bridge consists of two tubes of 2-lanes each approximately 2 kilometres (1.2 miles) in length. One side of the lower deck is exposed to ambient and the other side is connected to an underground station and a slip road to ambient environment. For this project, the M&E systems include:

- Tunnel Ventilation System (TVS);
- Fire Services (FS);
- Drainage System;
- Traffic Control and Surveillance System (TCSS);
- Electrical System (power supply for TVS, TCSS, FS, lighting system); and
- Monitoring and Control System.

## KEY CHALLENGES AND SOLUTIONS

### TUNNEL VENTILATION SYSTEM TO BE OPERATED UNDER A TYPHOON CONDITION

During this time, in the event of a fire inside the lower deck (e.g., 10 MW vehicle fire), the tunnel ventilation system shall be able to operate at an external wind condition of 120 kilometres per hour (75 miles per hour). The additional airflow resistance induced by a typhoon scenario was taken into consideration in the tunnel ventilation fan selection. The special fan and ductwork configuration has been designed to meet the operational requirement and site constraint.

In general, semi-transverse ventilation is adopted for smoke control inside the typical section of the lower deck of the bridge. Smoke extraction fans will be installed along the wall of the outer lane grouping into different ventilation zones. During fire emergency ventilation, fans in a number of continuous ventilation zones will be operated together for extracting the smoke from the tunnel. Makeup air will come from both ends of the tunnel and the 800 millimeter (31 inch) diameter opening on the wall of the inner lane. For localized areas where semi-transverse ventilation cannot be provided, a push-pull ventilation system is adopted.

To facilitate passenger evacuation from the vehicles and train, an evacuation walkway at 1.4 meters (4.6 feet) above the floor level is provided along the tunnel.

The smoke spread behavior and the time duration required for a smoke-clear environment to be maintained for safe evacuation under the design ventilation capacity has been verified by computational fluid dynamic (CFD) simulation analysis. In particular, it is very challenging to determine the wind effect on the smoke behavior with the consideration of the bridge configuration, the arrangement of the portals, the magnitude of the wind speed, and the wind direction. Moreover, a computerized evacuation model is applied to determine the time duration required for evacuating all the passengers inside the tunnel.

### COST EFFECTIVE POWER SUPPLY SYSTEM

The lower deck of the bridge is divided into different ventilation operation zones. During operation of the ventilation system, only the fans serving the corresponding zone will be operated.

Also, not more than two zones will operate at the same time. The cable arrangement for the fan is specially designed to reduce the total amount of cable (which also reduces the overall weight of the cable so that reinforcement for the bridge is not required) to achieve a cost effective design.

### FIRE AND LIFE SAFETY

The fire and life safety concept has been developed with reference to the requirements established in National Fire Protection Association (NPFA) 130 and NFPA 502 and in association with other related NFPA standards as quoted in NFPA 130 and NPFA 502. The Local Macau Fire Code has also been referenced in the fire and life safety design.

With the use of a fire engineering design approach, WSP | Parsons Brinckerhoff assisted the contractor in reducing the amount of modification work required and demonstrated that the proposed configuration of the tunnel evacuation walkway, the cross passage, and the fence opening achieves the evacuation time requirement.

## CONCLUSION

The design phase is completed and the project is under construction. WSP | Parsons Brinckerhoff has been making significant contributions to assist the contractor to: develop a cost effective scheme for the M&E system; reduce the weight/load input on the existing bridge structure; and enhance the safety provisions for the bridge, including resilience measures to ensure the safe operation of the enclosed lower deck under typhoon conditions.

***Cathy Kam*** *is a Mechanical Engineer and is the document controller and assistant coordinator for this bridge project in China.*

***Peter Wong*** *is a Mechanical Engineer specializing in tunnel ventilation system (TVS) design and computational simulation analysis of infrastructure projects. He is one of the design engineers of the ventilation system for this bridge project in China.*

***Alex Wan*** *is an Electrical/Control Engineer with over 23 years of experience and is MEP Deputy Project Manager for this bridge project in China.*

***Steven Lai****, Mechanical Engineer and Senior Professional Associate at WSP | Parsons Brinckerhoff, is MEP Project Manager for this bridge project. He is now working in Singapore as an M&E Project Manager for an upcoming metro line in Singapore.*

# DESIGNING MORE RESILIENT, SECURE TUNNELS WITH PASSIVE FIRE PROTECTION METHODS

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PASSIVE FIRE PROTECTION IS INTENDED TO CONTAIN FIRES, SLOW THE SPREAD OF FIRES, AND PREVENT STRUCTURAL COLLAPSE IN TUNNELS.

Today's complex underground structures and tunnels must be made ready for potential incidents affecting tunnel structures and services, especially tunnel fires. Fire protection comes in two specific forms, active and passive systems. Active systems are in the form of suppression, extinguishers, sprinklers, and extract ventilation. Passive fire protection (PFP) is an integral component of structural fire protection and fire life safety and is intended to contain fires, slow the spread of fire, and prevent structural collapse due to prolonged fire exposure through use of fire-resistant walls, floors, doors, and compartmentation (amongst other examples).

Passive fire protection is vitally important for tunnels and other underground structures because the large heat release rate potential (e.g., 10–20MW), limited escape facilities, and difficulties encountered by emergency services in gaining access for firefighting and rescue, can mean substantially increased risk factors. Providing passive fire protection will allow safe evacuation and emergency team access for firefighting. This article discusses explosive spalling during a fire incident in a tunnel and the different types of passive fire protection available for tunnels.

## EXPLOSIVE SPALLING

During a fire incident, protection of the tunnel walls from explosive spalling (which refers to a sudden and violent breaking away of a surface concrete layer) is very important. In general, explosive spalling is likely to be damaging to the concrete as the heating period increases and will lead to structural collapse if the section is reduced substantially. Explosive spalling occurs due to the release of water content within the concrete when subject to temperatures above 250°C and varies with many factors such as moisture in the concrete, aggregate size, applied load, concrete grade, and reinforcement concrete cover. The occurrence of explosive spalling depends on several factors:

- the strength of the concrete (density);
- the heat build-up rate;
- the compressive stress in the concrete member; and
- the thermal stability of the aggregate.

## METHODS OF PASSIVE FIRE PROTECTION

Passive fire safety provisions recommended in Eurocode 2: BS EN 1992-1-2 Design of concrete structures, indicate that the following methods may be adopted:

- Providing a thermal barrier (either a protection board or sprayed fireproofing lining);
- Adding polypropylene fiber (PPF) to concrete; and
- Adding a sacrificial concrete cover (SCC) and providing a reinforcing mesh within the concrete cover.

The first two methods of passive fire protection provisions are recommended in the *Guidelines for Structural Fire Resistance for Road Tunnels,* published by the International Tunneling Association with cooperative effort of the World Road Association (PIARC); and the *Handbook of Tunnel Fire Safety*, published by the Institution of Civil Engineers and adopted in many tunnel projects worldwide. In general, with suitable surface roughness (e.g., 3mm) stated in the specifications, the provision of a thermal barrier will not affect the friction factors used for the tunnel ventilation.

One caution in using a thermal barrier in the tunnel lining, the tunnel will converge in the first few months to two years after construction to suit the ground conditions. As thermal barriers are rigid systems, frequent inspection and rectification may be required in the first two years when the tunnel converges. Whilst it is possible to carry out a visual inspection of the protection boards installed, inspection of the sprayed fireproofing lining can only be carried out by a hammering check or infra-red detection to locate any void behind the lining.

The use of a sacrificial concrete cover may not meet the requirement for avoiding explosive spalling and limiting temperature increases in the concrete, and reinforcement can only be used with careful verification and testing.

The installation of passive protection for a tunnel may reduce the space for tunnel systems (e.g., space for environmental sensors in a road tunnel) and may have an impact on the installation requirements and sequences for various tunnel services.

## WSP | PARSONS BRINCKERHOFF'S RECOMMENDATIONS

Passive fire protection (PFP) was used in the tunnels of the Hong Kong Express Rail Link, a high speed railway, and the Hong Kong Mass Transit

Railway (MTR) South Island Line. PFP has now become a standard design for tunnels in Hong Kong MTR projects. In one of the recent passive fire protection projects done by WSP | Parsons Brinckerhoff, the following recommendations were made:

- A thermal barrier (sprayed or board) is recommended for a tunnel boring machine (TBM) excavation method using segmental concrete linings, including seismic joints made up of steel rings and rubber gaskets. There is a need to protect the gasket steel ring precast elements from excessive temperature during a fire. Sprayed non-vermiculate refractory cement (NVRC) fireproofing lining is preferred, as the concrete surface is curved. Intumescent paint and boards will be used at the seismic joints.
- For the cross passage lining, special fire protection is not required as the area inside the cross passages is small and separated from the main tunnel by fire-rated doors.
- For mass concrete lining in NATM[1] tunnels, adding polypropylene fibre (see Figure 1) as passive fire protection to prevent explosive spalling of the concrete may be considered. The polypropylene fibre will be evaporated when subject to heat above 180°C and form micro-cracks to release the water vapour, preventing the occurrence of explosive concrete spalling.
- For cut-and-cover (C&C) tunnels, the concrete members behave as frame structures and maintaining the temperature of the rebar is critical. Thermal barrier (sprayed NVRC fireproofing lining or composite cement/galvanized steel board) is recommended.
- Based on computational fluid dynamics (CFD) test results, the ventilation shafts will not be directly exposed to temperatures higher than 250°C. Hence, additional fire protection for concrete is not required.
- It is recommended that the anchors for heavy equipment on the soffit of the tunnel be protected by intumescent paint and that mechanical expansion anchors be used.
- For plant rooms in the ventilation buildings, concrete cover requirements for minimum fire resistance as per the local code is recommended as they will not be subject to the tunnel design fire and the associated fire curve. ›

[1] New Austrian Tunnelling method (NATM), also known as Sequential Excavation Method (SEM) describes a popular method of modern tunnel design and construction.

| | METHOD | | | |
|---|---|---|---|---|
| | COMPOSITE CEMENT/ GALVANIZED STEEL BOARD | SPRAYED FIREPROOFING LINING | SACRIFICIAL CONCRETE COVER | ADDING PPF IN CONCRETE |
| **GENERAL** | | | | |
| Protection of concrete | Concrete will not be directly exposed to heat source | Concrete will not be directly exposed to heat source | Sacrificial concrete cover will be placed on top of the regular concrete cover for reinforcement. | Concrete (with PPF) will be directly exposed to heat source. (This does not meet the requirement for tunnel environment.) |
| **INSTALLATION & FINISHED SURFACE** | | | | |
| Installation at curve surface (e.g., TBM tunnel) | Tailor–made frame is required. | No constraint | No constraint | No constraint |
| Installation at flat surface (e.g., C&C tunnel) | No constraint | No constraint | No constraint | No constraint |
| Painting | No constraint, normally painted dark colour at ceiling. | No constraint, normally painted dark colour at ceiling. | No constraint, normally painted dark colour at ceiling. | No constraint, normally painted dark colour at ceiling. |
| Surface roughness | Around 0.15mm | Similar to concrete surface (around 3mm) | Typical concrete surface (around 3mm) | Typical concrete surface (around 3mm) |
| Space requirement which may affect the installation of services in tunnels | Additional space is needed (30-60mm). | Additional space is needed (30-50mm). | No additional space is needed. | No additional space is needed. |
| **DESIGN LIFE** | | | | |
| Design life | 20~25 years design life | 10~15 years design life | No replacement required | No replacement required |
| **IMPACT ON CONSTRUCTION PROGRAMME** | | | | |
| Installation programme with the consideration of tunnel services | Board installed after ceiling hung service is installed. Increase installation programme by 1~3 months. | Spray after ceiling hung service installed. Increase installation programme by 1~3 months. | Concurrent with concreting programme. No impact on programme. | Concurrent with concreting programme. No impact on programme. |
| **RISK OF FALLING OBJECTIVE** | | | | |
| Risk of falling off after tunnel is used | If properly installed, risk of falling off is minimum. | Needs inspection for potential debonding or delamination, especially in the first two years. | No risk | No risk |
| **WATER & TUNNEL CONVERGENCE** | | | | |
| Effect of water leakage (e.g., sea water) and blasting | Waterproofing design is required. | More resistant to water leakage and blasting | No effect | No effect |
| Effect of water from tunnel cleaning | Resistant to water | More resistant to water | No effect | No effect |
| Effect of tunnel convergence | Need minor adjustment as tunnel converges in the first 2 years. | Need minor adjustment as tunnel converges in the first 2 years. | No effect | No effect |
| **INSPECTION & MAINTENANCE** | | | | |
| Inspection & Maintenance | Repair and maintenance required. Recommended frequency of inspection. | Repair and maintenance required. Debonding can be checked with infrared red equipment. | No maintenance | No maintenance required |
| Impact on tunnel operation during maintenance | Close one lane or total tunnel closure. | Close one lane or total tunnel closure. | No maintenance required | No maintenance required |
| **FIRE SITUATION** | | | | |
| Effect of steel insert during fire | Effects of heat transmission of insert will be determined by finite element method (FEM) analyses, if required apply intumescent paints to protect exposed steel parts. | Effects of heat transmission of insert will be determined by FEM analyses, if required apply intumescent paints to protect exposed steel parts. | Effects of heat transmission of insert will be determined by FEM analyses, if required apply intumescent paints to protect exposed steel parts. | Effects of heat transmission of insert will be determined by FEM analyses, if required apply intumescent paints to protect exposed steel parts. |
| Impact after large fire | Replace the board near the fire site. No need to replace the concrete. | Reapply the spray PFP. No need to replace the concrete. | Repair SSC as required. | Repair required for concrete without poly propylene fibres. |

TABLE 1 — COMPARISON OF DIFFERENT PASSIVE FIRE PROTECTION MEASURES (SOURCE: WSP | PARSONS BRINCKERHOFF)

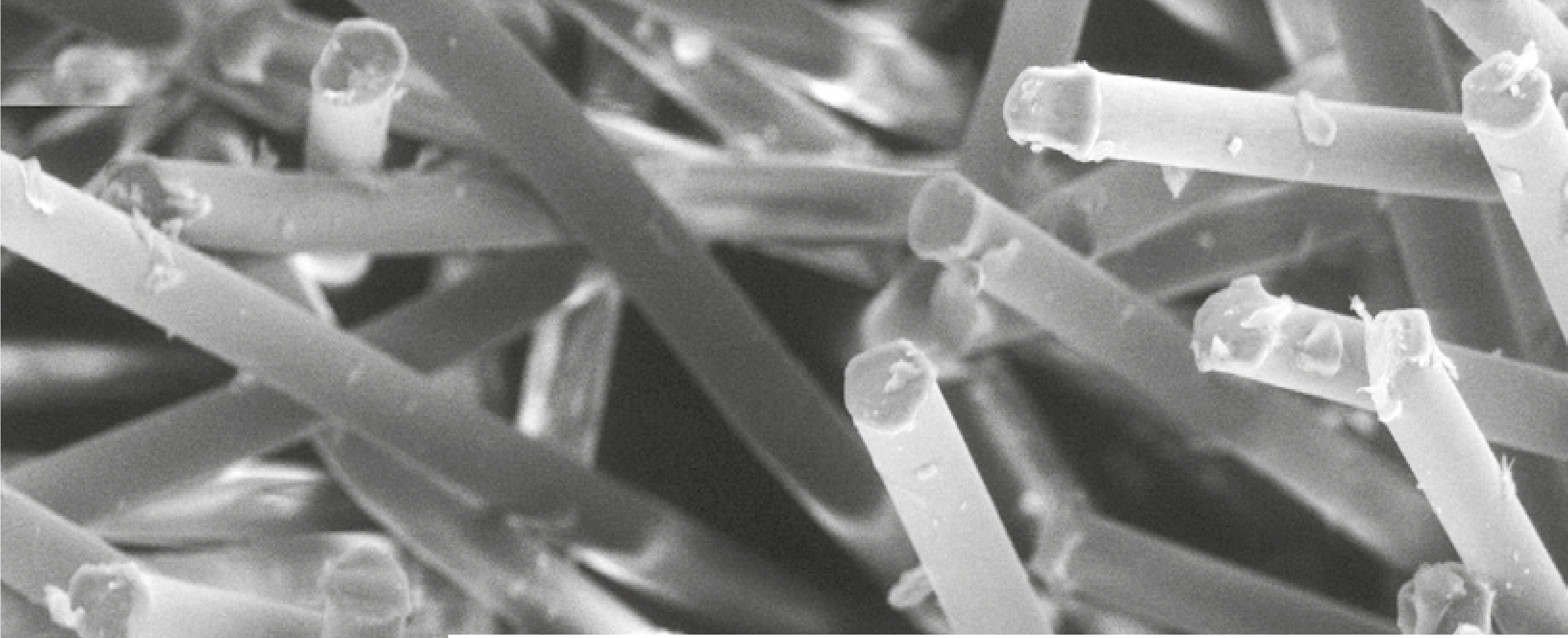
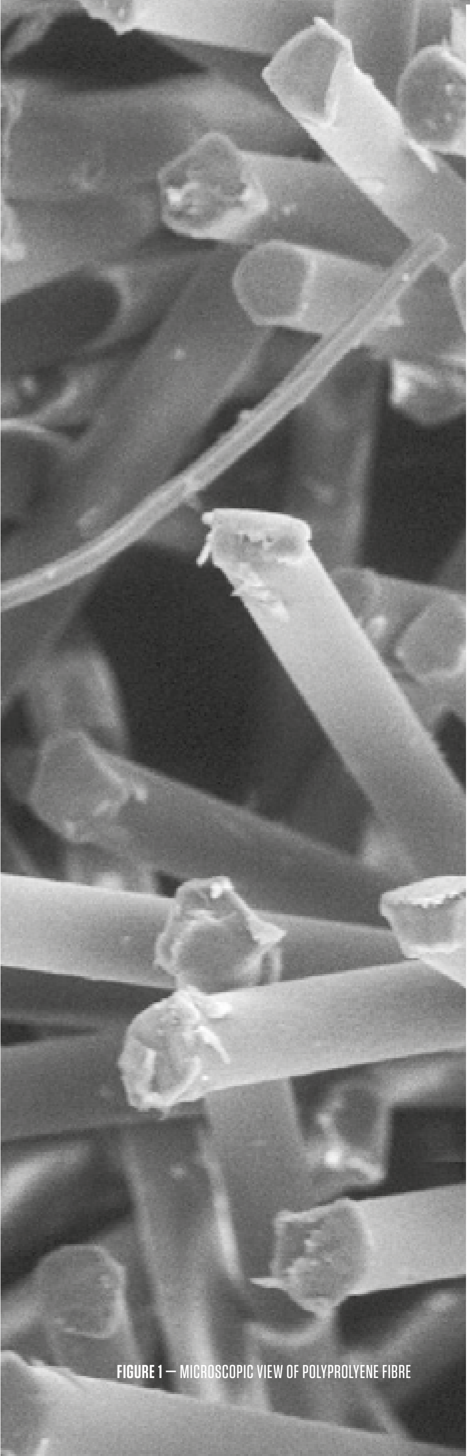

FIGURE 1 — MICROSCOPIC VIEW OF POLYPROLYENE FIBRE

Table 1 provides a comparison of the different means of passive fire protections.

## CONCLUSION

Designing more resilient and secure tunnels is a top priority for the engineering community, and this includes minimizing the impact of fire on tunnel structures and systems, especially those structures and systems involving life safety. The passive fire protection measures discussed provide fire protection and hardening of tunnel structural components. This, along with other fire life safety systems, helps provide passengers with safe egress in the case of a fire event, as well as protecting first responders. The measures also protect the tunnel structure from explosive spalling of concrete, ensuring that during and after a fire the structure withstands service loads and that damage to the tunnel structure is repairable, thereby minimizing economic impact.

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# PREDICTING PRESSURE EFFECTS ON A RESILIENT TUNNEL PLUG INSTALLATION IN A TRANSIT TUNNEL

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IN A POTENTIAL FLOODING EVENT, THE RTP CAN BE REMOTELY INFLATED WITH AIR TO FILL A TUNNEL CROSS SECTION.

FIGURE 1 — DEMONSRTATION OF RTP INFLATION — COURTESY OF ILC DOVER

## INTRODUCTION

New technologies that enhance tunnel safety and resiliency have recently been developed in response to extreme weather conditions. One such technology is a "Resilient Tunnel Plug" (RTP) made of state-of-the-art high strength material. The material can be folded into a compact shape and can be installed in a tunnel with minimal tunnel modification.

In a potential flooding event, the tunnel operator can remotely activate the pressurization system which will inflate the RTP with air or an inert gas to a specified pressure. The pressure will cause the RTP to fill the tunnel cross section (see Figure 1) and remain in place due to the friction between the RTP and the tunnel walls (see Figure 2). The non-uniform shape of the tunnel cross section will allow some flood water to leak past the RTP, but the amount of leakage can be mitigated with some minimal modifications to the tunnel cross section at the RTP location to make the cross section as smooth as possible. Once the flood event has subsided and the water has been pumped out, the RTP can be deflated and re-packed into its storage container, ready for the next deployment.

For a majority of the RTP's life in a transit tunnel, it will sit in a unique and difficult tunnel environment, subjected to high cyclic pressure loads due to passing trains. The RTP container and deployment structure should be constructed to withstand the daily cyclic pressure loads in a transit tunnel environment. The pressure signature of passing trains is predicted using the Subway Environment Simulation (SES) program[1] and that information is passed to the RTP designer to construct a suitable storage and deployment device.

## SES ANALYSIS

SES analysis was undertaken to predict the tunnel air pressure signatures that the RTP would experience from normal train traffic. The train speeds along the routes were modeled according to their normal operating speeds. Dwell times of 20 seconds were assumed for each station. Train headways of 3, 4, 5, 6, and 7 minutes were modeled to simulate worst case peak hour conditions. Relative train positions were modeled to determine the maximum pressure due to trains operating in both tunnels. The blockage introduced by the RTP installation was modeled as an airflow resistance assuming the airflow resistance effect of the RTP installation was similar to that of a thick-edged orifice. Figure 3 shows a cross section of the tunnel, the proposed RTP location is crosshatched.

[1] Subway Environmental Design Handbook. Volume II. Subway Environment Simulation Computer Program (SES). Part 1. User's Manual, 1975

**32 ft.**
LENGTH OF THE INFLATED PLUG

**16.2 ft.**
DIAMETER OF THE INFLATED PLUG

**11.6 psi**
POUND-FORCE PER SQUARE INCH

**850 lb/in**
LOAD THE INFLATED PLUG

**17 psi**
POUND-FORCE PER SQUARE INCH

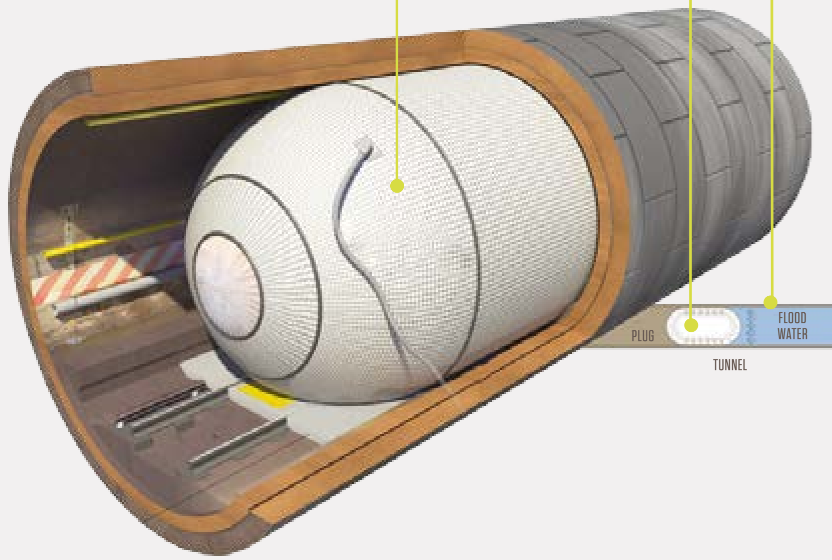


FIGURE 2 — RESILIENT TUNNEL PLUG (WITH PERMISSION FROM ILC DOVER)

A total of ten (10) SES simulations were performed to determine the maximum tunnel pressure signature generated at the RTP location by the movement of trains. The summary of the results for the train piston effect analysis are presented in Table 1.

The results of the study indicate that the maximum positive/maximum negative tunnel air pressure that the RTP would experience is 2.51 / 2.07 inch water gauge (this is with an added safety margin of 30 percent). The maximum positive tunnel air pressure occurs when trains are operating on a three-minute headway. The RTP designer should take into account the short duration of the pressure pulse due to the passing trains. ›

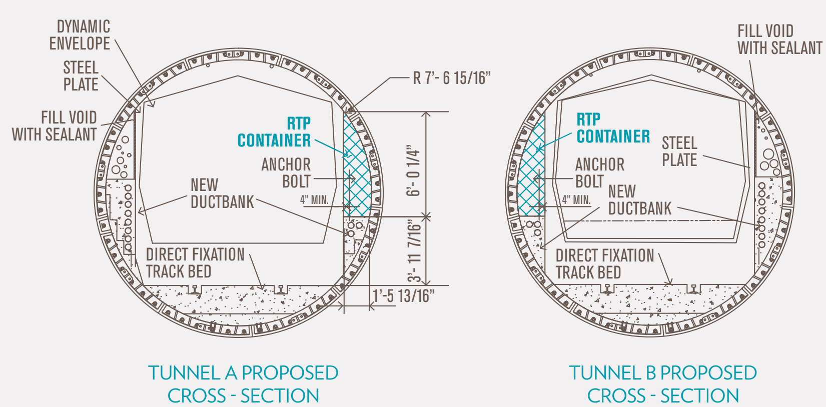


FIGURE 3 — RTP PROPOSED CROSS SECTION

SES IS A USEFUL TOOL FOR PREDICTING THE PRESSURE EFFECTS OF PASSING TRAINS IN A TUNNEL SYSTEM.

SES CAN BE USED TO EVALUATE MANY TUNNEL ENVIRONMENT SCENARIOS THAT CANNOT BE ACHIEVED WITH FULL-SCALE TESTING.

In addition to the maximum and minimum pressures, the pressure signature was plotted against time as the train passed the RTP location. The pressure signature profile gives information on the time duration of the pressure profile. A pressure signature that increases and decreases slowly will affect wayside equipment differently than a pressure signature that sharply increases and sharply changes from positive to negative or vice versa. The shape of the pressure profile is dependent on relative train position and whether trains are accelerating or decelerating. Figure 4 shows a typical pressure profile plot at the RTP location. The left plot shows the shape of the profile when the maximum pressure occurs, and the right plot shows when the minimum pressure occurs. The positive and minimum pressures often occur at long intervals. The plot was split up to show a higher resolution of the data near the maximum and minimum pressure times.

## CONCLUSION

The results of the study indicate that the maximum positive/maximum negative tunnel air pressure that the RTP would experience is 2.51 / 2.07 inch water gauge. SES is a useful tool for predicting the pressure effects of passing trains in a tunnel system. Innovative technologies that improve the safety and resiliency of tunnel systems can be developed more cost effectively without the need for expensive full-scale testing. In addition, SES can be used to evaluate many tunnel environment scenarios that cannot be achieved with full-scale testing, thereby giving the greatest confidence that the design of the RTP or any other tunnel technology would be designed properly to

withstand the challenging environment of a transit tunnel system.

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## THE MAXIMUM POSITIVE/MAXIMUM NEGATIVE TUNNEL AIR PRESSURE THAT THE RTP WOULD EXPERIENCE IS 2.51 / 2.07 INCH WATER GAUGE (WITH AN ADDED SAFETY MARGIN OF 30 PERCENT)

| RUN # | HEADWAY | TUNNEL | RTP TUNNEL PRESSURE (RELATIVE TO AMBIENT - INCH WATER GAUGE) MAX POSITIVE / MAX NEGATIVE |
|---|---|---|---|
| 1 | 3 MIN | A | 1.58 / -1.49 |
| | | B | 1.93 / -0.76 |
| 2 | 4 MIN | A | 0.44 / -1.57 |
| | | B | 1.73 / -1.59 |
| 3 | 5 MIN | A | 1.40 / -1.55 |
| | | B | 1.79 / -1.28 |
| 4 | 6 MIN | A | 1.15 / -0.88 |
| | | B | 1.56 / -0.97 |
| 5 | 7 MIN | A | 0.54 / -1.43 |
| | | B | 1.58 / -1.43 |

**TABLE 1** — SUMMARY OF RESULTS FOR TRAIN PISTON EFFECT ANALYSIS

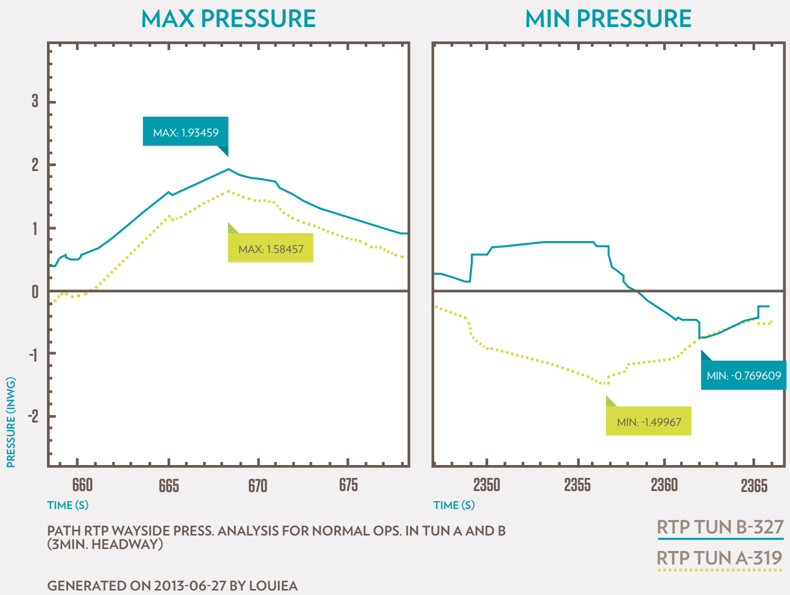


**FIGURE 4** — TYPICAL PRESSURE PROFILE PLOT AT THE RTP LOCATION

# TRANSIT TUNNEL BLAST ANALYSIS AND THE EFFECTIVENESS OF PROTECTION MEASURES

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A BLAST ANALYSIS STUDY WAS CONDUCTED TO SIMULATE EXPLOSIONS IN A TRANSIT TUNNEL TO PREDICT POTENTIAL DAMAGE TO THE TUNNEL STRUCTURE.

## INTRODUCTION

Terrorist attacks on transit tunnels in Madrid, London, Moscow, and other cities have resulted in enormous cost in loss of life, injuries, property damage, and economic consequences. A blast in a transit tunnel is particularly dangerous because of the confined underground space. According to the Blue Ribbon Panel on Bridge and Tunnel Security[1] (2003), there are more than 200 transit tunnels in the United States.

Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) performed extensive in-house research to improve the safety and security of infrastructure facilities[2] and developed a systematic approach named TARIF (see Figure 1), which has been applied to the design of several tunnels and underground facilities. This article discusses blast analysis on typical transit tunnel geometry and the effectiveness of protection measures which are widely used in current practice. The information from this study can assist owners and operators of underground infrastructure in making their systems more secure and resilient.

| TARIF'S FIVE STEPS |
|---|
| Identify threat |
| Evaluate assets |
| Calculate risk |
| Analyze impact |
| Provide fix |

FIGURE 1 – PROTECTIVE DESIGN STEPS FOR TUNNEL SECURITY (MUNFAKH, 2008)[3]

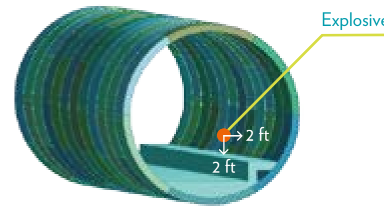


FIGURE 2 – CROSS SECTION OF TRANSIT TUNNEL IN 3D MODEL

## BASE CASE STUDY FOR BLAST ANALYSIS

According to the Federal Emergency Management Agency (FEMA), explosive charge weight and stand-off distance are two important parameters used to define a blast threat. The charge weight is usually measured in equivalent pounds of TNT, and the stand-off distance is the distance from the charge's center of gravity to the bearing surface of the structure. For this study, a backpack bomb with a conservative estimate of 100 pounds of TNT and a stand-off distance of 2 feet were selected as a reasonable potential threat.

The generic transit tunnel was modeled with a precast concrete segmental lining that is 11 inches thick and has an internal diameter of 20 feet (see Figure 2). Neighboring segments are connected by radial bolts; adjacent rings are connected by steel dowels.

WSP | Parsons Brinckerhoff used the commercial computer program ANSYS AUTODYN to perform the three-dimensional coupled Euler-Lagrange nonlinear finite element blast analysis to simulate explosions in a generic transit tunnel and to predict the potential damage. The simulation incorporated nonlinear dynamics, large strains and deformations, fluid–structure interactions, and interactions among structures. In the base scenario, the simulation predicted that an area in the lining of about 2.6 square feet would suffer severe damage.

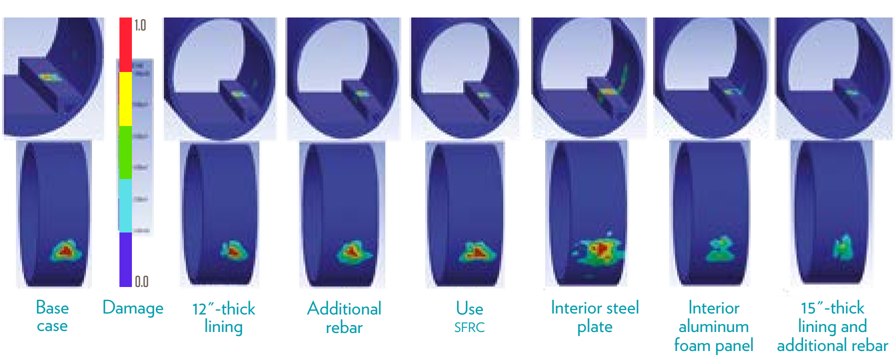


FIGURE 3 – DAMAGE SIMULATION FOR ALL SIX PROTECTION MEASURES

## PROTECTION MEASURES

In order to improve the security, safety, and resilience of transit tunnels, some protection measures are proposed (see Table 1). A series of numerical analysis were performed to quantify the effectiveness of the proposed measures. This study only considered the initial costs for the proposed measures. The durability and life-cycle cost was not included in the following cost-effective analysis. Figure 3 shows damage simulation for the base case and all six protection measures.

[1] The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) formed a Blue Ribbon Panel on Bridge and Tunnel Security after the terrorist attacks in the United States in 2001.

[2] Choi, S., Tunnel Stability Under Explosion; Parsons Brinckerhoff William Barclay Parsons Fellowship Monograph, 2009.

[3] Munfakh, G., Fixing a TARIF for Security, World Tunnelling, 2008.

| PROTECTION MEASURES | DAMAGE REDUCTION | TUNNEL LINING COST CHANGE (INCREASE + / SAVING -) |
|---|---|---|
| Increase concrete lining by 1 inch (from 11 inches to 12 inches) | 35% | +5% to +10% |
| Double the number of steel reinforcing bars | 45% | +20% to +40% |
| Use of steel fiber reinforced concrete (SFRC) | 14% | -15% to -20% |
| Install a 1 inch interior steel plate | Not effective | +30% to +35% |
| Apply a 4 inch interior aluminum foam panel | 99% | approximately +250% |
| Increase thickness of tunnel lining by 4 inches and add more steel reinforcing bars | 99% | approximately +100% |

TABLE 1 — COST AND EFFECTIVENESS OF TUNNEL PROTECTION MEASURES CONSIDERED

### INCREASE CONCRETE LINING BY 1 INCH

In general, a thicker tunnel lining tends to perform better under extreme loading events. In the first scenario, the lining thickness was increased from 11 inches to 12 inches. Compared with the base case, the damage in this case is reduced by 35 percent with a cost increase in the precast lining of 5 to 10 percent.

### ADDITIONAL REBAR

The second measure considered was to double the number of steel reinforcing bars. The damage to the tunnel lining in this scenario was reduced by 45 percent. The cost of the lining was estimated to increase approximately 20 to 40 percent compared to the base scenario.

### USE OF STEEL FIBER REINFORCED CONCRETE (SFRC)

The third protective measure consisted of using SFRC with a dosage of 80 pounds of steel fiber per cubic yard of concrete for the tunnel lining and interior structures. SFRC was modeled by assuming that steel fibers were uniformly distributed throughout the concrete elements. Based on the information from literature, it was assumed that the steel fibers increased the strength and improved the ductility for the concrete members with corresponding steel fiber dosage. This approach reduced the damaged area by 14 percent. Based on data from similar tunnels using SFRC, it was estimated that this approach would cost about 15 to 20 percent less than the base case due to reduced labor and simplified manufacturing process.

### INTERIOR STEEL PLATE

Another measure considered was bonding a 1-inch thick steel plate to the tunnel wall. The simulation showed that the concrete lining suffered more damage compared to the base case. This model demonstrated that the 1-inch plate did not provide substantial impact energy absorption and that the impact of the plate on the lining increased the destructiveness of the blast. The plate could increase the cost of the lining by 30 to 35 percent. Therefore, an interior 1-inch thick steel plate is not effective to mitigate the damage.

### INTERIOR ALUMINUM FOAM PANEL

Research proved that porous materials such as aluminum foam can effectively delay shock wave propagation and attenuate the amplitude by absorbing the kinetic energy through compaction of the material. This protection measure considers a 4-inch thick interior aluminum foam panel. Additional material cost could be about 2.5 times the cost of the base case (a 250 percent increase) but it nearly fully mitigated the damage to the lining. However, constructabilty may be an issue as interior clearances for installation of the panel may not meet fire life safety requirements.

### 15 INCH TUNNEL LINING + ADDITIONAL REBAR

This protection measure considers a 15-inch thick concrete lining reinforced by steel bars at reduced spacing. The tunnel lining in this scenario experienced some plastic deformation but the damage on the lining is nearly fully mitigated. Compared to the base case, the cost of tunnel lining, including additional excavation cost, could be doubled.

## CONCLUSION

Simulation reveals that it is possible to reduce the blast impact to the structure of the tunnel to almost nothing, for example by bonding an internal aluminum porous panel, but the cost is high and can be affordable for critical structures only. However, a conventional measure such as an increase in the lining thickness with design optimization using steel rebar can also significantly reduce the damage at a smaller cost increase. Optimization of the design of anchored hooks and transverse reinforcement bars can also be considered to increase resilience and further reduce structural damage.

This study on the effectiveness of proposed protections is valuable to those setting safety and resilience guidelines, especially when applied to problems that are difficult or costly to study experimentally. The objective of this study is to provide owners and operators of underground infrastructure with a guideline to elicit industry discussion on the value of various tunnel protection measures and blast protective design of tunnel linings. As transportation agencies or authorities balance multiple demands, this information can assist in the decision-making process to make their systems more secure and resilient.

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# CLIMATE CHANGE, EXTREME WEATHER EVENTS, AND THE HIGHWAY SYSTEM: IMPACTS AND ADAPTATION APPROACHES

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PARSONS BRINCKERHOFF, NOW PART OF WSP | PARSONS BRINCKERHOFF, LED THE DEVELOPMENT OF NCHRP REPORT 750, VOL. 2, ONE OF THE FIRST SYSTEMATIC EFFORTS IN THE U.S. TO IDENTIFY A PROCESS FOR TRANSPORTATION AGENCIES TO: PREPARE FOR EXTREME WEATHER EVENTS, MANAGE AGENCY OPERATIONS DURING THE EVENT, AND CONDUCT POST-RECOVERY OPERATIONS.

Over the past 10 years, the U.S. transportation community has become increasingly concerned about the impact of climate change and extreme weather events on transportation infrastructure and system resiliency. Partly in response to extreme weather events and major natural disasters such as hurricanes Sandy, Katrina, and Irene, massive flooding in the Midwest and large forest fires in the west, and in part due to a growing awareness of the potential threats of climate change described in research and policy studies, a growing number of transportation agencies are interested in understanding the risks associated with a changing climate.

A number of states, such as California, Massachusetts, and Washington, have legislative and executive directives for formally considering extreme weather and climate change factors in policy-making and agency decisions. At the federal level, the new Planning Order 5520 from the Federal Highway Administration (FHWA), the pilot studies on adaptation and vulnerability assessments supported by both FHWA and the Federal Transit Administration (FTA), and the new Executive Order on Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input (January 30, 2015) provide further motivation to better understand how adaptation measures need to be included in decision-making.

Although some question the projections of future climate conditions, most agree that the U.S. has experienced record extreme weather events over the past several years. The frequency and severity of such events have seemed to increase, infrastructure damage and community costs have risen, the impact of recovery costs on maintenance budgets and on regular operations activities continues to become more significant, and perhaps most importantly, public expectations of a transportation agency's ability to recover the transportation system quickly and efficiently have increased greatly. In several instances, the recurring pressures on state transportation officials to prepare for, manage, and recover from extreme weather events have caused organizational change, the development of new management responsibilities (e.g., emergency management officials), the modification of standard operating procedures, and staff training in managing and administering recovery efforts.

WSP | Parsons Brinckerhoff led the development of National Cooperative Highway Research Program[1] (NCHRP) Report 750, Vol. 2, which recommends steps that can be taken by transportation agencies to: prepare for extreme weather events, manage agency operations during the event, and conduct post-recovery operations.

NCHRP Report 750, Vol. 2 was one of the first systematic efforts in the U.S. to identify a process for investigating the vulnerability of transportation infrastructure to extreme weather events and, over the long-term, climate change. A successful vulnerability assessment as outlined in NCHRP Report 750, Vol. 2 incorporates an appreciation of the following:

## CLIMATE CHANGE AND EXTREME WEATHER EVENTS PRESENT A WIDE RANGE OF STRESSES ON THE TRANSPORTATION SYSTEM.

The report identified a large number of climate-related stresses and resulting impacts that could

[1] The National Cooperative Highway Research Program (NCHRP) is a forum for coordinated and collaborative research, which addresses issues integral to the state Departments of Transportation (DOTs) and transportation professionals at all levels of government and the private sector. The NCHRP provides practical, ready-to-implement solutions to pressing problems facing the industry. The NCHRP is administered by the Transportation Research Board (TRB) and sponsored by the member departments (i.e., individual state departments of transportation) of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA). Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

ALTHOUGH SOME QUESTION THE PROJECTIONS OF FUTURE CLIMATE CONDITIONS, MOST AGREE THAT THE U.S. HAS EXPERIENCED RECORD EXTREME WEATHER EVENTS OVER THE PAST SEVERAL YEARS.

affect the nation's road network in the future. Thus, one of the first tasks of any climate change vulnerability assessment is an understanding of the types of stresses and impacts that are of most concern to the highway system managers. Depending on the type of environmental stress caused by climate change and extreme weather, a range of impacts on the highway system can be anticipated. These impacts include both impacts to the infrastructure itself (and thus how facilities are designed and constructed) and to operations and maintenance.

In addition to the direct effects of climate changes on highways, climate change will affect ecological dynamics in ways that will have implications for transportation systems. The report identifies the different types of impacts likely to be faced by transportation infrastructure, and the types of strategies that can be used to avoid or minimize the impacts. The strategies for dealing with climate change and extreme weather events will differ by functional activity within a transportation agency. For example, climate change adaptation can be considered in planning, environmental analysis, design, infrastructure retrofit, construction, operations, maintenance, emergency response and public outreach and communications. The report identifies the likely effects that a concern for climate change and extreme weather events will have on different units in a transportation agency.

## VULNERABILITY ASSESSMENTS OF HIGHWAY ASSETS REQUIRE SEVERAL AREAS OF EXPERTISE, INCLUDING A LEVEL OF ENGINEERING EXPERTISE THAT HAS AT TIMES BEEN LACKING IN MORE POLICY AND PLANNING-ORIENTED EFFORTS.

Conducting substantive climate vulnerability assessments that can successfully lead to tangible and actionable measures is a challenge that requires experience and knowledge across a wide range of engineering disciplines. Vulnerability assessments and adaptation require an understanding of the design and operational performance characteristics of different types of assets and how these assets will respond to different types of climate and extreme weather stresses. For example, vulnerability assessments of the impacts of flooding benefit tremendously from expertise in hydrology and hydraulics and geotechnical knowledge is indispensable for slope vulnerability assessments.

Once vulnerabilities have been identified, decision-makers often want to know exactly what it means to apply an adaptation strategy to a particular asset or asset type. Cost, for example, is usually one of the most important factors for decision-makers interest and is a key factor in determining willingness to implement asset-related adaptation strategies. Likely effectiveness of different engineering strategies, under differing site and climatic circumstances, is another key factor.

## RISK IS A KEY FACTOR IN VULNERABILITY ASSESSMENTS.

There is a growing understanding among researchers and highway officials that climate change and extreme weather events are a threat to many aspects of the highway system, which warrants the investigation of the specific risks it poses. Most agencies that are concerned about adaptation begin by conducting a risk ›

FROM COASTAL STORM SURGE ALONG THE GULF COAST TO HIGH INTENSITY STORMWATER RUNOFF TO MELTING OF PERMAFROST IN ALASKA, THERE IS NO ONE-SIZE-FITS-ALL SOLUTION TO ASSESSING VULNERABILITY.

THIS EIGHT-STEP PROCESS IS INHERENTLY A MULTI-DISCIPLINARY AND COLLABORATIVE ONE.

assessment of existing assets.[2] Most of these risk assessments remain largely qualitative and based on professional judgment, although the report presents different quantitative and qualitative approaches for considering climate change-related risks. Climate-related risk is more broadly defined in that risk can relate to impacts beyond simply the failure of the asset. It relates to the failure of that asset in addition to the consequences or magnitudes of costs associated with that failure. In this case, a consequence might be the direct replacement costs of the asset, direct and indirect costs to asset users, and, even more broadly, the economic costs to society given the disruption to transportation caused by failure of the asset or even temporary loss of its services (e.g., a road is unusable when it is under water).

An integrated risk assessment is performed on vulnerable assets with the assessment considering the likelihood of impacts and their consequences. These two factors are related to each other and their intersection determines the risk level facing an asset. Adaptation options can then be considered for high or medium risk assets while low risk assets are given lower priority.

## DIFFERENT CLIMATE CHANGE STRESSORS HAVE DIFFERENT APPROACHES AND ANALYSIS METHODOLOGIES.

From coastal storm surge along the Gulf Coast to high intensity stormwater runoff to melting of permafrost in Alaska, there is no one-size-fits-all solution to assessing vulnerability. How one analyzes the impact of extreme precipitation events and flooding, for example, is very different from how one would analyze higher temperatures/drought (resulting in more intense forest fires). For this reason, NCHRP 750, Vol. 2 was accompanied by a CD that allows transportation professionals to identify the type of environmental stresses of interest, the databases and approaches that could be used to analyze potential impacts, and the range of options available as part of the design process.

## DATA AVAILABILITY AND QUALITY IS A CRITICAL FOUNDATION FOR ADAPTATION ANALYSIS.

Every adaptation study depends on data that is not only reflective of actual conditions, but is readily available. This was noted in a recent meeting of all the FHWA adaptation pilot study grantees where data was universally recognized as the limiting factor in conducting the pilot studies as envisioned. Much of the data would come from existing databases, such as pavement type, previous flooding records, annual average daily traffic (AADT), etc., whereas other data would come from databases developed by others or would have to be generated.

The lack of engineering-relevant and spatially precise climate data and the uncertainty surrounding those data remain obstacles and will likely remain so for the foreseeable future despite the best efforts of climate modelers. This should not, however, be an excuse for inaction.

NCHRP 750, Vol. 2 developed a diagnostic framework that provides transportation professionals with a general step-by-step approach for assessing climate change impacts and deciding on a course of action. The framework, which can be applied at the systems planning level down to the scale of individual projects, consists of the following steps:

| | |
|---|---|
| 1 | Identify key goals and performance measures for adaptation planning efforts; |
| 2 | Define policies on assets, asset types, or locations that will receive adaptation consideration; |
| 3 | Identify climate changes and effects on local environmental conditions; |
| 4 | Identify the vulnerabilities of asset(s) to changing environmental conditions; |
| 5 | Conduct risk appraisal of asset(s) given vulnerabilities; |
| 6 | Identify adaptation options for high-risk assets and assess feasibility, cost effectiveness, and defensibility of options; |
| 7 | Coordinate agency functions for adaptation program implementation (and optionally identify agency/public risk tolerance and set trigger thresholds); and |
| 8 | Conduct site analysis or modify designs, operating strategies, maintenance strategies, construction practices, etc. |

This eight-step process is inherently a multi-disciplinary and collaborative one. It is not likely that a state transportation agency has internal staff capability on climate science. In most cases, these agencies have been working with the local university or the state climatologist in order to obtain such input. In many cases, the vulnerability and risk assessment process depends on local input on what is considered to be the most critical assets in an urban area. Importantly, the actions taken by local communities and governments, such as land use approval and street/drainage design, could have significant impact on the ability of state

[2] Vulnerability assessment looks at the likelihood that damage or some kind of disruption occurs to infrastructure given an extreme weather event. Risk assessment takes into account the actual likelihood of the event occurring along with the economic consequences of disrupted infrastructure.

This article is adapted from "Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report" by Michael Meyer, Michael Flood, Jake Keller, Justin Lennon, Gary McVoy, Chris Dorney.

Readers can learn more about the series of reports at http://www.trb.org/Main/Blurbs/169781.aspx assets to handle larger loads, and thus the need for coordination.

Of particular interest, as agencies increasingly adopt transportation asset management (TAM) approaches, opportunities will exist to integrate consideration of weather risk and climate change into TAM objectives, data collection, performance measurement, monitoring, and resource allocation decisions. Over time, the integration of weather and climate information into TAM will help agencies make targeted investments or allocation decisions that will increase the resilience of the network and of individual assets to changing environmental conditions. A section in the report discusses the relationship between climate change and asset management.

The report concludes by discussing agency actions and initiatives. As noted, leadership is critical. Strong mandates (legislative or administrative) to consider adaptation and provide relevant data greatly encourage adaptation activities. That said, they need not be a prerequisite. Absent mandates, strong state or local leadership by individuals concerned about climate change can also spur action as is the case in most U.S. examples.

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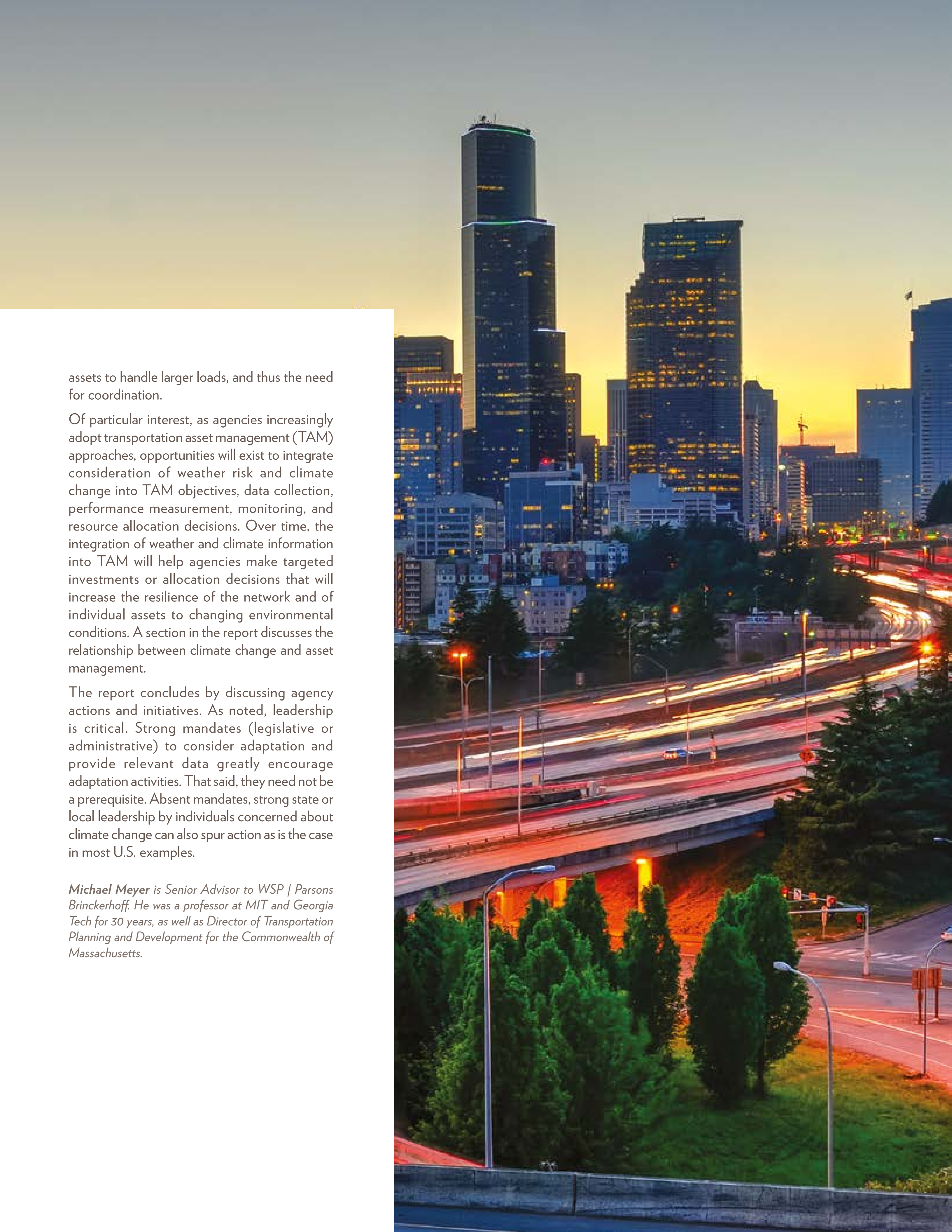

# ADOPTING A STANDARDISED APPROACH TO HIGHWAYS ASSET MANAGEMENT RESILIENCE

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STANDARDIZED APPROACHES TO RISK MANAGEMENT SUCH AS PAS 55 AND ISO 55000 BRING CONSISTENCY AND TRANSPARENCY AND HELP ASSET-OWNING ORGANIZATIONS MANAGE THEIR ASSETS SAFELY AND EFFICIENTLY.

Use of a standardised asset management model allows organisations to take a logical approach to improve their highway resilience and performance. Highways England (formerly the U.K. Highways Agency)[1] is demanding network resilience and asset management governance from its highway maintenance service providers through the use of PAS 55, British Standards Institution's publicly available specification for the optimised management of physical assets, and the agency's Network Management Manual.

## INTRODUCTION

The safe and free-flowing operation of England's strategic road network is vital to the U.K. and Europe's economy. It forms the backbone to regional, national, and international trade and provides a daily commute for millions of road users. To enable the road network to consistently perform to expected service levels during planned and unplanned incidents, including severe weather, a highly developed level of contingency planning - based on good asset data, historic and predictable dynamic information (traffic, accidents, and meteorology), and organisational competence - is required. All this needs to be managed within an effective operational model.

## INTRODUCING A STANDARDISED APPROACH TO MANAGE ASSET RESILIENCE

Increasingly, asset-owning organisations see the benefit of using a standardised approach to their asset management models, such as the Institute of Asset Management's PAS 55 specification published in 2008 or the recently published ISO 55000. The ISO standard expands the definition of assets and lifecycle activities and the value they bring to an organisation and its stakeholders. Introducing a formalised governance mechanism allows asset owners to create a consistent network performance approach, including resilience to external factors such as severe weather.

Organisations aspiring to PAS 55 accreditation are assessed against a generic set of requirements and given a maturity level of competence (from 0 to 4) which indicates the organization's asset management capability across the various elements of PAS 55. Parsons Brinckerhoff, now part of WSP | Parsons Brinckerhoff, is accredited as an Endorsed Assessor to PAS 55 and is part of the ISO 55000 pilot scheme being operated by the United Kingdom Accreditation Service (UKAS).

The PAS 55 and ISO 55000 models include the requirement for an organisation to show how it deals with emergency and incident response needs and both models include contingency planning as a key element in the PDCA (Plan-Do-Check-Act) traditional improvement cycle (see Figure 1). For example, highway maintenance operators need to demonstrate their competence in considering potential emergencies arising from significant failure of critical assets or extreme weather conditions, which could result in traffic disruption or hazardous driving conditions. Highways England uses the Met Office definitions for severe weather which include: heavy snow (more than 2 centimetres per hour of snow for at least 2 hours) and severe gales (repeated gusts of 70 miles per hour). Operators also need to consider the effects of incidents not only on their network but on adjacent networks and have a robust contingency plan and incident response plan in place to address both the immediate consequences and the restoration of safe traffic routes. ›

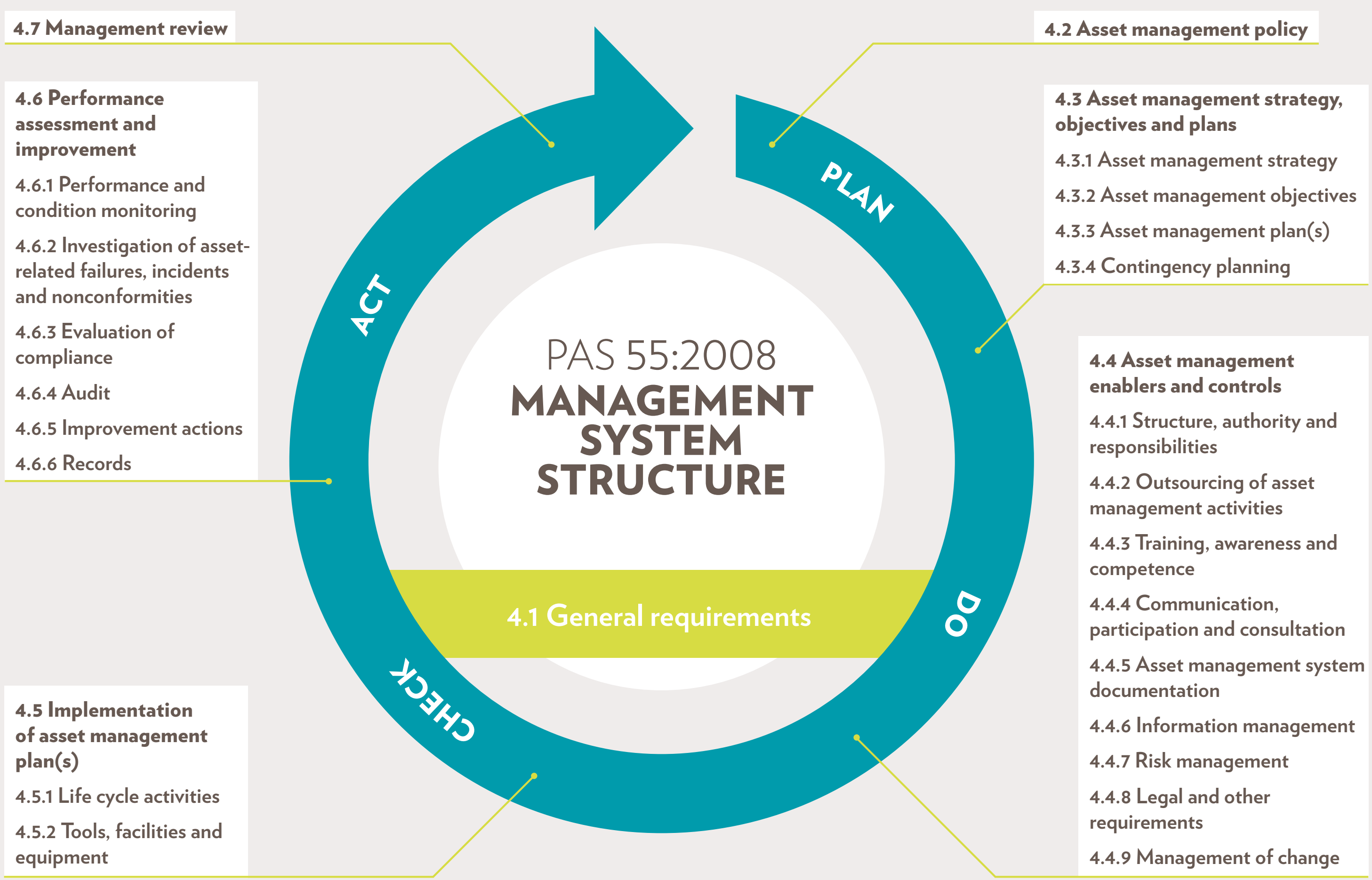


**FIGURE 1 – PAS 55:2008 MANAGEMENT SYSTEM STRUCTURE**
(source: Figure 6 Structure of PAS 55-1:2008) (adapted from PAS 99:2006)

[1] Highways Agency became Highways England in April 2015.

The case for asset owners adopting standardised asset management models to manage network resilience should be based on understanding the drivers, identifying the implications and benefits of standardisation on an organisation, and proving how such models help to realise practical benefits, including assuring network performance during critical incidents.

It is important for asset-owning organisations and their extended supply chain to have a contingency plan that demonstrates a 'line of sight' across their organisational strategy, objectives, and other operational plans. Key to this is the interface with relevant stakeholders such as emergency services and authorities providing mutual aid. The contingency plan should be able to adequately identify and respond to incidents and emergency situations and maintain the continuity of critical asset management activities.

## WSP | PARSONS BRINCKERHOFF'S PAS 55 AND ISO 55000 EXPERIENCE

As a PAS 55 Endorsed Assessor with the Institute of Asset Management, WSP | Parsons Brinckerhoff has been supporting road operators since 2008. We have helped Highways England and local highway authorities with the adoption and accreditation of two contracts to PAS 55 maturity level 3 competence[2]; the first contracts to achieve this in England. Important to this process was our in-depth experience and understanding of the highways maintenance sector, including network resilience models and contingency planning.

In 2012 Highways England decided to introduce PAS 55 as a governance tool in its new Asset Support Contract, using outcome instead of output based requirements to achieve minimum target service levels at an acceptable cost. The model introduced integrated asset management requirements and required the service provider to change the way it delivered network maintenance renewals and improvements. A system model such as PAS 55 was therefore important to define operational outcomes, risk-based approaches to asset management decision-making, people competency requirements, and asset data criticality and management.

## DEVELOPING AN EFFECTIVE CONTINGENCY PLAN AND INCIDENT RESPONSE PLAN

A requirement of the PAS 55 system is for an organization to have a contingency plan and an incident response plan (IRP). In an operational road context, an effective contingency plan describes how the service provider will escalate an incident response from operational (bronze) to tactical (silver) and strategic (gold) command[3] when required based on whether an incident is categorised as critical or major. It is specific to that highway network although it does recognise adjoining boundary road networks and the provision of mutual aid. The contingency plan includes escalation procedures, diversion routes, and other stakeholder information (see Figure 2).

In the U.K., Highways England is classed as a Category 2 Responder under the Civil Contingencies Act 2004 (CCA 2004) which establishes a clear set of roles and responsibilities for those involved in emergency preparation and response. Maintenance providers working for Highways England carry out these responsibilities when they are involved with any 'incident' that adversely affects or disrupts the normal operation and availability of the strategic road network. These incidents may include: major accidents involving vehicles and/or pedestrians, criminal or terrorist threats/activity, demonstrations and other events, and natural hazards such as severe weather.

The incident response plan complements and expands on information within the contingency plan and, together with an emergency diversion route document, defines the resilience response of the network operator. This is confirmed as part of the operator's PAS 55 model.

[2] PAS 55 maturity level 3: All elements of PS55 are in place and are being applied and are integrated. Only minor inconsistencies may exist.

[3] The gold-silver-bronze command structure is used by emergency services of the U.K. to establish a hierarchical framework for the command and control of major incidents and disasters.


TYPICAL INCIDENT RESPONSE ESCALATION PROCESS FOR U.K. STRATEGIC ROAD OPERATOR

**FIGURE 2** – ESCALATION PLAN


CHAMELEONSEYE / SHUTTERSTOCK.COM

## THE BENEFITS OF STANDARDISATION MODELS TO HIGHWAYS RESILIENCE

The successful adoption of an asset management system such as PAS 55 requires delivery organisations to 'think and embed' asset management culture and demonstrate 'line of sight' between resilience policy and outcomes. This includes in their incident response and maintenance regimes, using practical command and control techniques and escalation procedures, such as for severe weather and traffic incidents. As part of the model, contingency plans are assessed to ensure consistency of response to incident management and emergency situations. PAS 55 and ISO 55000 also bring:

- Increased confidence with asset data, asset lifecycle plans, and planning processes to consistently deliver asset schemes;
- A fully documented holistic asset management system including organisational competencies and accountabilities (a key to demonstrating the organisation is 'best in class');
- Clarity of objectives and improved staff motivation;
- Intelligence-led decision-making to improve asset performance, minimise asset deterioration and risk, and add value and resilience;
- Strengthened business cases for long-term funding; and
- Benchmarking opportunities.

The asset management maturity journey, which PAS 55 advocates, promotes refinement of a road operator's contingency plans and actions to improve maturity level 'gaps'. In addition to process effectiveness, organisations can identify competency-based training needs and cultural embedment opportunities to reinforce the importance of a resilient network.

## CONCLUSION

It is vital that road networks remain resilient to preserve the benefits they bring to communities and economies and to ensure that risks to the public and safety of road workers are effectively addressed. In order to determine which incidents and emergencies to consider as part of a resilience model many organisations are using risk management and scenario planning. PAS 55 and ISO 55000 offer asset owners a standardised approach to enhance their resilience models and that of their road operators, bringing greater consistency and transparency.

Achieving PAS 55 accreditation does not bring guarantees in the same way that ISO 9000 does not guarantee a quality product. But it provides the best chance to prevent network resilience failures through appropriate risk management and good governance. Asset-owning organisations, including road operators, should therefore embrace formalised governance frameworks such as PAS 55 and ISO 55000 to manage their assets safely and efficiently.

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# U.S. STATE DEPARTMENTS OF TRANSPORTATION (DOTS) BUILDING RESILIENCE: **WHAT STATES ARE DOING TO BETTER PREPARE FOR EXTREME WEATHER EVENTS**

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FLOODING WAS REPORTED TO BE OF THE GREATEST CONCERN TO STATE DOTs (96 PERCENT), FOLLOWED BY EXTREME SNOW AND ICE EVENTS (65 PERCENT), AND HURRICANES OR TROPICAL STORMS (39 PERCENT).

## INTRODUCTION

Extreme weather events can disrupt transportation services, damage expensive infrastructure, result in more frequent maintenance and, in some cases, influence decisions when rebuilding. In 2013 in the U.S., there were nine weather and climate disaster events of a magnitude that resulted in more than $1 billion each in losses. Together, these events caused 123 deaths and $23 billion in damages.[1]

There is strong evidence that heat, heavy precipitation, and coastal flooding events will grow in frequency and severity in coming decades and we will likely continue to experience droughts and tropical storms. Changes in the frequency or intensity of extreme weather events also influence changes in transportation system operations and planning, risk-based asset management, construction, and design inputs or considerations for engineers.

For example, changes in weather-related stressors such as increased wind or storm exposure, wave impacts, temperatures, precipitation, and freeze-thaw cycles may induce states to review and/or modify values or parameters associated with the design of pavements, hydraulic features, sign and lighting structures, and other aspects of the transportation infrastructure. Similarly, how would one assess the risk to existing infrastructure from increased incidence of extreme weather events?

## EXTREME WEATHER-RELATED CHALLENGES

State DOTs play a key role in not only the response to and recovery from extreme weather events, but also in improved preparedness and resiliency of the transportation system. In a 2014 survey[2] of state DOTs, the following common DOT challenges were noted:

- Concerns about the increasing frequency of unusual and extreme weather events, which drives the need for widespread sharing of resiliency and sustainability practices to promote efficient use of resources. State DOTs see benefit in peer exchange with other DOTs, metropolitan planning organizations (MPOs), transit organizations, and other transportation providers.
- Significant damage to assets and system disruptions as a result of extreme weather events.
- Difficulty managing state transportation infrastructure with existing state and federal funding constraints.
- Wide variation of changing weather patterns, impacts, consequences, and capacity for event recovery by state and location.

For challenges related to specific extreme weather event types, 96 percent of state DOT respondents reported flooding to be a high priority followed by extreme snow and ice events (65 percent) and hurricanes or tropical storms (39 percent).

## EXTREME WEATHER EVENTS SYMPOSIUM

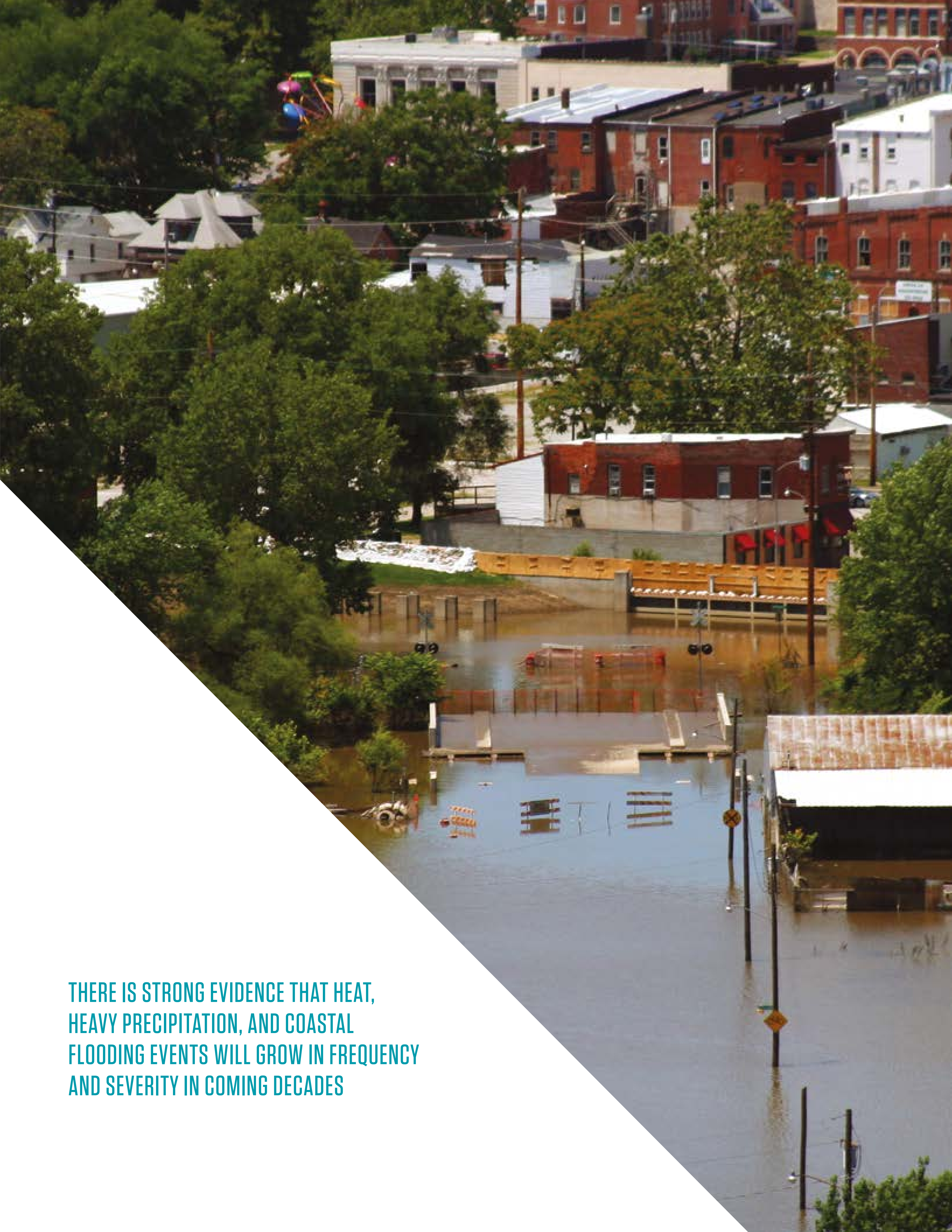
In 2013, the American Association of State Highway and Transportation Officials (AASHTO) held a national Extreme Weather Events Symposium[3] in Washington, D.C. that focused on the impacts of extreme weather events on transportation. It provided a platform for DOT staff from a variety of disciplines to convene and discuss DOT experiences and lessons learned from extreme weather events; trends and projections of extreme weather in the U.S.; costs of extreme weather events; and risk management strategies in design, ›



[1] The National Oceanic and Atmospheric Administration's National Climatic Data Center: Billion-Dollar Weather/Climate Disasters.

[2] The survey was conducted through the American Association of State Highway and Transportation Officials (AASHTO) Resilient and Sustainable Transportation System (RSTS) Technical Assistance Program with support from Parsons Brinckerhoff.

[3] The meeting was sponsored by AASHTO's Resilient and Sustainable Transportation Systems (RSTS) Technical Assistance Program, in coordination with the Center for Environmental Excellence (CEE) by AASHTO and the Federal Highway Administration (FHWA).



THERE IS STRONG EVIDENCE THAT HEAT, HEAVY PRECIPITATION, AND COASTAL FLOODING EVENTS WILL GROW IN FREQUENCY AND SEVERITY IN COMING DECADES

operations, maintenance, asset management, and emergency response.

Case studies presented by the various DOTs covered major events like storms and flooding (New Jersey DOT, Minnesota DOT, District of Columbia DOT), wildfires and dust storms (Colorado DOT, Arizona DOT, Maryland DOT). In those case study presentations, common challenges included communications, equipment and material shortages, and the sheer size and impact of the unprecedented event. In many cases, post-event debriefings took place for discussion on changes and improvements to existing procedures and practices. As an example, the District of Columbia DOT (DDOT) instituted the following changes after the 2010 "Snowmageddon" event:

- One floating plow truck in every ward with a captain as a backup for rapid response to any concerns from the snow command center or the mayor;
- Improved training programs for drivers and supervisors, simulator training to enhance driver plowing skills, expanded anti-icing pre-treatment of residential streets using four small spray trucks procured last year;
- Improved cost accounting with the StormTrak[4] system; and
- Contingency plans.

## DISCIPLINE-SPECIFIC APPLICATIONS

There has been a growing interest in discipline-specific resiliency information and case studies following extreme weather events. In the 2014 survey, 78 percent of respondents reported extreme weather and transportation systems management and operations (TSM&O) as a high priority topic. TSM&O includes: development and execution of contingency plans, evacuation and emergency route planning, traveler information, early warning systems, and pre-positioning of materials and equipment, among others.

As a follow-up to the 2013 Extreme Weather Events Symposium, the sponsors, with support from Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff), presented updates on the latest research, case studies, and tools pertaining to extreme weather and climate change.

Additionally, a "Top 10" list of suggestions and further resources was developed - through DOT interviews, case studies, project experience to date, and research recently completed or underway - to prepare practitioners in a specific discipline for extreme weather. Top 10 discipline-specific lists[5] were available for: TSM&O, highway design, bridges and structures, construction, and maintenance. These updates and lists were distributed at the 11 regional and technical committee meetings across the country.

Although DOT experience with operations varies by state and topic, below is a sample "Top 10" list of suggestions for TSM&O managers and staff to better prepare for extreme weather:

1. Have contingency plans for power outages, detours, debris clearance, and routing for overweight or disabled trucks - to include pre-approved contractors and funds.
2. Operate effective evacuation routes in high-risk areas.
3. Develop effective public and traveler information systems/services to inform travelers of travel options (including social media tools, mobile apps, and collecting real time conditions through vehicle technology).
4. Use response to "routine emergencies" to test staffing, deployment, and communications. Also, coordinate in advance with partners at the local, state, and federal level in the event response is required.
5. Develop strategies for responding to transportation system disruptions due to weather-related events, including pre-positioning replacement materials (culverts, etc.) in vulnerable areas.



[4] StormTrak is a web-based system enabling the tracking of snow and storm operations costs. It provides a complete history of all operational activities, decisions, costs and details for each event which has proven to be invaluable when preparing documentation for FEMA reimbursements or other expense justifications. Tracking categories include but are not limited to: employee attendance (regular hours worked, overtime, double time and any union differential), contracted drivers, and government vehicles deployed.

78%

RESPONDENTS TO A SURVEY REPORTED EXTREME WEATHER AND TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS (TSM&O) AS A HIGH PRIORITY TOPIC

6. Prepare backup communications such as satellite phones, portable highway advisory radios, truck radios, and alternative networks.
7. Identify facility locations vulnerable to risks (flooding, landslides, etc.), and develop appropriate strategies to minimize such risk.
8. Incorporate "early warning indicators" for potential extreme weather-related risks into asset and maintenance management systems.
9. Prepare for events with backup power generators, "hardened" sign structures and traffic signal wires, pre-positioned variable message sign boards, and support vehicles trucks.
10. Protect workers from extreme temperatures and weather during day-to-day and response activities.

## AVAILABLE RESOURCES FOR STATE DOTS

### AASHTO'S RESILIENT AND SUSTAINABLE TRANSPORTATION SYSTEMS (RSTS) TECHNICAL ASSISTANCE PROGRAM

This program provides timely information, tools, and technical assistance to state DOTs to manage challenging issues associated with extreme weather events, infrastructure vulnerabilities, energy demands, and diminishing resources. The technical assistance program[6] was created in May 2008 at the request of AASHTO members. AASHTO established a steering committee comprising various state DOT commissioners, secretaries, and directors to oversee the fee-based technical assistance program. Initially, the program was designed to respond to states' growing interest in transportation-related emissions reductions and to explore opportunities for state DOTs to participate in alternative fuel initiatives, provide increased travel options, and prepare for and respond to increased impacts of climate change.

Since 2008, the technical assistance program has sponsored a number of program activities to provide technical and policy support to the states. In addition to the 2013 Extreme Weather Event Symposium mentioned above, examples include:

- **Member-Only News:** A bimonthly newsletter that includes extreme weather event special reports featuring DOT case studies and lessons learned based on first-hand interviews with DOT officials. WSP | Parsons Brinckerhoff, in partnership with Bloomberg BNA, conducts the interviews and publishes the regular newsletter. Additional newsletter features include information on recent projects, programs, state practices, and technical information on responding and adapting to extreme weather events, and strategies for reducing energy consumption. Breaking news alerts on executive orders, funding announcements, or newly proposed legislation related to extreme weather and energy are also provided to members.
- **President's Task Force on Climate Preparedness and Resiliency** (March 2014): AASHTO, with support from WSP | Parsons Brinckerhoff, assisted the Vermont Agency of Transportation (VTrans) in collecting and synthesizing information on state DOT resiliency efforts to inform transportation sector recommendations for the President's Task Force on Climate Preparedness and Resiliency.
- **Website:** The AASHTO Transportation and Climate Change Resource Center provides information on recent developments, links to resources, successful state DOT practices, and webinars developed through the program. Design, maintenance, and forthcoming improvements are made possible with technical support by WSP | Parsons Brinckerhoff in partnership with Bloomberg BNA.
- **Webinars** (2010-2012): In 2010 and 2011, WSP | Parsons Brinckerhoff developed and conducted 12 webinars for AASHTO, providing useful information to state DOTs on reducing energy consumption. In 2012, AASHTO hosted a webinar on best practices and challenges related to infrastructure adaptation.
- **Electric Vehicle Publication** (July 2011 – March 2012): The technical assistance program supported the development of the publication "An Action Plan to Integrate Plugin Electric Vehicles with the U.S. Electrical Grid".
- **Research, Policy Support, Stakeholder Coordination**

The technical assistance program has evolved over time to provide assistance on a range of topics. Most recently, and as evidenced in the above examples, the program has expanded its focus to creating more resilient transportation systems in the face of increasingly frequent extreme weather events.

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*__Jennifer Brickett__ is the Director of the AASHTO Project Finance Institute. She previously managed AASHTO's RSTS Technical Assistance Program and served as the liaison to AASHTO's Air Quality, Climate Change, and Energy subcommittee.*

*__Shannon Eggleston__ is the Program Director for Environment at AASHTO. In this capacity, she is the liaison to the Standing Committee on Environment, and oversees and manages the Center for Environmental Excellence, the RSTS programs and other environmental programs.*

[5] To view the complete set of discipline-specific handouts on extreme weather and the transportation system, please visit: http://environment.transportation.org/center/products_programs/conference/2014_extreme_weather_sessions.aspx

[6] Formerly known as Sustainable Transportation: Energy, Infrastructure, and Climate Solutions (STEICS).



# EXPLORING RESILIENCE THROUGH SUSTAINABLE LIGHT RAIL STATION DESIGN

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CASE STUDIES TO IDENTIFY AND EVALUATE SUSTAINABLE DESIGN MEASURES FOR TWO LIGHT RAIL EXTENSION PROJECTS ARE PRESENTED. BY INCORPORATING SOME OF THESE MEASURES, THE TRANSIT AGENCY CONTRIBUTES TO THE GREATER RESILIENCE OF THE COMMUNITIES IN WHICH IT OPERATES AND THE REGION AS A WHOLE.

## INTRODUCTION

Sound Transit, the regional transit agency serving Washington State's Puget Sound region, is developing strategies to build a sustainable transit system that contributes to resiliency of the region and local communities in which Sound Transit operates. In 2011, Sound Transit established a sustainability plan that committed the agency to reducing its environmental footprint and contains a section on climate change adaptation, including the setting of an initiative to "ensure climate impacts are addressed in risk management, safety and security plans." Sound Transit recently completed an assessment of agency resiliency to climate change impacts, one of seven climate change adaptation pilot projects from the Federal Transit Administration (FTA). The assessment identified potential climate change-related impacts to existing and future Sound Transit services, including flooding, sea level rise, and heat stress on agency facilities. These issues relate to how climate change can affect Sound Transit capital facilities and its ability to provide services and operations. This paper describes the former aspect of resilience; by incorporating sustainable design features into its capital projects, Sound Transit can contribute to not only its own resilience as an agency, but also to the greater resilience of the communities in which it operates and the region as a whole.

Sound Transit's design criteria manual establishes requirements for sustainability-related design approaches in project development, including a sustainability checklist to be used for all capital projects. The checklist, which is modeled after the LEED rating system, provides a basis for identifying and evaluating sustainable features to be considered for inclusion in projects. Sound Transit has been gradually incorporating this into its project planning and design processes. Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) has recently led the evaluation of sustainable design elements in two Link light rail extension projects: East Link Final Design and Lynnwood Link Extension EIS and Preliminary Engineering. For East Link, the introduction of new sustainable design elements has been limited due to the late stage of project development (final design). The Lynnwood Link project provides an opportunity to introduce these measures at an earlier stage in project development. These evaluation efforts are described below. WSP | Parsons Brinckerhoff is helping Sound Transit to incorporate sustainability at an even earlier stage with the recent start of development of a new system expansion plan.

## EAST LINK

WSP | Parsons Brinckerhoff is conducting final design to extend light rail from Seattle to the eastern suburbs of Mercer Island and Bellevue across Lake Washington. The project, which will involve constructing light rail on a floating bridge for the first time, includes two new stations as well as retrofitting two existing roadway tunnels to

accommodate light rail. The contract calls for the design team to identify and evaluate potential sustainability measures, work with Sound Transit staff to select which measures to incorporate into the design, and then complete a checklist and sustainability report to document the process and reasons for including or not including measures.

WSP | Parsons Brinckerhoff facilitated multiple workshops with Sound Transit and the design team staff, as well as representatives from the other partner public agencies. The attendees first agreed upon a set of general sustainability goals and then used the sustainability checklist from the Sound Transit design criteria manual to identify a range of potential concepts for evaluation. The design team then conducted a high-level qualitative assessment of cost and construction implications for these measures. Based on the results of this initial assessment, a more detailed total cost of ownership (TCO) analysis was conducted for the most promising measures. Those measures and the key findings are listed below:

- Solar panels on station roofs, estimated to provide between 2 percent and 12 percent of the annual electricity needs of the station, depending on the system size;
- LED lighting in tunnels with cost savings estimated at more than $200,000 over 25 years for using LED fixtures instead of florescent fixtures (LED lighting is being incorporated into a Sound Transit tunnel project currently under construction);
- Green roofs on stations that reduce stormwater runoff and serve as a visible example of Sound Transit's commitment to sustainability (due to stations' adjacency to an interstate freeway); and
- Rainwater harvesting that would provide a total of 166,000 gallons annually for landscaping irrigation.

While the TCO analysis indicated that photovoltaic panels would increase the station construction cost, the ideal south-facing orientation of the station roof and unimpeded solar exposure, combined with high visibility to motorists using an adjacent freeway, made this measure appealing to Sound Transit staff. The final design team is now in the process of incorporating solar panels into the station design for one of the stations.

## LYNNWOOD LINK

Phase 3 of this 8-mile extension of light rail between North Seattle and the city of Lynnwood in neighboring Snohomish County includes completing preliminary engineering (PE) and environmental analysis for Sound Transit's identified preferred alternative. The consultant team is currently evaluating five sustainable design measures for potential inclusion. The evaluation process is similar to the evaluation conducted for East Link, but takes place in an earlier phase of project development, which may influence the outcome of potential inclusion in the project. Based on guidance from

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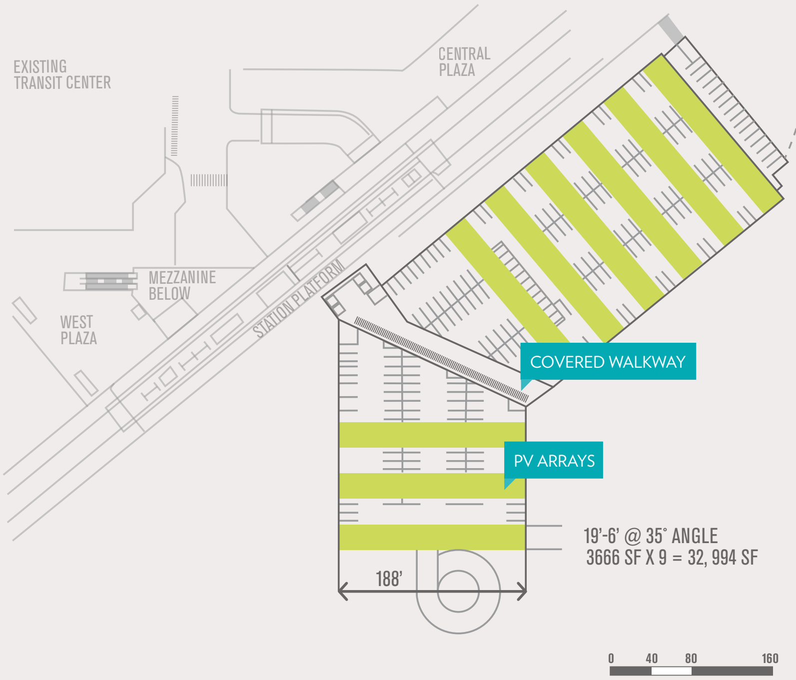


**FIGURE 1** - LYNNWOOD TRANSIT CENTER PARKING GARAGE PV PANEL CONCEPT

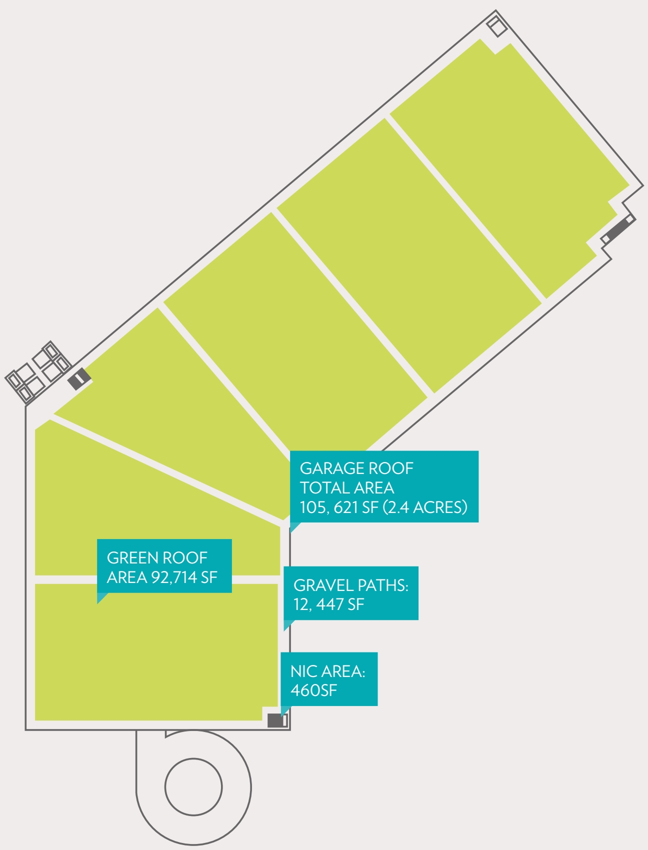


**FIGURE 2** - LYNNWOOD TRANSIT CENTER PARKING GARAGE GREEN ROOF CONCEPT

SOUND TRANSIT CAN CONTRIBUTE TO NOT ONLY ITS OWN RESILIENCE AS AN AGENCY, BUT ALSO TO THE GREATER RESILIENCE OF THE COMMUNITIES IN WHICH IT OPERATES AND THE REGION AS A WHOLE.

THE USE OF GREEN STORMWATER INFRASTRUCTURE MEASURES SUCH AS PERVIOUS PAVING CAN HELP RECHARGE GROUNDWATER AND UNDERGROUND AQUIFERS WHILE REDUCING THE NEED FOR COSTLY DETENTION AND TREATMENT FACILITIES.

Sound Transit, WSP | Parsons Brinckerhoff, in partnership with Parametrix as North Corridor Transit Partners, LLC, developed a new total cost of ownership (TCO) tool to analyze baseline and alternative scenarios for three out of five potential sustainable design measures. A high-level evaluation was conducted for the remaining two measures. Those measures and preliminary findings include:

- Solar panels atop a station parking garage and station canopy that could generate up to 40 percent of the station's annual energy demand (see Figure 1);
- A green roof atop a station parking garage that requires significant financial investment above the current open air (no roof) PE design but reduces stormwater detention and water quality treatment facility needs (see Figure 2);
- Pervious pavement for parking and pedestrian areas that reduces downstream stormwater management systems and recharge groundwater;
- Collection and reuse of rain water from a station parking garage roof for irrigation of station landscape areas; and
- Potential locations and system configuration criteria for use of wall systems that support plant life, allowing site water movement while providing required long term structural function.

Sound Transit will refine the evaluation findings to better meet the scale of the project and ability to invest in such features. This information will then be presented to decision-makers in order to determine how to move forward with investing in green infrastructure design in the Lynnwood Link Extension Project.

## CONCLUSION

As indicated previously, the FTA-sponsored risk reduction project identified resiliency issues in terms of how climate change can affect Sound Transit capital facilities and its ability to provide services and operations. However, the sustainable design efforts described in this paper present another aspect of resilience; by incorporating some of these measures, Sound Transit can contribute to not only its own resilience as an agency, but also to the greater resilience of the communities in which it operates and the region as a whole. For example, the incorporation of solar panels in its projects will reduce the reliance of the grid in general on other sources of energy, including gas, coal, and even hydro-power (which, while considered a carbon-free energy source, is likely to become less reliable in the future due to the region's decreasing mountain snowpack). The use of green stormwater infrastructure measures such as pervious paving can help recharge groundwater and underground aquifers while reducing the need for costly detention and treatment facilities.

Going forward, WSP | Parsons Brinckerhoff is helping Sound Transit incorporate sustainability considerations earlier in the project development process. As part of the recent update of the Sound Transit long-range plan, WSP | Parsons Brinckerhoff staff researched and developed an issue paper with recommendations on the most appropriate actions to be undertaken during Sound Transit's early planning efforts. The paper reported on research and interviews conducted regarding incorporation of sustainability by peer agencies into system planning and project development. Key recommendations included a specific focus on potential funding mechanisms for incorporating sustainable design into infrastructure projects. WSP | Parsons Brinckerhoff has recently begun a project with Sound Transit to help in the development of a new system expansion plan, and will be implementing some of the recommendations from the issue paper as the plan develops.

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# CLIMATE CHANGE ADAPTATION FOR AIRPORTS

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LONDON LUTON AIRPORT AND CARDIFF AIRPORT COMMISSIONED PARSONS BRINCKERHOFF (NOW PART OF WSP | PARSONS BRINCKERHOFF) TO HELP THEM IDENTIFY HOW RESILIENT THEIR ORGANIZATIONS AND OPERATIONS ARE TO FUTURE CLIMATE CHANGE IMPACTS.

## OVERVIEW

In 2011, the U.K. government mandated all reporting authorities (organisations with functions of a public nature and statutory undertakers) to complete a climate change adaptation report. Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) helped Cardiff and Luton airports develop a risk assessment methodology to identify the preparedness of their operations and assets for potential climate change impacts. The output was a prioritised risk assessment and adaptation action plan that met with U.K. Department for Environment, Food and Rural Affairs (Defra) reporting requirements, and supported the U.K. government with developing its first national adaptation plan.

## AN UNDERSTANDING OF CLIMATE CHANGE AND THE POTENTIAL IMPACTS ON INFRASTRUCTURE AND ITS MANAGEMENT

During the last 8 years, the U.K. has witnessed some of the most severe weather events on British record (see figures 1 and 2). Summer flood events in 2007 caused widespread disruption, economic loss, and social distress, resulting in a national catastrophe being declared by the government. The Environment Agency estimated national losses at £4 billion[1], of which £674 million of damages were to 'important national infrastructure' and the operation of essential services.

In December 2010, the 'big freeze' caused the economy to shrink by 0.5 percent in the last three months of 2010 (see figures 3 and 4), whilst in January 2013 snowfall across the U.K. cost the economy an estimated £470 million a day, based on unprecedented travel disruption[2].

In response, the U.K. government recognised that a national adaptation programme (NAP) was required to identify the preparedness of major industry sectors for climate change impacts. Within the NAP infrastructure review, all reporting authorities - including the aviation sector - were mandated to prepare a climate change adaptation report which stated how resilient their organisation and operations are to future climate change impacts. The output of the reports was of significance to the U.K. government, as it used all reports to underpin the U.K.'s first climate change risk assessment[3].

London Luton Airport Operations Limited (LLAOL) and Cardiff Airport (CA) commissioned WSP | Parsons Brinckerhoff to help them understand the requirements, assess their readiness, and present this back to government.

## CHALLENGES AND INNOVATION

Defra recognised that each climate change adaptation report would be unique to the operations of reporting authorities. As such, a reporting framework was issued but a specific risk assessment methodology was not prescribed. Without a set of guidelines

FIGURE 1 - AUGUST 2006, HEAVY RAIN AND POOR DRAINAGE CAUSES FLOODING OF THE CARRIAGEWAY (M25 J11 - 12)

FIGURE 2 - JAN 2006, HIGH WINDS OVERTURN HGVS (M25 J29)

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291190/scho1109brja-e-e.pdf

[2] http://www.bbc.co.uk/news/business-21121219

[3] U.K. Climate Change Risk Assessment https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report

FIGURE 3 - EXTREME WEATHER EVENTS AT CARDIFF AIRPORT DURING 2010'S 'BIG FREEZE' (VERESHCHAGIN DMITRY / SHUTTERSTOCK.COM)

FIGURE 4 - SNOWFALL GROUNDS PLANES ACROSS THE U.K.'S AIRPORTS DURING THE 2010 'BIG FREEZE'

for the report, WSP | Parsons Brinckerhoff needed to develop a methodology that would provide a transparent, robust, and consistent methodology for both airports. To overcome this challenge, WSP | Parsons Brinckerhoff worked collaboratively to produce a process that assisted LLAOL and Cardiff Airport to:

- understand the likely impacts of climate change in their local areas;
- identify the airports' assets and operations which were vulnerable to these impacts;
- assess the significance of vulnerabilities through developing a risk prioritisation tool;
- produce a risk register;
- identify adaptation measures for prioritised impacts, resulting in a climate change adaptation plan; and
- produce a report for Defra and other interested stakeholders.

## RISK REDUCTION STRATEGIES

Using climate change projections from U.K. Climate Impacts Programme (UKCIP)[4], WSP | Parsons Brinckerhoff developed a risk assessment methodology that aligned with the broader risk management processes already used by the airports' parent group, TBI/Abertis. This ensured the airports benefited from an approach that effectively embedded climate change risk assessment into their current business processes, environmental management systems, and decision-making protocols, and one that had the potential to inform policy change. The methodology was applied to help the airports understand how climate change risks could potentially impact the following key business areas:

- Air Traffic Control
- Airfield Operations
- Terminal
- Cargo
- Fire Service
- Surface Access – roads and carparks
- Office & Markets

## USE OF EXPERT KNOWLEDGE

Gaining key staff and stakeholder buy-in was critical in effectively appraising risks, and identifying areas of the airports' assets and operations that were threatened by potential impacts.

Drawing on previous work completed for the U.K. Highways Agency climate change portfolio, WSP | Parsons Brinkerhoff knew that 'expert knowledge' would likely come from unexpected sources. In this case, staff who worked 'on the ground' knew how the business and its operations become affected throughout the seasons, and offered invaluable perspective and insight ›

[4] UKCIP http://www.ukcip.org.uk/

when considering impacts. They held important information about the day-to-day operation and maintenance of assets that may otherwise have been overlooked, or simply not have been important historically – but have real relevance when looking forward.

We accessed the information they held through organising a climate change risk assessment workshop at each airport. Working collaboratively, key staff agreed and scored potential climate change impacts and identified mitigation measures.

Engaging with external stakeholders was also important for demonstrating that managing interdependencies with external organisations was a key part of adapting to climate change. At Luton Airport, for example, WSP | Parsons Brinckerhoff supported engagements with Luton Borough Council, National Air Traffic Services, and surface water drainage engineers Veolia, as areas of Luton Airport's access roads were known to be prone to flooding. The flooding causes access issues for airport customers and traffic build-up on local highways, and so future flood events were found to be high risk for the airport. Interdependent work with local highways experts and drainage engineers will be vital for maintaining access to the airport, and the surrounding road network.

## THE IMPACT OF WSP | PARSONS BRINCKERHOFF'S SOLUTION ON THE PROJECT

The outcome of the consultation exercise and workshop was a risk appraised adaptation action plan, including a prioritised set of risks and actions to help increase the resilience of the airports to the impacts of climate change. Responsibilities for actions were also assigned to named staff. The ten most significant risks were identified for both airports and included threats to airfield operations, airport terminal operations, and National Air Traffic

| Residual Risk Rating | Business function & headline climate variable | Timescale over which risks are expected to materialise and action is planned | Rationale | Primary impact of climate variable | Threshold(s) above which this will affect Cardiff Airport | Likelihood of threshold(s) being exceeded in the future and confidence in assessment | Potential impacts on organisation and stakeholders | Proposed action to mitigate impact |
|---|---|---|---|---|---|---|---|---|
| SHORT TERM RISK - 12<br>MEDIUM TERM RISK - 20<br>LONG TERM RISK - 20 | Airfield Operations<br>Milder, wetter, winters | Short term: Action planned over 9 years<br>Medium-long term: Action planned over 15-20 years | Experience of mild, wet weather conditions has previously caused increases to the number of fog days at Cardiff Airport. Projected increases in these conditions are therefore expected to increase the amount of fog that Cardiff Airport experiences | More frequent disruption to operations, flight delays and low visibility procedures (LVP) | Past experience of mild, wet winters will be used to identify the thresholds past which fog days are triggered, and how they impact operations | Occasional occurence in the short term; likely occurence in the medium-longer term<br>Experience of similar climatic conditions indicates that projected increases in these conditions are likely to impact Cardiff Airport operations | Delays to flights, increased re-routed flights from other airports experiencing low visibility fog days<br>CAT 3 Instrument Landing System (ILS) and above ground level (AGL) equipment required. Costs incurred through increased need for generators to maintain the AGL in the event of power cut. The ILS will remain in service via UPS | Review the capability and performance of CAT 1 Instrument Landing System (ILS) and instrumented runway visual range equipment. Review longer term plans to introduce CAT 2 or 3 ILS |
| SHORT TERM RISK - 16<br>MEDIUM TERM RISK - 16<br>LONG TERM RISK - 16 | Airport Terminal<br>Warmer, drier summers | Short term: Action planned over 5-9 years<br>Medium-long term: Action planned over 15 years | During peak summer months, the terminal currently experiences increased internal temperatures. Under the medium to higher emission/probability, the occurrence of high temperatures may significantly increase. Existing terminal building infrastructure may not cope with projected temperature increases without modification | Warmer conditions in terminal - for staff and passengers | Past experience of raised summer temperatures will be used to identify the thresholds past which Airport Terminal conditions impact staff and passengers | Occasional occurence. Terminal currently experiences increased internal temperatures during peak summer periods. The existing terminal building infrastructure is unlikely to cope with projected temperature increases without modification | Higher levels of air conditioning for prolonged periods, increased maintenance and energy costs, change in breaks and staff rotas due to weather conditions | Assess current Building Management System (BMS) and heating, ventilation and air conditioning (HVAC) set up in the terminal building. Establish whether current system will be able to cope with longer-term temperature projections |
| MEDIUM TERM RISK - 12<br>LONG TERM RISK - 12 | Air Traffic Control<br>Increasing frequency of extreme weather | Medium-long term: Action planned over 20 years | The likelihood of extreme adverse weather events occuring/ re-occuring is remote. However, should this scenario take place, the impact would be significant | Greater risks of airport closure due to extreme and sustained weather events | Experience of how extreme weather events have affected Cardiff Airport and other Abertis Group airports will be used to identify the thresholds past which NATS may be impacted | Remote occurrence. Predicted increases in the frequency of extreme weather events have the potential to occasionally create conditions which will impact operation | Financial loss from airport, negative national publicity due to stranded/delayed passengers, divert aircraft to other airports | Monitor effects of extreme weather events on airport and accessibility to NATS facilities. Liaise with Met Office and UKCIP to make sure the most up to date climate data is observed. Update procedure as appropriate |

**FIGURE 5** - ADAPTATION ACTION PLANS FOR KEY BUSINESS AREAS FOR CARDIFF AIRPORT

Services (NATS), as shown in Figure 5.

In addition to a quantified risk assessment and action plan, the approach that WSP | Parsons Brinckerhoff implemented benefitted both airports by fostering better relations between the owning company and local stakeholders. For example, since our involvement Luton Airport has spearheaded a climate change stakeholder group, gaining buy-in from local authorities and interest groups.

## THE FINANCIAL COSTS OF ADAPTATION

The U.K. National Adaptation Programme estimates that, across Europe, every £1 spent on increasing resilience now could yield £4 in damages avoided[5]. Identifying and taking early action is therefore imperative for ensuring adaptation actions are affordable and worthwhile.

Both Luton and Cardiff Airports appraised the risk of climate change against the financial and reputational impacts to their businesses, and the ability to deliver services to stakeholder expectations. In addition, reviewing the investment in capital projects, existing equipment capabilities, and liaising closely with stakeholders (including NATS and the Met Office) were all significant on-going actions identified through WSP | Parsons Brinckerhoff's risk assessment and management process.

## THE MEANING OF THE NEW TECHNOLOGY OR TECHNIQUE TO WSP | PARSONS BRINCKERHOFF AND THE STATE-OF-THE-ART OF THE INDUSTRY

The climate change adaptation frameworks and risk assessment methodologies WSP | Parsons Brinckerhoff delivered resulted in our gaining a more precise knowledge of using and applying climate data. We are now able to integrate risk assessments directly into business values and targets and align them with embedded management systems. This makes it easier for staff to adopt, understand, implement, and take ownership of the risk assessment process - therefore making the process for building resilience more effective, workable, and successful.

Having evolved the climate change adaptation framework developed for the Highways Agency (2007-2008) for the airport sector, our methodologies are demonstrably flexible and easily updated for other industry sectors. Not only do we deliver the process for preparing infrastructure assets and operations for climate change impacts, we are also able to supply engineering solutions on the ground.

## THE CURRENT STATUS OF THE PROJECT, TECHNIQUE, AND TECHNOLOGY

The information in our report was submitted to Defra in 2012 and subsequently used, along with other adaptation reports, to form the U.K. Climate Change Risk Assessment (CCRA). The U.K. CCRA sets out the framework for the U.K. to adapt for climate change, and is the first in a five year cycle of updates. It sets out the main priorities for adaptation in the U.K. and describes the policy context and action already in place to tackle some of the risks in each area. The next phase is for the U.K. government to undertake another round of reporting in 2017, and we are well-placed to support our clients with meeting any new requirements and criteria.

***Abigail Frost**'s main areas of interest are climate change adaptation and mitigation. She took lead roles within the project teams that won WSP | Parsons Brinkerhoff's 2013 Global Sustainability Project of the Year for delivering a carbon assessment of Network Rail's Northern Hub programme, and PB's 2009 U.K. Sustainability Project of the Year for delivering the Highways Agency's Climate Change Portfolio.*

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[5] U.K. National Adaptation Programme 2013 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf

# RECOVERY AND REHABILITATION OF NEW JERSEY'S NAVIGATION CHANNELS IN THE WAKE OF SUPERSTORM SANDY

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LAND-BASED DAMAGE TO PROPERTIES AND INFRASTRUCTURE BY THE STORM WAS READILY APPARENT, BUT DAMAGE TO THE STATE'S NAVIGATION CHANNELS WAS UNCLEAR. PARSONS BRINCKERHOFF (NOW PART OF WSP | PARSONS BRINCKERHOFF) WAS CONTRACTED TO EVALUATE THE DAMAGE AND SUPPORT CHANNEL RECOVERY AND RESTORATION.

On October 29, 2012 at about 8 PM EDT the eye of "Superstorm Sandy" made landfall near Atlantic City, New Jersey. A full moon made the high tides approximately 20 percent higher and amplified the record storm surge. The destructive "right hook" of Sandy's hurricane wind pattern devastated the New Jersey and New York coastline situated north of where the eye made landfall. Along New Jersey's Raritan Bayshore region, the tidal surge was recorded to be more than 9 feet above the mean high water elevations.

After Superstorm Sandy, the land-based damage to properties and infrastructure was readily apparent, but damage to the state's navigation channels was unclear. Prior to the storm, New Jersey's navigation channels were maintained by the New Jersey Department of Environmental Protection's (NJDEP's) Bureau of Coastal Engineering. To develop a more dynamic program to maintain the state's navigation channels, the responsibility for maintenance was transferred from the NJDEP to the New Jersey Department of Transportation's (NJDOT's) Office of Maritime Resources (OMR).

## WSP | PARSONS BRINCKERHOFF'S ROLE IN CHANNEL ASSESSMENT AND RECOVERY

The NJDOT selected a team, led by WSP | Parsons Brinckerhoff, to perform bathymetric surveys[1] and side-scan sonar[2] along 209 state channels, comprising nearly 200 nautical miles, to evaluate the damage done by Superstorm Sandy. This evaluation served multiple purposes in enabling the team and client to: review the physical condition of the channels to identify shoals and debris targets; prioritize remediation efforts through an evaluation of the economic value and usage of specific channels; and prioritize the restoration of the channels in order to protect the public from hazardous conditions.

After the completion of the channel assessment phase, the WSP | Parsons Brinckerhoff team was awarded a follow-on contract for continued work with NJDOT to prioritize channel maintenance dredging projects and assist the NJDOT in developing, funding, and executing an annual $15 million capital program to design, permit, and construct the maintenance dredging of the state's channel system.

The WSP | Parsons Brinckerhoff team is responsible for the following activities in supporting channel recovery and restoration:

- Project management;
- Evaluation of various design alternatives for the dredging of navigation channels and sediment disposal utilizing existing upland confined disposal facilities (CDFs);
- Evaluation and geotechnical investigation of existing CDFs along the New Jersey shore to determine their available capacity and ability to accept dredged material;
- Complete design plans, environmental permits, and contract documents for maintenance dredging projects;
- Design and permitting of confined disposal facility construction for the placement of dredge material;
- Assisting NJDOT with the advertisement and award phases of maintenance dredging projects; ›

[1] Bathymetric surveys are conducted to collect data to determine the depths of water bodies, the topography of the sea floor and coastline, and other physical features of water bodies.

[2] Side-scan sonar is a category of sonar system that is used to efficiently create an image of large areas of the sea floor to locate and define physical obstructions on the floor of a water body.

- Monitoring the progress of and providing construction services for the active maintenance dredging projects to clear the channels across the state's navigation system; and
- Providing contract documents for maintenance dredging projects on an accelerated schedule.

## CONFINED DISPOSAL FACILITIES

Confined disposal facilities (CDFs) are basically constructed, earthern bowls where the dredge slurry mix of water and sediment is pumped (see Figure 1). The perimeter of a CDF is constructed out of earthern berms that can vary in height from 5 feet to 30 feet. Depending upon the geotechnical properties of the available material, the confining berms have slopes somewhere between 2 feet horizontal to 1 foot vertical (2:1) and 3 to 1 (3:1). Confining berms are also designed to have an 8-foot to 10-foot wide flat top, to allow for construction vehicle maintenance equipment access. The sole function of a CDF is to hold the dredge slurry until the solid matter can settle out. After a settling period, clean water is drained from the CDF using a weir-type outlet structure and the solids are retained within the CDF.

## DREDGING IN THE RARITAN BAYSHORE REGION AND PROVIDING RESILIENCY SIMULTANEOUSLY

The biggest challenge in dredging is the availability of placement sites. State regulations dictate that if the dredge material is less than 75 percent sand, then it must be contained in an upland CDF. Dredge material that is 75 percent to 90 percent sand can be used for dune restoration and material that is 90 percent or greater sand is considered beach quality sand.

The placement of sand on the beach and/or restoring or creating protective dunes is an excellent example of the dual benefits of dredging and coastline resiliency provided by this program. The channels are cleared to their permitted design depth and the dredge material can be used to protect the coastline from tidal surges and flooding.

Another concept that serves this dual purpose is the construction of CDFs in a linear fashion parallel to the coastline (see Figure 2). This would allow for the placement of more fine-grained material adjacent to the shoreline. After placement, the filled CDF would actually be more stable than a dune made solely of sand since fine-grained material has more natural cohesion. The CDF constructed in the borough of Keansburg in Monmouth County, NJ is precisely this application (see Section A-A on Figure 3).

The borough of Keansburg in the Raritan Bayshore region of New Jersey was severely impacted by Superstorm Sandy. Prior to the storm, contract documents were prepared and environmental permits were issued for the maintenance dredging of Waackaack (pronounced way' cake) Creek and Thorns Creek. In Keansburg, the U.S. Army Corps of Engineers created a flood protection levee and installed a floodgate on Waackaack Creek back in the late 1960's. The floodgate separated the inland portion of Waackaack Creek and Thorns Creek from the portion of Waackaack Creek that extends into Raritan Bay and out to the NJ Intracoastal Waterway (see Figure 3). The nature of the material to be dredged was beach-quality sand in the outer channel and a more fine-grained material in the channels inside the floodgate.

An upland CDF already existed less than 200 feet from the mean high water line, but it was already filled to present capacity with dredge material from the previous maintenance cycle. NJDOT approached the borough with the prospect of removing the dredge material for the

FIGURE 1 - CONFINED DISPOSAL FACILITY (CDF) IN USE

construction of another coastal CDF in another Monmouth County town. The borough did not accept this proposal and viewed this coastal CDF and the material in it as an added protection to their town from the next superstorm.

The design team took this idea and ran with it. If the proposed CDF stayed within the original permitted footprint, we could use some of the material on the inside of the CDF to raise the confining berms, thereby creating more capacity. This would allow for the placement of the fine-grained material into the raised portion of the CDF and provide the town with an even larger natural barrier to Raritan Bay storm surges. The coarse-grained material from outside the floodgate was designed into a dune-like feature simply by extending the top of the confining berm's elevation waterward for a set distance, and then transitioning down to the existing beach grade at a 3 foot horizontal to 1 foot vertical (3:1) slope. The slope met the existing beach grade well upland of the mean high water elevation line.

The dual benefits of the long-awaited dredging of Waackaack Creek and Thorns Creek, combined with a naturally hardened section of coastline, had the borough so pleased that they suggested that the state construct more CDFs along the coastline. The CDFs would be aligned linearly and parallel to the coastline adjacent to the CDF used during this dredge cycle. The state and the borough have been having preliminary negotiations to make that concept a reality.

FIGURE 2 - CONSTRUCTION OF BEACH-FILL BERM

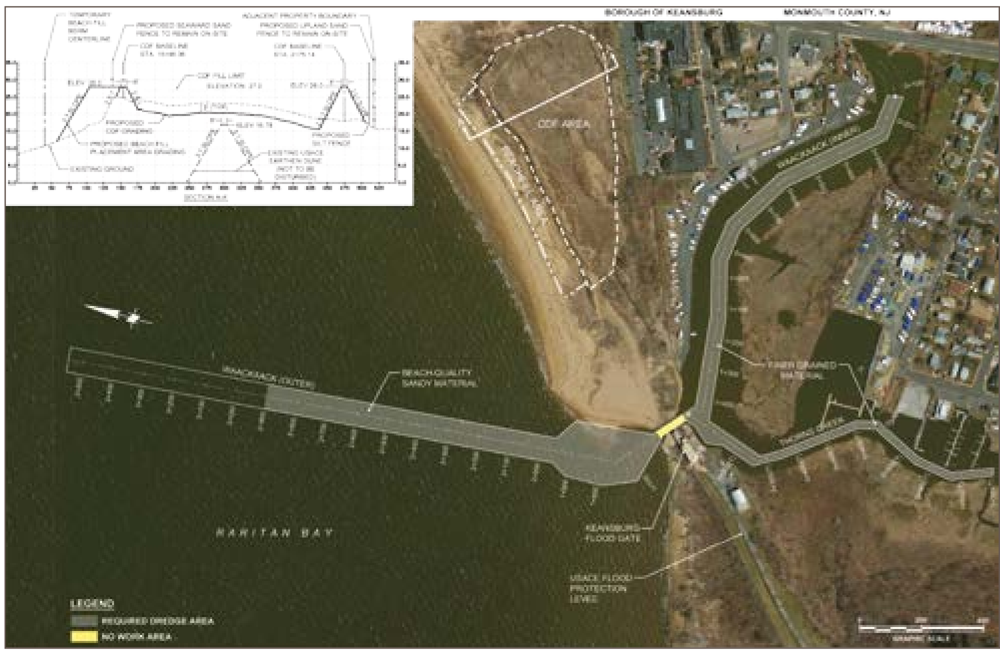


FIGURE 3 – PROJECT MAP WITH SECTION A-A OF THE KEANSBURG CDF

## CONCLUSION

The WSP | Parsons Brinckerhoff team completed the design, permitting, and construction of the following projects in 2014:

- Maintenance dredging and channel improvements for Waackaack Creek and Thorns Creek in the borough of Keansburg, Monmouth County;
- Maintenance dredging and channel improvements for St. Georges Thorofare in the city of Brigantine, Atlantic County; and
- Maintenance dredging and channel improvements for Spicers Creek, Cape Island Creek, Schellengers Creek, Devils Reach and Middle Thorofare, Lower Township and the City of Cape May, Cape May County.

The team is presently advancing eight to ten more maintenance dredging projects for construction in 2015 and beyond. The implementation of this annual maintenance dredging program will provide the navigation channels with resilience against future storms, and the strategic placement of the dredged material can provide resilience and protection for the adjacent coastal communities.

## ACKNOWLEDGEMENTS

The author would like to acknowledge Kavita Dave, PE a water resources engineer in WSP | Parsons Brinckerhoff's Lawrenceville, NJ office who contributed to this article. Gahagan and Bryant Associates (GBA) were absolutely essential for the success of this project. GBA are the dredged material management subject matter experts on the WSP | Parsons Brinckerhoff team.

***Michael Marano*** *is a Professional Engineer with over 22 years of experience with WSP | Parsons Brinckerhoff. While most of his experience was gained in the roadway and bridge market, he has been working almost solely on maritime projects since Superstorm Sandy struck the New Jersey coast.*

# A NEW MODEL FOR INTEGRATED PLANNING IN TRANSPORTATION, CLIMATE RESILIENCY, AND HABITAT RESTORATION

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THIS PROGRAM ALLOWS FOR LONG-TERM PLANNING OF BOTH TRANSPORTATION AND ENVIRONMENTAL PROJECTS IN THE CALIFORNIA COASTAL ZONE, AND PROVIDES AN OPPORTUNITY FOR SIGNIFICANT ADVANCEMENTS IN THE CORRIDOR'S CLIMATE RESILIENCY.

## PROJECT SUMMARY

The Public Works Plan/Transportation and Resource Enhancement Program (PWP/TREP) is a $6 billion, 40-year infrastructure plan in the California coastal zone that incorporates sea level rise planning and habitat restoration into a program of multimodal transportation improvements through the year 2050. The PWP/TREP is focused on the 27-mile North Coast Corridor, which serves as the northern gateway to San Diego County and provides access to its extensive coastal resources, including world-renowned beaches, lagoons, and upland recreation areas (see Figure 1). A joint product of the California Department of Transportation and the San Diego Association of Governments, the PWP/TREP contains a broad suite of freeway, rail, transit, bicycle, pedestrian, and environmental projects aimed at improving both mobility and sustainability. Major projects include:

- Construction of two Express Lanes[1] in each direction on Interstate 5 (I-5);
- Double-tracking the San Diego segments of the Los Angeles-San Diego (LOSSAN) rail corridor;
- Construction of over 30 miles of new bicycle and pedestrian facilities;
- Replacement of multiple freeway and rail bridges crossing the corridor's six coastal lagoons; and
- Large-scale restorations of two coastal lagoons, plus the preservation and/or enhancement of numerous other habitat areas.

### A NEW MODEL FOR INTEGRATED PLANNING

Managed by Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) with substantial contributions from environmental consultant Dudek, the PWP/TREP has established a new precedent for long-term infrastructure programs in California. Its comprehensive approach allows for better long-term planning of both transportation and environmental projects, and ›

CONSTRUCTION OF TWO EXPRESS LANES IN EACH DIRECTION ON INTERSTATE 5 (I-5).

DOUBLE-TRACKING THE SAN DIEGO SEGMENTS OF THE LOS ANGELES-SAN DIEGO (LOSSAN) RAIL CORRIDOR.

CONSTRUCTION OF OVER 30 MILES OF NEW BICYCLE AND PEDESTRIAN FACILITIES.

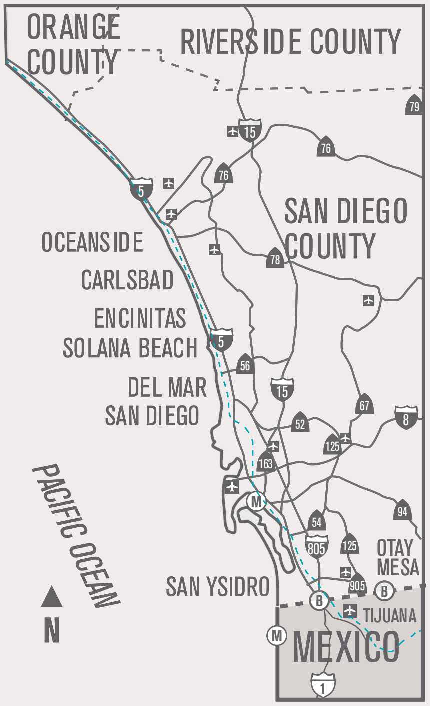


**FIGURE 1** – SAN DIEGO'S NORTH COAST CORRIDOR. (GRAPHIC: SOUTHWEST STRATEGIES)

[1] Express Lanes are free for carpools and buses, but charge a toll to single-occupant vehicles. The toll price varies based on real-time traffic levels and is intended to ensure free-flow conditions.

FIGURE 2 – THE ORIGINAL I-5 BRIDGE OVER BATIQUITOS LAGOON UTILIZED SUBSTANTIAL FILL, ARTIFICIALLY NARROWING THE LAGOON CHANNEL AND CREATING IMPACTS TO BOTH WETLAND HABITATS AND NEIGHBORING PROPERTIES. (PHOTO: CALIFORNIA DEPARTMENT OF TRANSPORTATION)

the integration between the two types of projects provides opportunities for synergy and impact minimization that otherwise would not occur.

### A PHASED, CONSTRAINED APPROACH ENSURING BROAD BENEFITS

The California Coastal Commission's unanimous support for the PWP/TREP stemmed largely from the assurances provided by the implementation plan. Rather than contemplating a freeway expansion by itself, the PWP/TREP divided the freeway project into 10-year phases and then tied each phase to major rail and transit improvements, numerous bicycle and pedestrian projects, and a comprehensive suite of environmental measures to preserve and enhance sensitive coastal habitat and improve coastal access. This assures the Coastal Commission and the public that all multimodal and environmental components will be implemented at the same pace as the highway improvements.

To further reduce impacts, multimodal projects in the same location—such as rail and highway bridge replacements in the same lagoon—are planned for concurrent construction. Additionally, every project will be required to comply with a comprehensive list of conditions and implementation measures that were specifically crafted by the lead agencies, the Coastal Commission, and the WSP | Parsons Brinckerhoff/Dudek team to protect and enhance sensitive resources.

## PLANNING FOR RESILIENCE

In addition to being a transportation lifeline serving both regional and international users, the North Coast Corridor is also an environmentally sensitive area. Both the I-5 freeway and LOSSAN rail alignments are located very close to the coastline, crossing six coastal lagoons and numerous sensitive habitat areas.[2] A total of eight lagoon bridges—including some wooden rail trestles that are over 100 years old—are slated for replacement as part of the freeway and rail capacity enhancements programmed in the PWP/TREP. The program therefore provides corridor planners with a tremendous opportunity to make significant advancements in the corridor's climate resiliency and overall environmental health.

### DESIGNING FOR SEA LEVEL RISE AND EROSION

The new lagoon bridges are being designed in accordance with the PWP/TREP's sea level rise risk assessment, a technical analysis which was undertaken to assess all lagoon sites for future flood risk, and to verify that the planned bridge freeboards were consistent with current projections of sea levels and flood events likely to occur in the future.[3]

Given its 40-year implementation timeframe, the PWP/TREP also incorporated flexibility for changes, directing the future re-assessment of sea level risks at the later-phase bridge sites. With construction of some bridges not planned until 2030 or later, their design will be able to take advantage of the latest science on sea level rise and climate change.

The PWP/TREP also addresses shoreline erosion, a significant issue in the North Coast Corridor owing to its multiple waterbodies and sensitive coastal bluffs. Corridor-wide, the planned improvements will increase the treatment of runoff from impervious surfaces, and most lagoon and river mouths will benefit from the removal of culverts and other historic alterations to the shoreline's natural state. Shoreline armoring will be permitted only for structures in the lagoons that have been proven to be in danger from erosion. Finally, one of the PWP/TREP's largest single projects is the potential removal of the LOSSAN railroad tracks from the coastal bluffs in Del Mar, which is currently envisioned in the program's final 10 year phase. The new rail alignment has not yet been decided, but if it does end up moving the tracks eastward, this will improve the long-term resilience of the LOSSAN corridor and reduce the need for future stabilization projects on the bluffs.

### OPTIMIZING BRIDGES FOR LAGOON HEALTH

Constructed in the 1960s-70s, the existing freeway lagoon bridges sit atop substantial fill areas, which were originally aimed at reducing both the length and height of the required bridge structures (see Figure 2). Unfortunately, this also narrowed the lagoon channels and altered their natural behavior, creating a cascade of harmful impacts: to tidal flows, to water quality, to wetland habitats and even to the flood risks of surrounding properties. The planned bridge replacements therefore offered a golden opportunity to reverse these impacts.

A series of bridge optimization studies were commissioned for the PWP/TREP to examine the lagoons to determine the ideal widths and depths of their channels. These studies directly informed the design process, resulting in substantially longer bridges that will better convey tides and storm flows, helping to restore the lagoons' natural functions and protect against future flood vulnerability.

The optimization studies utilized hydrodynamic models, calibrated with recent bathymetry data from the lagoons, to simulate various tidal and flood conditions. Using sensitivity analyses, the

[2] In general, the rail alignment is located within 1,000 feet of the coastline, and is a mere 100 feet away in some locations. The freeway is slightly to the east, located approximately ¼-½ mile from the coast.

[3] The sea level rise risk assessment was led by engineers Moffatt & Nichol. Freeboard is defined as the clearance between the lowest point of the bridge superstructure (bottom of girder) and the design water surface elevation immediately upstream of the bridge.

## A TOTAL OF EIGHT LAGOON BRIDGES—INCLUDING SOME WOODEN RAIL TRESTLES THAT ARE OVER 100 YEARS OLD—ARE SLATED FOR REPLACEMENT AS PART OF THE FREEWAY AND RAIL CAPACITY ENHANCEMENTS PROGRAMMED IN THE PWP/TREP.

studies determined an optimal design length for each bridge: the point at which tidal range and flood conveyance are highly favorable, and any further increases in channel width and depth would only capture minimal benefit.

### RESTORING & PRESERVING HABITAT

Accounting for the PWP/TREP's large and varied suite of environmental enhancements and mitigations required intensive planning and analysis. To accomplish this, the WSP | Parsons Brinckerhoff/Dudek team worked closely with the Coastal Commission, the U.S. Army Corps of Engineers, and other agencies to develop a comprehensive and innovative Resource Enhancement and Mitigation Program (REMP).

The REMP lays out a detailed program of preservation, establishment, and restoration activities for the North Coast Corridor's sensitive coastal resources which include two major lagoon systems and 220 acres of wetland and upland parcels. It also provides mitigation for the full suite of transportation improvements and accounts for 40 years' worth of restoration and preservation activities.

## AN UNPRECEDENTED APPROVAL

The Coastal Commission has a long history of opposing both freeway expansions and multi-decade permits within its coastal zone jurisdiction. But in August 2014, the Coastal Commission unanimously adopted the PWP/TREP, issuing its broad approval for all 40 years of North Coast Corridor projects.

The Coastal Commission's support was unprecedented not just because it was a multi-decade approval that contained a major freeway expansion, but also because the PWP/TREP combined over 60 projects and three types of development permits—which typically must be analyzed and approved separately—into one omnibus document, saving the public substantial time and money.

The programmatic approval also greatly reduced regulatory risk by providing assurances to the lead agencies that the full program could be implemented. This will allow the San Diego region to plan and deliver the 40-year program in a coherent, coordinated fashion.

## CONCLUSION

The North Coast Corridor PWP/TREP was an unprecedented, innovative document: a 40 year permit for a comprehensive transportation and environmental program of projects in California's coastal zone. As this type of broad approval had never been granted before, it required a unique interagency process that evolved as the analyses and negotiations progressed.

From a sustainability perspective, the North Coast Corridor program will leave San Diego's coastal environment healthier and stronger than any time in the past fifty years. By designing transportation projects for climate resilience and planning them together with environmental improvements, the PWP/TREP was able to capture mutual benefits while greatly reducing overall impacts—ultimately realizing more benefits for environmental health and sustainability than would have been possible without the transportation projects.

The PWP/TREP demonstrated that large multi-decade infrastructure programs can address concerns and provide benefits to satisfy even the most ardent regulatory agencies. The project has created a new model for public infrastructure programs in California, one that provides long-term assurances for mobility planning while simultaneously increasing the environmental health and resilience of local communities.

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# U.K. INFRASTRUCTURE: CAN WE COPE WITH FLOODING?

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INCREASINGLY FREQUENT EXTREME WEATHER EVENTS TAKING PLACE IN THE U.K. HAVE POSED SIGNIFICANT CHALLENGES TO U.K. INFRASTRUCTURE OWNERS AND OPERATORS.

## INTRODUCTION

The latest U.K. Climate Projections 2009 (UKCP09)[1] indicate that rising sea levels and increasingly severe and frequent rainstorms mean the risk of flooding will increase for people, communities, and key infrastructure such as roads, railways, power substations, and water treatment plants.

This article focusses on some of the more extreme weather events, particularly flood events since these have posed perhaps the most significant challenges for U.K. infrastructure in recent years, and the initial steps being taken to adapt to these challenges.

The U.K. is not alone in this experience of extreme weather, a U.K. Government Office for Science report, "Measuring the Human and Economic Impact of Disasters"[2], gives a global perspective on natural disaster trends over the last century and notes that between 1961-1970, one in 138 people worldwide were affected by natural hazards compared to one in 28 in the decade 2001-2010, and the economic costs associated with these natural disasters increased more than eightfold.

## STORMY WEATHER IN THE U.K.

The U.K. has certainly experienced some unusual weather events in the last decade or so as detailed by the U.K. Met Office[3] and as highlighted by year in Figure 1.

Some of the more significant flood events are briefly summarised below and the locations are indicated on the map in Figure 2:

- Autumn 2000 - the wettest since records began in 1776, with 489 millimetres (mm) of rain. Flooding in York, Shrewsbury, Lewes, Uckfield, and Maidstone affected more than 10,000 households and caused damage in excess of 1 billion GBP.
- Summer 2007 - the wettest summer on record. Yorkshire suffered many road and rail closures, power cuts, and evacuations, with Sheffield severely hit. Other areas heavily affected include Hull, Gloucestershire, and Worcestershire. Around 48,000 households and 7,300 businesses were flooded and the damage caused was in excess of 3 billion GBP. Damage to critical infrastructure was estimated at over 650 million GBP.
- November 2009 - the heaviest rainfall ever in the U.K., 316.4mm in 24 hours. Flooding was concentrated in Cumbria including Cockermouth, Keswick, Workington, Kendal, and Ulverston. Four people were killed as a direct result of the flooding.
- December 2013 - the stormiest since 1969. On 5 December, Scotland's rail network shutdown and 100,000 homes were without electricity. On the 6th of December, the east coast of England experienced the highest tidal surge in 60 years.
- January 2014 - England's wettest January since records began in 1776. Southern England had 175mm of rain from 1-28 January. Flooding was severe in the Somerset Levels, the Thames Valley, Worcestershire, and Herefordshire. Over 5,800 properties flooded and the damage caused was in excess of 0.5 billion GBP.

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DROUGHT | | | | | | | | | | | | | | | ● | | |
| HOT DRY SPELLS | | | | | | ● | | | ● | | | | | ● | | ● | |
| SNOW AND LOW TEMPERATURES | | | | | | | | | | | ● | ● | ● | | | ● | |
| STRONG WINDS | | | | | ● | | ● | ● | | | ● | | | ● | ● | ● | ● |
| HEAVY RAINFALL/ FLOODING | ● | | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | | ● | ● | ● |

**FIGURE 1** – UNUSUAL WEATHER EVENTS IN THE U.K. 1998-2014 (ADAPTED FROM U.K. MET OFFICE INFO)

See footnotes on page 87

## SOME CHALLENGES POSED BY FLOODING TO U.K. INFRASTRUCTURE

### ELECTRICITY SUPPLY

- Summer 2007 - floods caused 40,000 people in Gloucestershire to lose their electricity supply for 24 hours. Walham substation in Gloucestershire was close to being inundated; if this had happened 500,000 people would have lost their electricity supply. In Yorkshire four major electrical substations and 55 secondary substations were flooded, affecting the electricity supply to 130,000 people.


**FIGURE 2** – SOME OF THE MOST SEVERE FLOOD EVENTS IN THE IN THE U.K. (1998 – 2014)

- December 2013 - from the 24th to the 27 th storms and high winds caused 50,000 households to lose their electricity supply.
- 12 February 2014 - 130,000 homes lost their electricity supply.

### WATER SUPPLY

- Summer 2007 - the flooding of the Mythe water treatment plant in Gloucestershire caused the loss of water supplies to 350,000 people for up to 17 days.

### ROADS

- Summer 2007 - 10,000 people were stranded in their cars on the M5 motorway in Gloucestershire.
- November 2009 - Flooding in Cumbria caused six road bridges to collapse, cutting off communities.
- Winters of 2012 and 2013 - Many local roads were inundated and impassable during the flooding of the Somerset Levels.

### RAILWAY

- Summer 2007 - heavy rainfall resulted in embankment landslips and flooding on the railway.
- Winter 2013/2014 - the floods of 2013/14 inundated large areas of Somerset for months, severing railway communications in North Somerset and washing away the railway line at Dawlish on the Devon coast. Railway service for passengers west of Exeter with the rest of the country was discontinued for 2 months while the line was repaired. Coastal railway lines in Wales and Cumbria were also closed for weeks following damage from storms coinciding with high tides. Inland railways at various locations around the country were also closed for repairs due to several large scale embankment landslips following very heavy rainfall.

## IMPROVING THE RESILIENCE OF U.K. INFRASTRUCTURE TO FLOODING

An example of how infrastructure and flood warning improvements can dramatically reduce damage and save life was experienced on the 6 December 2013 when the east coast of England experienced the highest tidal surge in 60 years. Warnings were given and thousands of people were successfully evacuated, preventing the terrible loss of life experienced in the 1953 flood event (see Network Issue 72, "United Kingdom Coastal Monitoring and Forecasting", by Neil Fanning which discusses improvements to coastal flood forecasting).

The flooding experienced in the last decade or so has challenged the U.K. to make further improvements to the resilience of our infrastructure. The U.K. government invited independent reviews following the Easter 1998 floods (by Peter Bye) and again following the summer floods of 2007 (by Sir Michael Pitt). The Pitt Review[4] made many recommendations, including the development of a national standard of resilience against flooding.

## SECTOR RESILIENCE PLANS

In 2009, the government initiated the development of Sector Resilience Plans (SRPs)[5] for the U.K.'s national infrastructure, defined by the government as "those facilities, systems, sites, and networks necessary for the functioning of the country and the delivery of the essential services upon which daily life in the U.K. depends".

Sector Resilience Plans are based on the relevant risks to this infrastructure as identified in the National Risk Assessment (NRA)[6], which provides a government assessment of the likelihood and potential impact of civil emergencies (including the risk of terrorism, major accidents, and natural hazards) that may directly affect the U.K. over the next 5 years. An unclassified summary is issued annually. The Sector Resilience Plans are produced annually and present the risk and vulnerability of each infrastructure sector[7], the desirable level of resilience, a programme of actions for achieving the desired resilience level, and methods of reporting the progress towards achieving the target resilience.

## FINDINGS OF SECTOR RESILIENCE PLANS

Some of the early findings of the Sector Resilience Plans[8] focused on flooding for the following sectors are detailed below:

### ENERGY

Electricity supply – electricity transmission and distribution companies plan to provide a target level of protection of 0.1 percent annual flooding probability (1 in 1000 year standard) for critical assets. A similar approach is being taken for gas supply assets.

The U.K.'s Committee on Climate Change issued the Adaptation Subcommittee Progress Report 2014, "Managing climate risks to well-being and the economy"[9], which notes the following:

- By 2013, flood risk assessments had been completed for nearly 80 percent of the major distribution substations identified as being at flood risk. The remaining substations are due to have flood risk assessments completed by 2015.
- Progress with the implementation of flood protection measures generally appears to be on track, with nearly 20 percent of the 300 major substations located in areas susceptible to river and coastal flooding having already benefited from protection, and most of the remainder on course to have measures implemented by 2020.

### WATER

Water supply – the water sector is vulnerable to flooding due to the position of assets close to rivers and lakes. In 2009, the water regulator Ofwat allowed water companies to increase charges to customers to protect assets to 0.5 percent annual flooding probability (meaning protection to a level that has a 1 in 200 chance of being equalled or exceeded each year).

Legislation in the form of a new Water Act was introduced in May 2014[10] specifically to:

- reform the water industry to make it more innovative and responsive to customers;
- increase the resilience of water supplies to natural hazards such as drought and floods;
- bring forward measures to address the availability and affordability of insurance for those households at high flood risk; and
- ensure a smooth transition to the free market over the longer term.

### TRANSPORT

A large range of transport options are available (road, rail, aviation, and shipping), and these can provide alternatives in the event of disruption ›

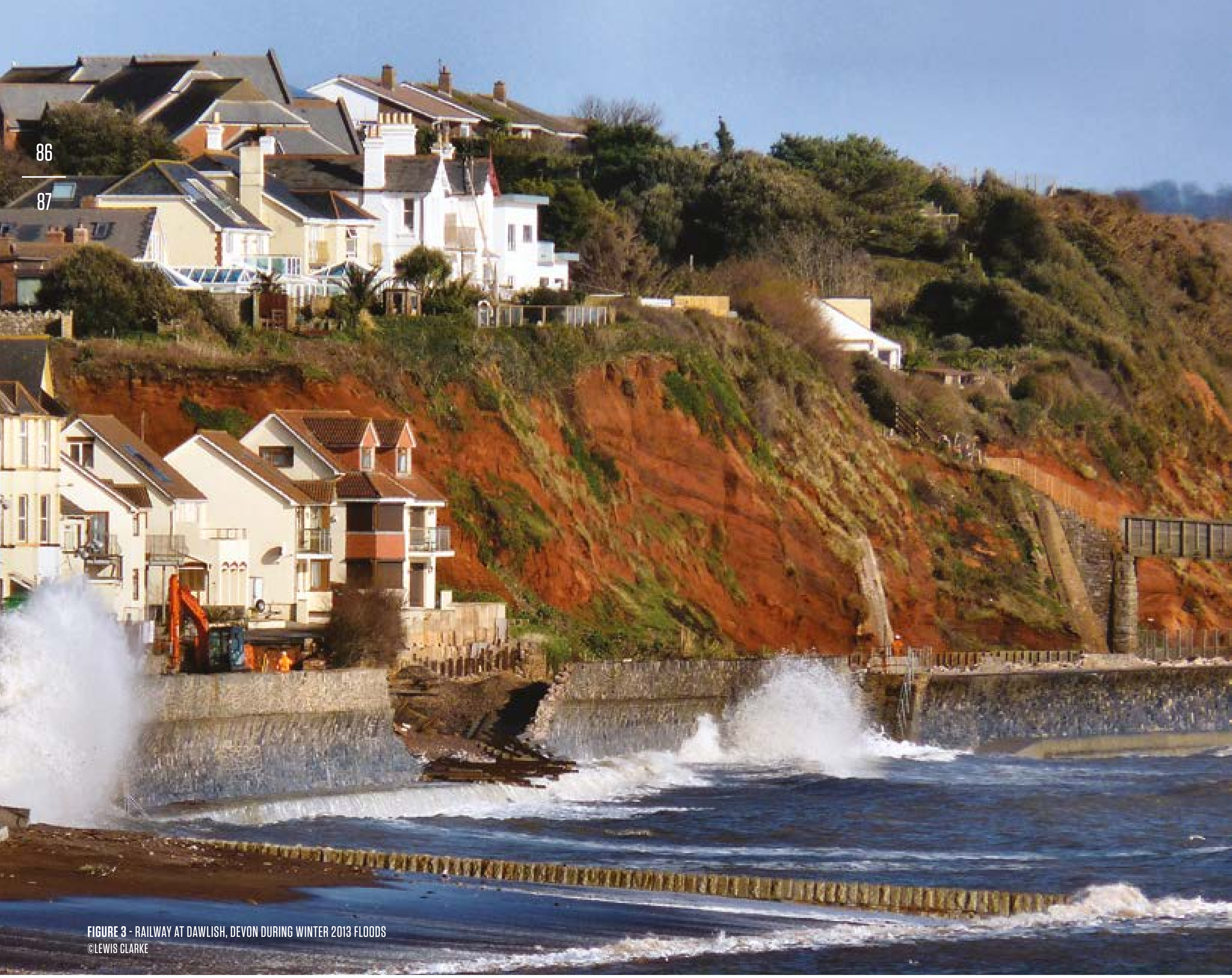

**FIGURE 3** - RAILWAY AT DAWLISH, DEVON DURING WINTER 2013 FLOODS
©LEWIS CLARKE



to part of the strategic transport network. Following the significant damage to railway infrastructure during the winter 2013/2014 storms and flooding, the railway sector set up weather resilience and climate change adaption plans[11] for major routes, and a special study[12] was conducted following the destruction and repair of the coastal line at Dawlish (Figure 3). Further reviews have been undertaken following the winter 2013/2014 flooding including the July 2014 Transport Resilience Review titled "A review of the resilience of the transport network to extreme weather events"[13]. The following is a selection of recommendations from this review:

### Strategic Road Network

Given the importance of drainage to resilience, the Highways Agency (HA) should complete its drainage asset inventory. The review also recommends that the HA should consult with freight operators about restricting high-sided vehicles from travelling on exposed sections of the strategic road network during high winds, so that these locations can be kept open longer for all other users. It further recommends that the HA works with the Met Office to improve wind forecasts for the benefit of lorry (truck) fleet operators.

### Local Roads

It is recommended that local highway authorities identify a 'resilient network' to which they will give priority, in order to maintain economic activity and access to key services during extreme weather. In locations where formal reviews of the winter's events have been held, local authorities should ensure that recommendations are enacted. In those locations that were not affected, local authorities should nevertheless continue to prepare for future extreme weather.

### Railways

The correlation of earthwork slips with heavy rainfall derailments is shown in Figure 4, reproduced from the Transport Resilience Review published in July 2014.

On engineering structures, the review recommends that Network Rail:

- continues to trial newly available condition monitoring and slope stabilisation technologies; and
- develops plans to raise track heights and raise lineside equipment cabinets above track level on sections of track at risk of flooding, as part of its new Route Resilience Plans.

Lineside trees were found to be a major factor in the winter 2013 disruption and it is recommended that Network Rail:

- develops a ten-year strategy to significantly reduce the number of trees, particularly those

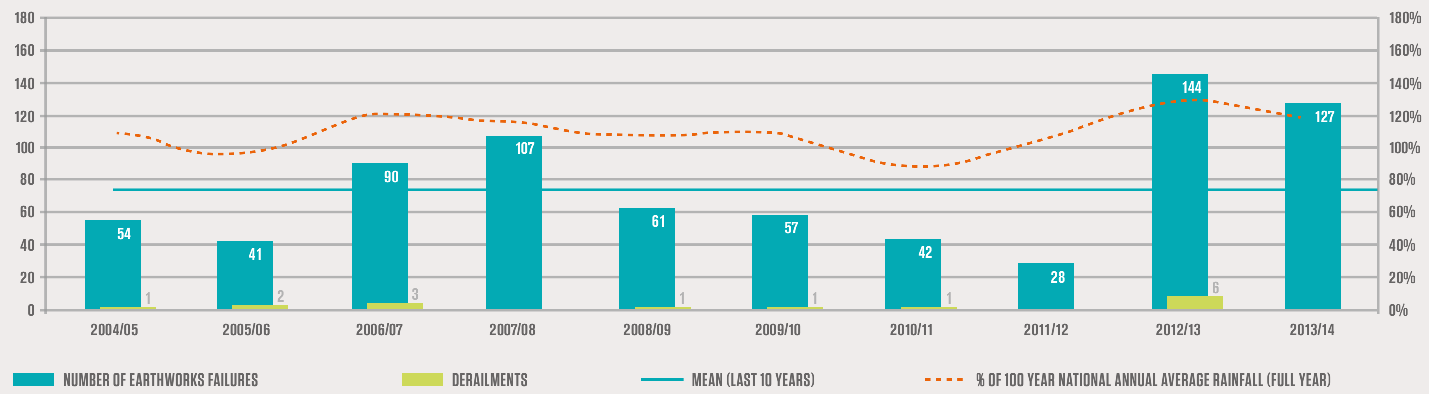


**FIGURE 4** - NETWORK RAIL EARTHWORK SLIPS AND RESULTING DERAILMENTS SINCE 2004/2005 (SOURCE: TRANSPORT RESILIENCE REVIEW, JULY 2014, FIGURE 6.3)

posing a risk to the railway and its users, and the overall level of vegetation.

## WSP | PARSONS BRINCKERHOFF'S INVOLVEMENT

Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) has supported the U.K. Environment Agency with a range of real-time system projects over the past 20 years, including the following:

- telemetry data gathering (see Network Issue 45, "Telemetry and Forecasting Systems for Managing Rivers and the Environment" by Alan Knott);
- weather radar visualisation system;
- the specification and procurement of the National Flood Forecasting System and the development of flood forecasting models for the Southern Region (see Network Issue 77, "A Forecasting Modelling System to Help Protect the South East of England from the Impact of Flooding").

Recent examples of WSP | Parsons Brinckerhoff teams working with clients to examine opportunities to improve infrastructure resiliency include:

- Highways Agency 2009: A Parsons Brinckerhoff-led consortium, including WSP and the U.K. Met Office, helped to develop the Highway Agency climate change adaption framework including an adaptation model which provides a framework for systematically managing the impacts of climate change.
- Dorset County Council in 2012: WSP | Parsons Brinckerhoff was appointed to design and supervise ground investigation and subsequent slope stabilisation measures for the steep slopes above both portals of the U.K.'s oldest road tunnel at Beaminster.
- Network Rail in 2013-2014: WSP | Parsons Brinckerhoff undertook the investigation, design, and submission of whole life cost remediation proposals which were accepted without rework by Network Rail for fourteen railway earthworks (twelve embankments and two rock cuttings) across Kent, Sussex, and London, which had become substandard as a result of movements through either displacement or weathering.
- The U.K. Environment Agency in 2013: WSP | Parsons Brinckerhoff collected information on climate change impacts to U.K. industry sectors, including agriculture, forestry, business and services, the built environment, health and wellbeing, local government, infrastructure, and the natural environment. The purpose of this work was to identify how much relevant information each sector could access, whether they were in a position to use it to make appropriate resiliency decisions, and how to improve the Environment Agency 'Climate Ready Support Service' to better serve those particular sector needs.
- Transport for Greater Manchester (TfGM) in 2014: WSP | Parsons Brinckerhoff assisted TfGM project managers by developing a toolkit that (among a number of other sustainability and whole-life costing topics) prompted them to consider the potential impacts of flooding and climate change by asking the scheme designers key questions such as: "Have climate change impacts been considered in the design of your asset?" and "How have you adapted the design of your asset to prepare it for the likely impacts of climate change?"
- Network Rail in 2015: WSP | Parsons Brinckerhoff assisted Network Rail in improving its prediction and response to adverse weather events by helping re-write the structural and a wind codes of practice. These make use of a wind speed weather map and now include a U.K. weather map for ice and snow prediction.

## ACKNOWLEDGEMENT


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[1] UKCP09 is the fifth generation of climate change information for the U.K., and its projections are based on a new methodology designed by the Met Office. Climate science and computer modelling have advanced significantly - UKCP09 reflects scientists' best understanding of how the climate system operates, how it might change in the future, and allows a measure of the uncertainty in future climate projections to be included.

[2] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/286966/12-1295-measuring-human-economic-impact-disasters.pdf

[3] http://www.metoffice.gov.uk/climate/uk/interesting

[4] http://webarchive.nationalarchives.gov.uk/20100807034701/http:/archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html

[5] https://www.gov.uk/government/collections/sector-resilience-plans

[6] https://www.gov.uk/risk-assessment-how-the-risk-of-emergencies-in-the-uk-is-assessed

[7] U.K. national infrastructure is categorized into nine sectors: communications, emergency services, energy, finance, food, government, health, transport, and water.

[8] http://www.parliament.uk/documents/post/postpn362-resilience-of-UK-infrastructure.pdf

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# IMPROVING FLOOD PROTECTION IN QATAR

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## THE RAPID PACE OF URBANIZATION HAS INCREASED THE IMPACT OF SEVERE RAINFALL EVENTS IN QATAR.

The State of Qatar in the Arabian Gulf is one of the most arid regions in the world. With average annual rainfall of around 80 millimetres per year[1], it is not often thought of as being a place where flooding is of great concern. However, due to the rapid pace of urbanization across the country, particularly in the capital city, Doha, rainfall generally and particularly severe rainfall events now have a greater impact on populated areas as a consequence of the associated increase in impervious surfaces (see figures 1 and 2). This now requires designers to consider carefully how to protect infrastructure from flood damage, ensure strategic facilities continue to function, and protect lives. Parsons Brinckerhoff worked with Ashghal, the Public Works Authority of Qatar, on the Local Roads and Drainage Programme (LR&DP) in Qatar to develop better guidance for consultants involved in the design of surface water drainage systems.

## QATAR DESIGN STANDARDS

The Qatar Sewerage and Drainage Design Manual (QSDDM) provides guidance on the level of flood protection to be applied and the design standards that are to be used in the design of surface water drainage systems in Qatar. The design approach taken in the QSDDM is to design the drainage system around the maximum capacity of the system to convey stormwater without exceedance flow being generated for a particular design flooding return period. It does not provide guidance on the appropriate design storm return period to be used in the design of the minor systems (i.e., guidance for pipe full flow) as is traditionally used in design practice in the U.K. The choice of which level of service for flood protection is to be used in a drainage design is based on land use, and this is defined in the QSDDM as shown in Table 1.

It is necessary for a design check to be carried out by the designer to ensure that adequate flood protection is provided within a drainage catchment appropriate to the designated land use. The designer must be aware that most catchments are composed of different land uses. For example, parks and playgrounds may be found next to government institutional and other official developments, and the designer has to address this mix of land use by running multiple design iterations to confirm that each area within a catchment receives the appropriate level of flood protection.

## PARSONS BRINCKERHOFF'S ROLE

Parsons Brinckerhoff in its role as the programme management consultant for the Local Roads and Drainage Programme is responsible for ensuring that design standards are correctly followed by the general engineering consultants (GECs) working on the programme. This role involves reviewing current design standards and, where necessary, revising them or writing clarifications to ensure the intent of the standard is correctly understood by the users. Following a review of surface water design submissions received from the GECs by Parsons Brinckerhoff and the Public Works Authority (PWA) in Qatar (Ashghal), it was concluded that an advice document was needed to ensure consistent interpretation of the surface water design standards by designers. Parsons Brinckerhoff undertook this task in collaboration with the PWA.

When interpreted correctly the use of the design manual produces a design that meets ›

[1] Reference the Qatar Integrated Drainage Master Plan

| RAINFALL EVENT | AREA |
|---|---|
| 1 IN 2 YEARS STORM | Parks<br>Playgrounds<br>Natural areas<br>Minor roads |
| 1 IN 5 YEARS STORM | General housing<br>Major roads |
| 1 IN 10 YEARS STORM | Government institutional and other official development<br>Technically sensitive property<br>Basements<br>Power equipment |
| 1 IN 25 YEARS STORM | High prestige or ceremonial developments |

**TABLE 1** - LEVELS OF FLOOD PROTECTION REQUIRED FOR VARIOUS AREAS IN QATAR (REPRODUCED FROM QSDDM, VOLUME 3, SW DRAINAGE, PAGE 2)

FIGURE 2 – WEST BAY DOHA 2014 (SOPHIE JAMES / SHUTTERSTOCK.COM

## IT IS NECESSARY FOR A DESIGN CHECK TO BE CARRIED OUT BY THE DESIGNER TO ENSURE THAT ADEQUATE FLOOD PROTECTION IS PROVIDED WITHIN A DRAINAGE CATCHMENT APPROPRIATE TO THE DESIGNATED LAND USE.

THE GUIDANCE WAS UPDATED TO REFLECT THE NEW FUNCTIONAL CLASSIFICATION OF ROADS AND TO MAKE CLEAR TO THE DESIGNER THE APPROPRIATE DESIGN STORM TO BE USED IN RESIDENTIAL AREAS.

CLARITY WAS PROVIDED ON THE RANGE OF STORM DURATIONS TO BE USED IN DESIGN AND WHEN CARRYING OUT THE LEVEL OF SERVICE CHECK, WHICH IS REQUIRED TO ENSURE FLOODING DOES NOT OCCUR FOR A RANGE OF STORM DURATIONS UP TO 24 HOURS.

FIGURE 1 – WEST BAY DOHA CIRCA 1984

the needs of the PWA and provides a satisfactory level of flood protection and service to residents. However, a lack of understanding by some designers of the design approach used in the reference standards from which the design manual was derived, resulted in an inconsistent approach to design. For example, the choice of design storm event for residential areas was a source of confusion due to the lack of definition over the risk factor the client was willing to accept. In residential areas a 1 in 5 year event or the 1 in 10 year event could be used. This had resulted in different design storms being used on adjacent catchments.

Other parts of the design manual covering exceedance flows, storm durations, and sizing of trench soakaways also caused some confusion amongst designers and it was determined that more explicit guidance was required.

Parsons Brinckerhoff reviewed the current design standards in collaboration with the PWA and prepared an interim advice note (IAN 013) that gave guidance on the use of the current PWA design standards for the design of surface water and ground water drainage systems. Attention was given to known areas of uncertainty within the standard which were presenting difficulty to designers; these areas were:

- Selection of the design storm event;
- Freeboard distance from ground level to hydraulic gradient[2] or top water surface;
- Range of storm durations to be used in design;
- Soakaway design; and
- Exceedance flow.

## SELECTION OF THE DESIGN STORM EVENT

The first area to be dealt with was the selection of the appropriate design storm. The guidance was updated to reflect the new functional classification of roads and to make clear to the designer the appropriate design storm to be used in residential areas; the design guidance now clearly stated that the appropriate level of service to prevent flooding on the local roadway network in residential catchments is a 1 in 5 year storm event. Previously the designer only had to consider rainfall events up to a 1 in 25 year storm. The opportunity was now taken to formalize guidance given for the level of flood protection provided at highway underpasses, which require a 1 in 50 year rainfall event to be considered by the designer. This level of flood protection, although not previously given in the QSDDM, is consistent with design advice followed by expressway designers in Qatar and the European Standard BS EN 752:2008 - Drain and sewer systems outside buildings. The revised guidance is illustrated in Table 2.

## FREEBOARD DISTANCE FROM GROUND TO HYDRAULIC GRADIENT

The second area to be addressed was the distance from ground level to the hydraulic gradient. In Qatar there has been a requirement that the designer provide a freeboard between the top of the hydraulic gradient and ground level of 300 millimetres (mm) within the drainage network. This is not an unusual requirement; the Ministry of Public Works in Kuwait has a similar requirement written into its surface water design specification, although it uses a distance of 500mm to ensure that gully outlets are not restricted by surcharging within the drainage network for the design storm event. However, the PWA wished to increase this distance to 1000mm from the 300mm specified in the QSDDM to account for uncertainties in the estimation of catchment areas.

## RANGE OF STORM DURATIONS TO BE USED IN DESIGN

Clarity was provided on the range of storm durations to be used in design and when carrying out the level of service check, which is required



[2] The hydraulic gradient is defined as a line joining the points of highest elevation of water in a series of vertical open pipes (in this case the vertical open pipes are the manholes) rising from a pipeline in which water flows under pressure, the pipeline is surcharged. If the pipeline is not surcharged and water is flowing freely along the pipeline the hydraulic gradient will be the water surface and is more or less parallel with the line of pipes

to ensure flooding does not occur for a range of storm durations up to 24 hours. The range of durations that designers are recommended to use are 15mins, 30mins, 60mins, 2hrs, 6hrs, 12hrs, and 24hrs.

### SOAKAWAY DESIGN

No explicit guidance was given in the QSDDM on the required emptying time of soakaways such that there is sufficient volume to accept a follow-on or sequential storm event. A specific clause was written into the advice note stating that infiltration systems should discharge from full to half volume within 24 hours.

### EXCEEDANCE FLOW

Within the QSDDM there is a requirement to identify flood plans and routes. This is not well developed within the manual and required further clarification. It should be noted though that this requirement is also not explicitly covered in the reference documents for the QSDDM, either BS EN 752:2008 and Sewers for Adoption (WRc, 2006), which do not provide guidance on the requirements for the storm return period for which exceedance flows and overland flood routes are to be assessed. To assist designers, a requirement was included in the advice note that the impact of a 1 in 50 year return period storm on the catchment was to be examined specifically to confirm that flooding of underpasses does not occur and to identify areas where flooding can be predicted to occur. The designer was specifically directed to identify flood routes based on this storm event.

In preparing this advice document, Parsons Brinckerhoff collaborated with the PWA Drainage Networks Design Department to produce an interim advice note that met their requirements and provided clarity to designers, thus eliminating overdesign and ensuring consistency in design approach across Qatar.

The interim advice note (IAN 013) was accepted by the PWA and now forms part of Qatar's national design standards. Since its implementation, improvements in the design approach used by designers have resulted in better and more cost effective surface water design.

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| RAINFALL EVENT | AREA |
|---|---|
| 1 IN 2 YEARS STORM | Parks<br>Playgrounds<br>Natural areas |
| 1 IN 5 YEARS STORM | Residential housing<br>Major arterial<br>Minor arterial<br>Major collector<br>Minor collector |
| 1 IN 10 YEARS STORM | Governmental institutional and other official development<br>Hospitals<br>Schools<br>Commercial / business<br>Expressways<br>Power equipment |
| 1 IN 25 YEARS | High prestige or ceremonial developments |
| 1 IN 50 YEARS | Highway underpasses |

**TABLE 2** - REVISED GUIDANCE OF LEVELS OF FLOOD PROTECTION REQUIRED FOR VARIOUS AREAS IN QATAR (REPRODUCED FROM INTERIM ADVICE NOTE 013)

# LAKE MÄLAREN, SWEDEN: THE CONSEQUENCES OF FLOODING

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## WSP | PARSONS BRINCKERHOFF CONDUCTS A STUDY OF THE INCREASED FLOOD RISK TO LAKE MÄLAREN AND ITS SURROUNDING AREA - WHERE DO THE ACTUAL RISKS LIE AND WHAT ARE THE CRITICAL AND VULNERABLE POINTS?

Lake Mälaren is the third largest lake in Sweden (see Figure 1), with 24 cities and municipalities bordering the lakefront, including Stockholm. The lake is the drinking water source for two million people and also serves as a major port (see Figure 2).

The risk of flooding in Lake Mälaren is very high due to milder winters and heavier rainfalls. The winter of 2000 was unseasonably wet and much more water flowed into the lake than could be let out through the sluices that manage the water levels. There was extensive local surface water flooding and flooding nearly reached the central underground station tunnel of Stockholm.

Local disruption was thankfully a one-off at that point in time; however, it is forecast to be less of a one-off in a changed climate. Forecasts show that winter rainfall in Stockholm will increase, there will be greater year-on-year variations in precipitation, and the snowmelt will be greater. So there will be much more water flowing into the lake in the future.

## THE STUDY

The Swedish National Security Administration realised the need to prepare for increased flood risk and wanted to understand where the actual risks lie and what the critical and vulnerable points are. They wanted to create a database for guidance on what to do if flooding increases in this area and hired WSP (now part of WSP | Parsons Brinckerhoff) to conduct a study to understand in detail how the area could be affected.

Together with the client, the boundary of the study was defined. The focus was to study the flood consequences of such activities that are important to the functioning of society. The WSP | Parsons Brinckerhoff team, in a desk-top and on-site study, looked at a wide variety of installations and service providers – such as banks, hospitals, IT, phones, police - and

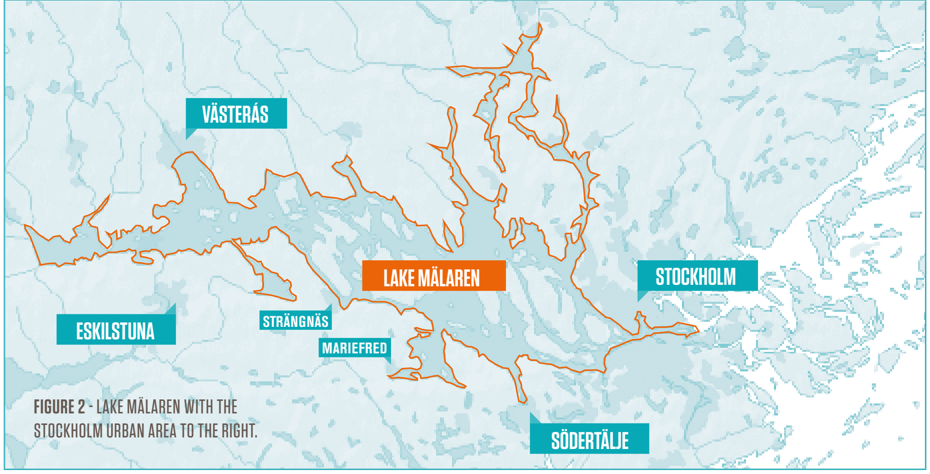


FIGURE 2 - LAKE MÄLAREN WITH THE STOCKHOLM URBAN AREA TO THE RIGHT.

identified 236 objects – installations, utilities, services, pipes – that are important to society in the flood risk area.

The study revealed that people, industry, and critical infrastructure around Lake Mälaren were in fact more vulnerable than previously thought.

## MANAGING THE PROCESS

The WSP | Parsons Brinckerhoff team consisted of 30 people of all disciplines and areas of expertise. To collect the data for the database, we identified potentially vulnerable "objects", then went out and talked to local authorities, people in the relevant companies, and technical officers in the 24 municipalities. Normally such studies are entirely desk-based, so it was a treat for the researchers to make site visits, and these enabled the team's hypotheses to be tested and confirmed.

More than 400 "objects" (e.g., installations, supply mains, service provision locations) had critical information, but the results needed to be aggregated and a regional analysis performed to report on their status and the recommended actions to be taken. WSP | Parsons Brinckerhoff had all the expertise in-house, and this made it easier to coordinate all the work to be done.

We used flooding overlays to identify each object and contacted the operational manager for it, by phone and then in a site visit, to identify important features such as threshold levels, valves, tubing, etc. From this we were able to identify the critical water level, measuring the levels on location with accurate GPS and other such tools. We digitised coordinates to preserve confidentiality. Confidentiality was important and the city of Stockholm requested information security.

For purposes of information security, this article gives only broad, summarized findings and results. ›


FIGURE 1 – LAKE MALAREN IN SWEDEN

## SOME KEY FINDINGS

- The risk of flooding in Lake Mälaren is currently high because the inflow to the lake may be higher than the outflow capacity. Until an increase in bottleneck capacity, or prevention and preparedness-raising on a very large scale has been implemented, the risk remains high.
- Water levels only 0.5 metres above the mean water level of Lake Mälaren begin to impact establishments carrying out important public activities. This can mean great risk or danger to life and health, social functionality, or society's basic values.
- Of a total of 236 inventoried socially important objects within the flood prone area, more than 180 items can have consequences that are serious, very serious, or even catastrophic for the objects and thus affect society. Twenty-two of these items provide service to very large parts of the population in various municipalities. The consequences would typically involve the non-delivery of electricity, drinking water, sewerage, or heating.
- The impact of a rising water level is greatest in the sectors of electricity and local technical support.
- Many socially important objects are vulnerable for reasons other than flooding. Several of them have critical dependencies on other objects.
- During a flood event of up to a +1.4 metre rising water level, ground types of agriculture, forestry, and nature conservation areas are affected. At levels above +1.4 metres, settlements, buildings, roads, etc. will be increasingly affected. Large numbers of people will be affected at levels above +1.7 metres.
- At a "1 in 100 year" event, about a +1.9 metre rising water level and a duration of three weeks, the direct costs of the socially important objects are estimated at approximately €64 million and about 230,000 people will be without service. At the design water level +3.1 metres, the direct costs are estimated at almost €1 billion and more than 600,000 people will be directly affected.
- During a flood event with high water levels in Lake Mälaren, the problems are likely to be very large, even in the tributaries and within a larger region of the country. There will be competition for society's collective resources with great challenges and limited capacity as a result.
- There may be a reason for a number of items that deliver important public services to have steps taken to reduce their vulnerability until an increased outlet capacity from Lake Mälaren is provided.
- By increasing the outlet capacity and by adopting a different water regulation regime, the high water levels could not occur. Achieving the same protection of the community through prevention and preparedness-raising is not a realistic option.
- For areas freed up by an increased outlet capacity from Lake Mälaren, municipalities should take into account the long-term risks of flooding in the planning process.

## RESULTS

The Swedish Meteorological and Hydrological Institute had done modelling of climate scenarios for Lake Mälaren, which provided us with the lake levels for different annual probabilities. However, WSP | Parsons Brinckerhoff did not have to consider return periods or probabilities, but only reviewed the consequences of each 10 centimetre rise in water level. The results did not follow a steady slope. Rather the graph was stepped, with a 10 centimetre rise at one level causing a domino effect - such as electricity loss in one area producing consequences elsewhere. For example, the flooding of an IT server room would prevent a municipality from delivering services; or a pump losing power would cause flooding, electricity outages, or drinking water

pollution elsewhere. The next few 10 centimetre steps would typically have no impact.

It was originally thought that the roads would be flooded, and people would be isolated and run out of fuel and food, also that hospitals would be affected by flooding.

What we discovered, contrary to what might have been found from a desk-top study alone, was that the main problem happens before the water reaches the buildings, because the link to electricity and other utilities becomes cut off before then. The critical vulnerable point may well be the electricity cable entering the building 0.5 metres underground, which could get short-circuited well in advance of the buildings flooding.

Most utilities had control of their own building and functions, but assumed they would have electricity to power pumps, IT servers, internet, etc. (although they had generators for some equipment). So they relied on the electricity supply company; and the critical vulnerable local electricity location could be serving, and therefore enabling, several services or installations.

The study results showed the following consequences:

- five municipalities would not have drinking water because the pumps were out of action, and the lake itself – the source of drinking water – could become polluted;
- Critical metro tunnels would flood even with only a small rise in water level;
- Fuel for electricity/district heating, transported by water, would not be available because the locks were needed for flood control;
- Key municipal data centres in building basements would be flooded, along with their backup systems; and
- There would be no sewage treatment in some areas, because receiving waters would be too high.

The direct cost was estimated at €1 billion but the indirect cost would be much higher, and drinking water quality could be compromised. The largest impact would be on the two million people who get their drinking water from the lake; electricity outages from flooding could result in sewage leaking back into the lake's drinking water supply.

Also impacted would be a major government department building which has its computer system below ground level, and back-ups even lower. Flooding would totally shut down the building access.

## CONCLUSION

Besides giving the government a comprehensive analysis and assessment of the impact of a flood in Lake Mälaren, the focus of the study has also been to encourage the continued development and management of flood issues. Sluices on Lake Mälaren are now being remodelled, and contingency actions are being taken on some of the most sensitive areas. Negotiations are in progress to design a new lock on the lake in Stockholm, with three times the current capacity. The benefits to society will likely far exceed the costs, but both have yet to be established.

Knowing the risks of flooding today means that the city authorities can take action, and municipalities, utilities, and other national authorities have subsequently asked WSP | Parsons Brinckerhoff to help find solutions to all the objects identified as being at risk.

Our research brings two insights for other cities. Firstly, that climate change can impact major infrastructure and not necessarily in the way originally envisaged. Secondly, that the full impact only really becomes clear when you get out the office, involve the engineers, and get into the details of municipal infrastructure design.

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# STREAM DIVERSION DESIGN CASE STUDY: McALWAY-CHURCHILL PROJECT

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SOLUTIONS TO PROVIDE FLOOD RELIEF TO RESIDENTS OF THIS WATERSHED AREA INCLUDED A STREAM DIVERSION TO DEFLECT HIGH FLOWS FROM THE LOWER REACH OF THE MAIN TRIBUTARY.

The city of Charlotte in North Carolina contracted Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) to provide planning and preliminary design, alternatives analysis, and development of design plans for flood mitigation improvements in the McAlway-Churchill drainage basin, which is a 320-acre developed area within the Briar Creek watershed. Residents within the watershed experience frequent flooding of their homes and streets. WSP | Parsons Brinckerhoff worked with both the city and local residents to develop solutions to mitigate the flooding. The study includes approximately 11,000 linear feet of stream corridor, 10,000 linear feet of secondary open and closed drainage systems, and 21 bridges/culverts.

## STREAM DIVERSION CONCEPT

One of the major elements of the McAlway-Churchill flood mitigation project is a stream diversion to deflect high flows from the lower reach of the main tributary, thereby providing flood relief to seven residences along the stream corridor. The stream diversion will consist of a low weir[1] wall, 18 feet in length and 1.5 feet above the stream bed invert, that will act as the hydraulic control. Immediately downstream of the weir will be a bypass trunk line consisting of a 4 foot high x 18.5 foot wide reinforced concrete box culvert about 373 feet in length that will convey the diverted flow under Meadowbrook Road which runs along the stream, and discharge it to an large open area for energy dissipation and flow dispersion (see Figure 1). The discharged flow will pass over a concrete overflow wall 125 feet in length that will be constructed at grade to promote a wide dispersal of the flow into the existing undeveloped floodplain within the Catawba Lands Conservancy preserve adjacent to Briar Creek. The design of the diversion and bypass trunk line involved a number of technical challenges including an unavoidable conflict between the bypass trunk line and a gravity sanitary sewer main, and a diversion structure that was hydraulically complex to model.

## DESIGN CHALLENGES

### GRAVITY SANITARY SEWER

The existing 8-inch gravity sanitary sewer main in Meadowbrook Road could not be horizontally or vertically relocated. Therefore, the bypass trunk line was designed to accommodate the conflict by allowing the sanitary main to pass through the new box culvert. A 12-inch steel casing will be provided to protect the sewer main within the culvert opening. The vertical alignment of the bypass trunk line was set so that the sewer main will be located within the upper part of the box culvert trunk line. Hydraulic calculations were performed to confirm that the sewer main will be above the flow in the culvert. Design of this conflict was coordinated with Charlotte-Mecklenburg Utilities Department, the owner of the sewer main.

### MODELING A DIVERSION STRUCTURE

A hydraulic model of the watershed stream system was created for the project using the HEC-RAS program (Hydraulic Engineering Center – River Analysis System) developed by the U.S. Army Corps of Engineers. To determine the flood mitigation benefits that would be obtained using the stream diversion, the diversion was modeled in HEC-RAS as a "lateral structure" that removed flow from the main tributary. An "inline" weir is constructed across a watercourse, while a "lateral" weir is constructed along one of the stream banks, parallel to the flow of the water, such that flow over the weir is removed from the watercourse. The diversion was defined in HEC-RAS as a water surface elevation (WSE) vs. discharge (Q) rating curve. The main challenge in designing this diversion was to take into account the many factors that influence the hydraulic performance of the weir. Each of these factors is discussed below.

#### End contractions

The formula for calculating flow over a weir is generally expressed as:

$$Q=CLH^{1.5}$$

Where $Q$ is the calculated discharge, $C$ is the coefficient of discharge, $L$ is the effective length of the weir, and $H$ is the head over the weir. Since the approach flow to the weir is wider than the weir itself, the weir will perform as a "contracted" weir, such that the effective length of the weir decreases as the head increases. To mitigate this effect such that $L$ will equal the actual length of the weir for all values of $H$, the diversion was designed as a "Cipolletti" weir, which is trapezoidal in shape with end walls at each side that are not vertical but constructed at a slope of 1:4 inclining outward from the base, horizontal to vertical (Brater & King, 1976). See Figure 2.

#### Coefficient of discharge

The coefficient of discharge is a critical parameter in evaluating the hydraulic performance of a weir since the discharge over the weir is directly proportional to the coefficient of discharge. The ›

[1] A weir is a typically horizontal structure used for controlling or measuring the flow of water. In most cases, weirs take the form of obstructions smaller than most conventional dams, pooling water behind them while also allowing it to flow steadily over their tops.

## ONE OF THE MAJOR ELEMENTS OF THE McALWAY-CHURCHILL FLOOD MITIGATION PROJECT IS A STREAM DIVERSION TO DEFLECT HIGH FLOWS FROM THE LOWER REACH OF THE MAIN TRIBUTARY

**11,000**

LINEAR FEET OF STREAM CORRIDOR

**10,000**

LINEAR FEET OF SECONDARY OPEN AND CLOSED DRAINAGE SYSTEMS

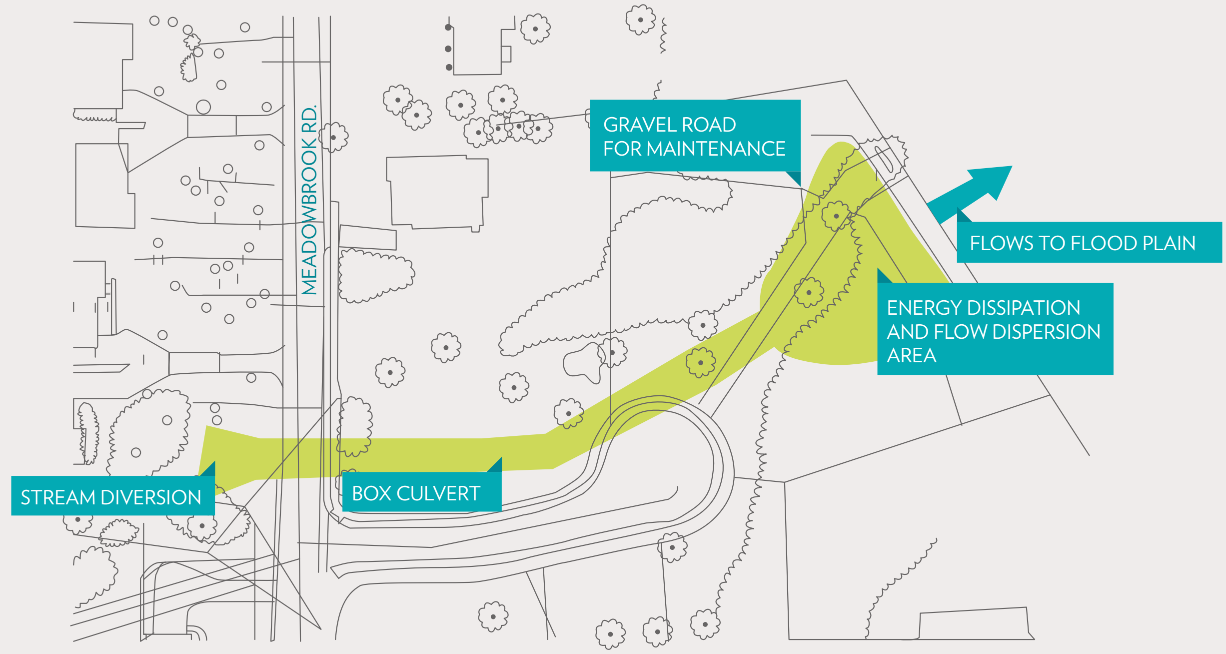


FIGURE 1 – PLAN VIEW OF DIVERSION AND BYPASS TRUNK LINE.

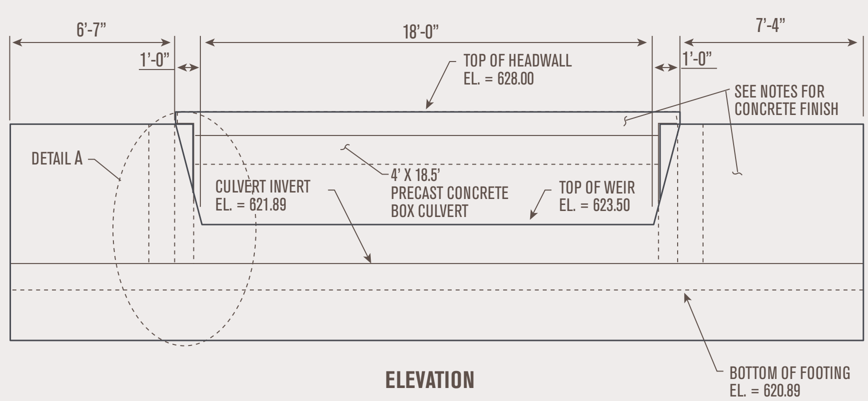


FIGURE 2 – ELEVATION VIEW OF "CIPOLLETTI" TYPE DIVERSION WEIR.

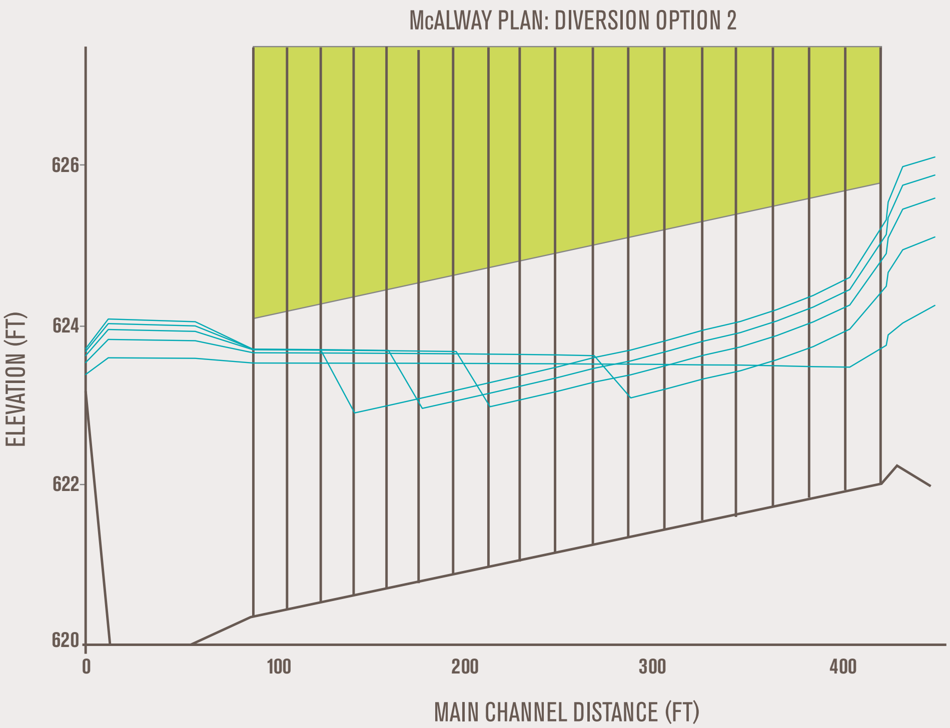


**FIGURE 3** – HEC-RAS PROFILES TO CREATE RATING CURVE UPSTREAM OF CULVERT.

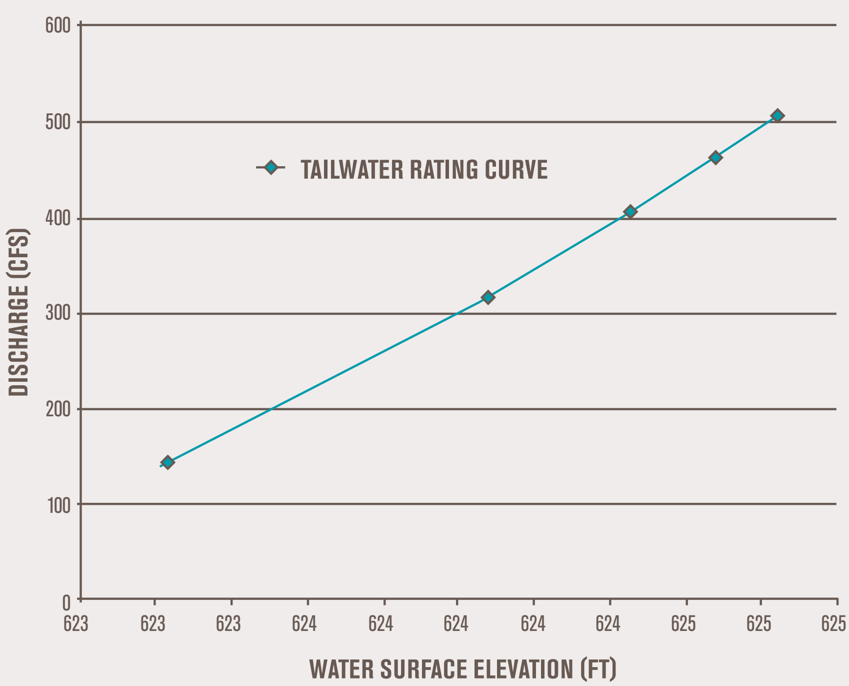


**FIGURE 4** – FINAL RATING CURVE FOR DIVERSION, ILLUSTRATING "CLUSTERS" OF DATA WHERE MOST NEEDED.

WHEN FLOW OVER THE WEIR IS SUPPORTED BY THE WEIR CREST, IT IS CONSIDERED "BROAD-CRESTED".

THE PROJECT ALSO ENHANCES THE RESILIENCY OF THE CITY'S INFRASTRUCTURE IN SEVERAL WAYS.

**IT IS ESTIMATED THAT THE STREAM DIVERSION OPTION SAVED OVER $1 MILLION IN COMPARISON TO THE STREAM WIDENING ALTERNATIVE.**

value of this coefficient can vary significantly depending on whether the weir will function as a "broad-crested" or "sharp-crested" weir. When flow over the weir is supported by the weir crest, it is considered "broad-crested". When the head over a weir becomes one to two times the breadth (thickness) of the weir crest, the flow separates from the crest and the weir performs as a sharp-crested weir. This ratio ranges from 1.5 to 3.5 for the proposed diversion weir. Therefore, the Rehbock formula for sharp-crested weirs (Chow, 1959) was used to determine the coefficient of discharge:

$$C = 3.27 + 0.40\,\frac{H}{h}$$

Where $H$ is the head over the weir, and $h$ is the height of the weir over the stream bed. As the above formula indicates, the coefficient of discharge varies with the head at the weir. Therefore, in developing the performance rating curve for the diversion, the coefficient of discharge needed to be calculated at each successive WSE.

### Weir submergence

Headwater at the upstream end of the box culvert under Meadowbrook Road will be higher than the weir crest elevation for the design discharges, causing the weir to be "submerged". Submergence of a weir reduces its hydraulic capacity such that the discharge under submerged conditions is less than the discharge calculated assuming no submergence. In order to calculate the actual discharge during submerged conditions, the Villemonte equation (Brater & King, 1976) was used:

$$\frac{Q}{Q_1} = \left[1 - \left(\frac{H_2}{H_1}\right)^{1.5}\right]^{0.385}$$

Where $Q$ is the submerged discharge, $Q_1$ is the unsubmerged discharge, $H_1$ is the head on the weir on the upstream side, and $H_2$ is the head on the downstream side. To determine the value of $H_2$, HEC-RAS was used to analyze the box culvert downstream of the weir over a range of discharges to establish the WSE vs. $Q$ rating curve immediately upstream of the culvert (see Figure 3). Since the value of $H_2$ can thus be determined for any discharge, the unsubmerged and submerged values of $Q$ can be calculated through iterative methods. This was accomplished using a spreadsheet to compute the final WSE vs. Q rating curve for the diversion weir. This rating curve information was then used to define the lateral structure in the HEC-RAS model so that the amount of flow diverted from the stream for the 2, 10, 25, 50, and 100-year storms could be calculated.

### Model Stability

The final challenge in designing the diversion was overcoming the inherent instability of the HEC-RAS model, which used an iterative process to determine the flow split at the diversion for each storm event scenario. Initial attempts to run the model were not successful since HEC-RAS was not able to converge on a solution at the diversion. This problem was solved by recognizing the information provided by the diversion rating curve need not be evenly distributed throughout the range of possible water surface elevations, but should be concentrated in "clusters" of information near the likely occurrences of the peak water surface elevations (see Figure 4). Once this was done, the HEC-RAS model converged on a solution for each storm event without any problems.

## SUMMARY

Although much more challenging to design than a traditional stream widening approach, the stream diversion and bypass trunk line will not only provide flood mitigation benefits to the neighborhood, but will do so with less impact to the environment and local residents, and much less cost to the city than the competing alternative of widening the existing channel for a distance of 1300 feet. It is estimated that the stream diversion option saved over $1 million in comparison to the stream widening alternative. The project also enhances the resiliency of the city's infrastructure in several ways. First, the project reduces flood impacts to Meadowbrook Road, reducing the frequency of road closures due to flooding and maintaining access for both residents and emergency personnel. Second, the project reduces flood impacts to several residential structures, which reduces risks to local residents as well as emergency responders. Third, the project reduces financial losses for the city that result from repetitive flood impacts.

***Karl Dauber*** *is Practice Area Lead for Drainage Systems and Floodplain Management. He has 29 years of experience in civil engineering specializing in hydrology and hydraulics and has expertise in highway drainage system design, floodplain and bridge waterway analysis, stormwater management and flood mitigation, and stream stability and bridge scour analysis.*

# IMPROVING THE RESILIENCE AND ADAPTABILITY OF WASTEWATER CONVEYANCE SYSTEMS

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WITH STORM INTENSITY AND FREQUENCY, HYDRAULIC ENGINEERING IS INCREASINGLY NECESSARY TO ENABLE WASTEWATER CONVEYANCE SYSTEMS TO COPE WITH UNPREDICTABLE CHANGE.

Resilience of a system, be it natural or engineered, is described as its inherent (or built-in) ability to accommodate acute and often drastic fluctuations of its operating parameters and return to normal levels of service without sustaining permanent damage or change. Adaptability refers to the system's ability to gradually adapt to changes in what is considered "normal". Hydraulic engineering is increasingly required to enable wastewater conveyance systems to cope with both planned and unpredictable change.

## THE CHALLENGE IN BRIEF

From the perspective of resilience and adaptability, both new and old pumped wastewater conveyance systems face several key challenges:

### INFLOW AND INFILTRATION (I&I) ARE INCREASING

The gravity sewer system feeding a lift station[1] deteriorates with age, resulting in groundwater inflow and rainfall-driven infiltration along the pipes/joints, at manholes and into wet wells, contributing to the flow requirements of the station.

### THE DESIGN STORM IS CHANGING

While wastewater systems are designed to accommodate a certain level of I&I, this value changes drastically with increasing storm intensity – aggravated as a result of climate change. For example, a 100-year design storm for a wastewater system designed in 1970 occurs at a far greater frequency today. Also, what is actually the new 100-year storm may convey a far greater peak flow than estimated in 1970.

### PUMP STATION TURN-UP RATIOS ARE INCREASING

The turn-up ratio is a hydraulic term describing the variation pumps must handle, defined as the ratio of wet weather flow (WWF) to dry weather flow (DWF) or base flow. Pump selection and operation in an environment with a large range in flow is challenging, made worse by increased I&I and peak storm frequency. This often requires a range of duty pumps, variable-speed drives or even additional, dedicated storm pumps, increasing costs for space below ground, machinery, and electrical systems.

### POWER OUTAGES ARE INCREASINGLY FREQUENT

Power outages result from electrical system failures at the grid, local, or even facility level. As extreme weather events become more frequent, the likelihood of power failure, pump shutdown, and surge (hydraulic transient) events increases.

### URBAN AREAS ARE INTENSIFYING

The load on conveyance systems may be increased significantly by urban intensification. Infill studies and capacity allocations typically consider the increased DWF but not the potential for future I&I.

## CASE STUDIES

### HALLS MILL FORCE MAIN NETWORK, MOBILE, ALABAMA

The Halls Mill wastewater system consists of five (5) lift stations with design flows ranging from 1,000 gallons per minute (gpm) for its smallest station to 6,000 gpm for its largest station. Individual force mains[2] ranging from 12 inches to 36 inches in diameter connect these 5 lift stations to a large common discharge force main that is 48 inches in diameter and over 9 miles in length. This force main discharges to the William Wastewater Treatment Plant in Mobile Bay via a vertical overflow.

The system presents the following key challenges:

- Frequent power failures at each of the lift stations, causing large pressure surges in the force main that have resulted in joint movement, air valve float collapse, and pipe breaks;
- Lack of pump start/stop coordination between different lift stations, resulting in rapid changes in flows and pressures; and
- Capacity issues during heavy rainfall periods, potentially resulting in surcharge in upstream sewers and flooding of the lift station and its immediate environs. An off-line WWF storage tank (by others) is used to accept a large volume during storms that flow-back to the wet well afterwards.

WSP (now part of WSP | Parsons Brinckerhoff) collaborated with the owner and other consultants to identify the causes of hydraulic

[1] Lift stations contain the pumps, valves and electrical equipment necessary to move sewage from low to high elevation, making them an essential component of many municipal sewer systems.

[2] Force main is a principal conduit through which water is pumped as distinguished from one through which it flows by gravity.

transients and to devise a system of closed surge tanks (e.g., hydrodynamic or pressure vessels) to absorb rapid changes in pressure resulting from normal or emergency pump shut-downs or re-starts. This enables the system to withstand any combination of operational inputs, making it more resilient. It also limits all transient pressures, decreasing fatigue in the system and the resulting wire break frequency in the reinforced concrete pipe on the main line. Together with improved air handling to maintain capacity, plus the existing and proposed WWF off-line storage tanks, the system's adaptability has been maximized.

### UNNAMED FORCE MAIN NETWORK, SEWER DISTRICT X OUTSIDE CHARLOTTE, NORTH CAROLINA

This system contains four (4) lift stations with design flows ranging from 140 gpm for its smallest station to 875 gpm for its largest station. Individual force mains ranging from 4 inches to 8 inches in diameter connect these 4 lift stations to a common discharge force main that is 12 inches in diameter and over 9 miles in length.

The system presents the following key challenges, some of which are influenced by climate change:

- Need to reverse the direction of flow, as a result of the planned construction of a new wastewater treatment plant (WWTP) at the system's opposite (southern) end. The system currently discharges to a plant to its north. The construction of a new plant highlights the system-wide growth and capacity constraints that designers are often asked to conform to;
- Flooding of the system's largest lift station and its immediate environs, with a very high wet weather flow/dry weather flow multiple anticipated in the future, thereby requiring specialized pump selection and careful station design; and,
- Due to budget limitations, there was a need to prioritize/phase construction with an emphasis on targeting the most effective strategies and reusing existing system components wherever possible. Potential reuse of the pumps required careful assessment of "efficiency versus cost of new purchase" to justify the decision to relocate them (to pump in a different direction).

Hydraulic modeling revealed the following additional challenges at this location:

- Pumping backwards results in significant portions of the force main being pumped downhill. This required a detailed hydraulic transient analysis to identify areas susceptible to sewage column separation, air pocket formation, and potential relocation and resizing of air release valves;
- Accommodating the high turn-up ratio at pumping station 5 creates high system heads when the storm pump is on. These target heads cannot be met by the smaller lift stations; and
- The high turn-up ratio presented the challenge of pump selection for a large range of heads and flows at lifting station 5.

WSP | Parsons Brinckerhoff recommended the following key design features to increase the long-term resilience and adaptability of the system:

- Employ a staged pump system comprised of: two (2) active duty, high head, medium volume pumps; one (1) identical standby pump to accommodate peak dry weather flows; one (1) active duty, medium head, high volume peak wet weather pump; and one (1) identical pump on standby.
- Place variable frequency drives (VFDs) at lift station 5 in order to maintain conveyance even at a low level (critical flood mitigation measure).
- Provide a sensor-actuated (SCADA driven) system to "back off" (turn off) smaller lift stations at a wet well level set-point in order to allow the medium-head storm pump to rapidly drain the wet well at pumping station 5, significantly lowering the risk of flooding there.
- Re-route the smaller lift stations to the wet wells of larger ones to reduce target heads;
- Employ soft starters and ramped shutdowns to minimize wear-and-tear from hydraulic transients. For the same reasons, re-size sewage combination air valves (SCAVs) to avoid excessive water column separation and the upsurge pressures that could result upon air expulsion (pump restart).
- Place a large detention-tank tiered wet well at pumping station 5, to accommodate the high turn up ratio during major storms.
- Install a SCADA-activated pinch valve (pressure sustaining valve) at the discharge point to the new WWTP, in order to prevent the force main's downhill segments from draining/ emptying when pumps are off and system heads are low. This will reduce corrosion due to air overlying stagnant areas when the line stops for any length of time.

## LESSONS LEARNED AND CONCLUSION

Using a detailed computer model of steady-state and transient hydraulics, it is possible to refurbish a system with multiple lift stations and force mains without requiring complex SCADA controls and interlocks to coordinate pump starts; while also improving system resilience and adaptability.

The high turn-up ratios in sewer flow are a result of both aging infrastructure and climate change, and they are here to stay. Designers should therefore prepare to employ staged pump systems (i.e., a combination of SCADA-driven low-flow to high-flow pumps) to accommodate the wide range of flows efficiently. Using a high number (3 or 4) of identical pumps often results in diminishing returns of flow for every additional pump engaged, due to steep system curves for an economical force main, such that "more pumps are less" effective in handling peak storm-driven flows. This is a key aspect of resiliency and adaptability of the pumped sewage system.

Flow should be consolidated where possible. Smaller lift stations struggle to perform when discharging to systems with large, continuously operating lift stations. Gravity flow or station-to-station pumping should be used where possible to discharge to larger wet wells and pumps that handle the total flow. Connecting directly to large common discharge headers may present pump selection issues and operational constraints; although pressure vessels can lessen the impact of un-coordinated or un-planned pump starts or stops (or power failures).

Hydraulic modeling is an invaluable tool in minimizing long-term costs and it should be employed in the earliest possible stages of design. Minor system features can be identified by hydraulic modeling that can make large budgetary differences, for example, a pressure sustaining valve or right-sized air valve. For large or complex projects, consider both 3D flows in sumps and hydraulic transients for operations.

Retrofitting and modifying wastewater systems is a daunting and costly task. The design of new systems and lift stations should employ long-term resiliency thinking.

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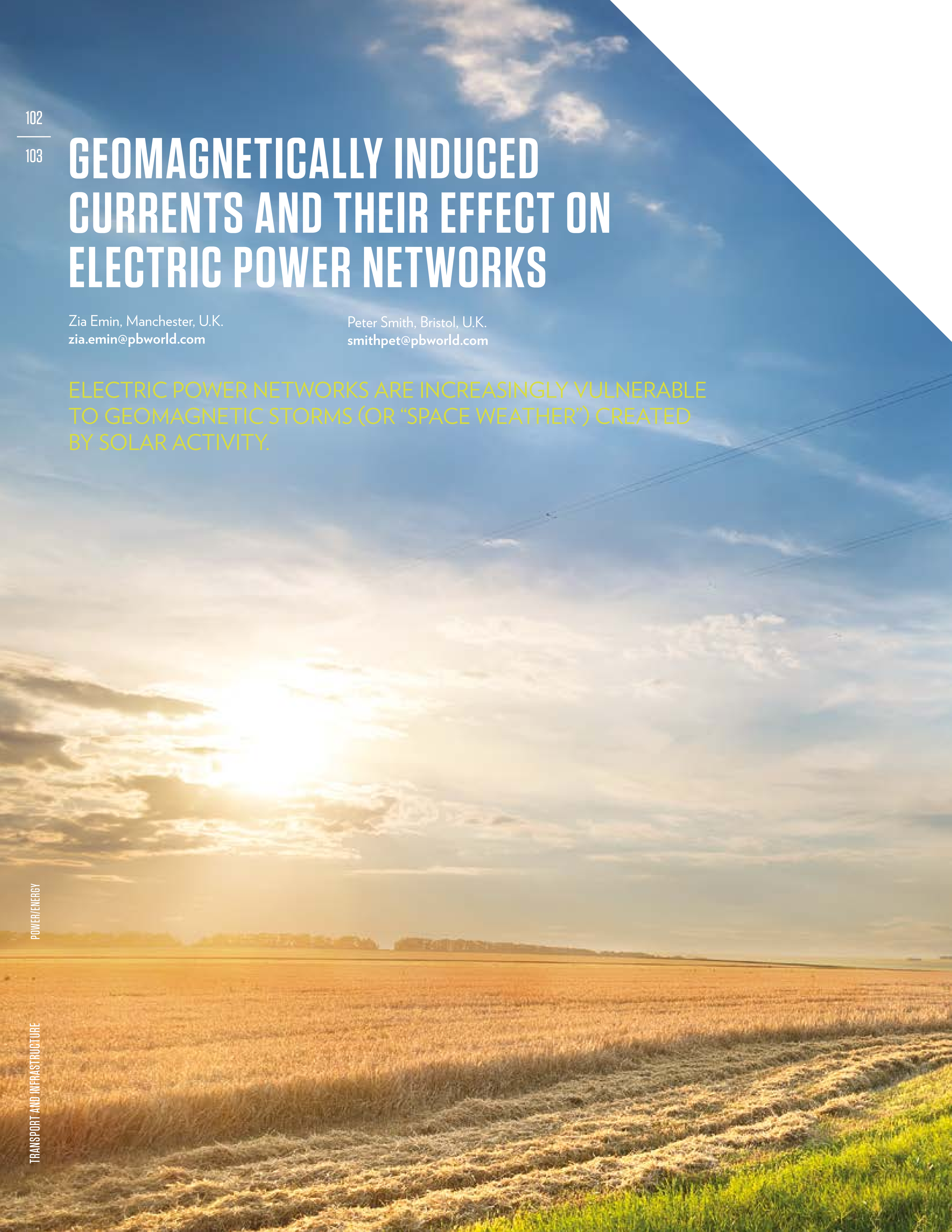
***Jean-Luc Daviau*** *leads the Hydraulic Centre of Excellence at WSP | Parsons Brinckerhoff and has over 23 years of multi-disciplinary experience in the investigation and control of flow or surges (hydraulic transients) for plants and pipelines. He is a reviewer for the ASCE and part of AWWA's sub-committee on hydraulic transients.*



# GEOMAGNETICALLY INDUCED CURRENTS AND THEIR EFFECT ON ELECTRIC POWER NETWORKS

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ELECTRIC POWER NETWORKS ARE INCREASINGLY VULNERABLE TO GEOMAGNETIC STORMS (OR "SPACE WEATHER") CREATED BY SOLAR ACTIVITY.

The importance of electricity in our daily lives, powering an entire nation from individual households to industry, is unquestionable. Large electric power networks are designed, built, and operated with a very high degree of reliability, and with consideration for variations in terrestrial weather. However, this may not be true for "space weather" effects in the form of geomagnetically induced currents, even though geomagnetic storms created by solar activity have caused problems in the operation of high voltage power grids throughout the world. Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) is part of a working group for the International Council on Large Electric Systems (CIGRE), tasked with a study of the geomagnetic storm environment.

## GEOMAGNETIC DISTURBANCES

The sun follows roughly an 11-year cycle of sunspot activity with several spots during the peak period. We are currently in 24th solar cycle since records began in 1755 and, based on the sunspot number predictions, it is postulated to be one with the lowest number of sunspots. Figure 1 shows the current prediction from NASA together with solar cycle 23 (1996-2008). Solar flares are another form of sun storm manifestation, with a massive burst of solar wind and magnetic fields rising above the solar corona or being released into space. This is commonly referred to as a coronal mass ejection (CME). When CMEs are directed to earth and reach it, earth's magnetosphere may be disrupted, creating aurorae around the magnetic poles. These are commonly known as the northern and southern lights (aurora borealis and aurora australis) in the respective hemispheres. The scale used to categorize the intensity of geomagnetic storms is the K-index. The index ranges from zero to nine, zero corresponding to minimum geomagnetic disturbance.

## GEOMAGNETICALLY INDUCED CURRENTS

When a geomagnetic storm interacts with the Earth's magnetic field it induces geoelectric fields at the Earth's surface (as shown in Figure 2), giving rise to voltages in pipes, telecommunication circuits, transmission lines, etc. The induced voltages are classified as quasi-DC due to their frequency being much lower than the grid system frequency. The currents resulting from these voltages are termed geomagnetically induced currents (GICs), and they enter and leave the network via transformer neutrals, which are connected to earth, mainly at the extremities of the network. These flow through the transformer windings, producing extra magnetisation which in turn can saturate the core of the transformer. This produces extra eddy currents in the transformer core but, due to the large thermal capacity of extra high voltage transformers, it manifests itself only as localised heating (hot spots with possible damage to transformer windings). There will also be extra noise and vibration.

Another side effect of GIC is the generation of extra harmonics that can cause mal-operation of protection relays, hence possible tripping of individual transmission circuits leading to system collapse. The most pronounced effect though is on the increased requirements for reactive power. This is due to the transformer's operating point being shifted into the saturation region. A typical example of this would be a 600 MVA[1] transformer with the excitation current jumping from 6 amps to 300 amps under the application of 75 amps GIC current, producing an extra 50 Mvar reactive power loss and subsequent voltage drop[2]. A system-wide increase in reactive power requirement puts excessive demand on the available reactive power compensation trying to support voltage levels. ›

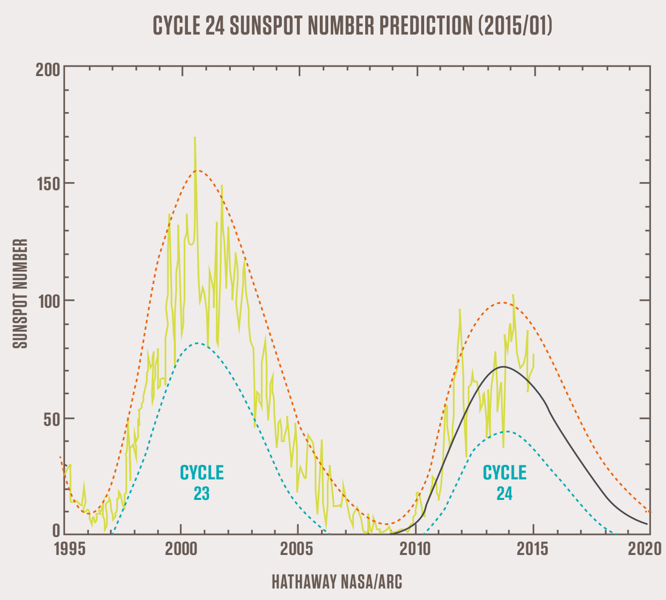


FIGURE 1 - CYCLE 24 SUNSPOT PREDICTION BY NASA (SOURCE: HTTP://SOLARSCIENCE.MSFC.NASA.GOV/PREDICT.SHTML)

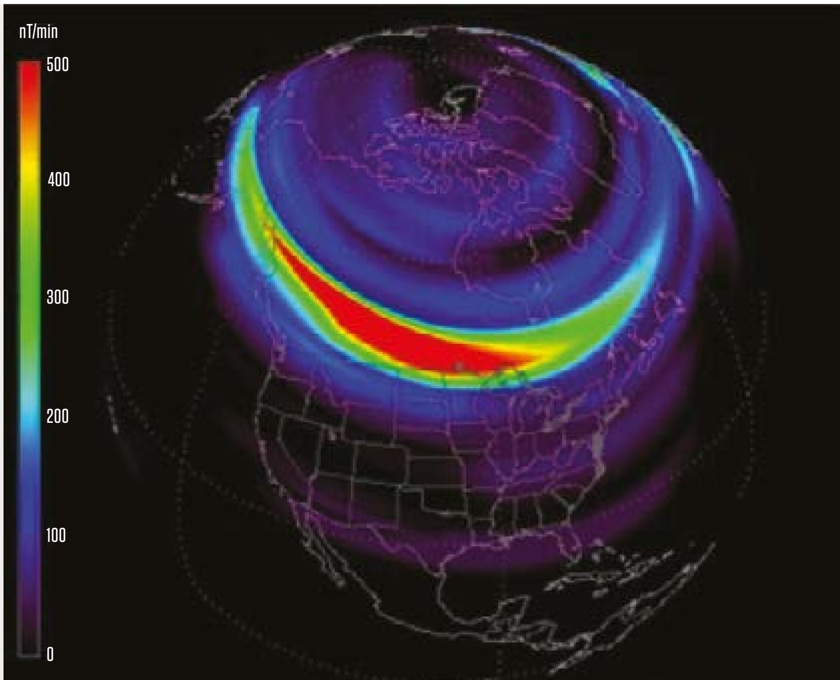


FIGURE 2 - CONTOURS OF THE 13 MARCH 1989 STORM[3] (nT/min = NANOTESLA PER MINUTE)

[1] MVA is the effective power of an AC power system, comprising real power measured in MW, and reactive power which is only present in AC systems, and is measured in Mvar.

[2] J. G. Kappenman and V. D. Albertson, "Bracing for the geomagnetic storms," IEEE Spectrum, vol. 27, pp. 27-33, March 1990.

[3] J. G. Kappenman, "A perfect storm of planetary proportions," IEEE Spectrum, vol. 49, pp. 26-31, February 2012.

Added to this are the extra harmonic currents being generated and possibly flowing into the capacitor banks. As a result, reactive power compensation devices may be overloaded and likely to trip under such strain, leaving the system with even more requirement for voltage support. With no such support, the eventual result is the tripping of transmission lines with a complete collapse of the system.

## HYDRO-QUÉBEC SYSTEM COLLAPSE OF 1989

The best example of such an event is the Hydro-Québec system blackout that took place in March 1989 in the Canadian province of Québec. This blackout was due to a magnetic super-storm with a CME estimated to be the size of 36 earths. At the time, two 735 kV transmission corridors were transmitting power from the north to the load centres in the south more than 1000 kilometres away. One corridor was running from the La Grande Complex in the James Bay area and the other from the Churchill Falls in Labrador, each with five transmission lines. Seven static compensation schemes were active in the La Grande transmission corridor for system stability and voltage control purposes.

An intense magnetic storm took place on 13 March 1989 around 2:45am which saturated the cores of transformers generating excessive, even-harmonic, currents that in turn overloaded and then tripped all the seven static var compensators[4] in the La Grande transmission corridor. No preventive action could be taken during this tripping, as all took place within less than minute. The tripping of the last static compensator was followed after nine seconds by the tripping of one of the 735 kV transmission lines, resulting in automatic rejection of two generating units followed by the tripping of three further 735 kV transmission lines from the La Grande corridor as well as other faults. The last remaining transmission line was to trip next in the same transmission corridor which separated La Grande from the remaining Hydro-Québec system. The result of this was a rapid drop in system frequency (as seen in Figure 3) triggering the automatic load shedding system that started tripping all loads.

Even then, the loss of approximately 9500 MW generation from the La Grande complex was not offset, hence the result was a total collapse of the remaining system. As a result of the whole event some strategic transmission equipment was damaged on the Hydro-Québec system. Hence the cost of such an event is twofold: loss of revenue from the transmission or sale of electrical energy and the replacement of damaged equipment. Hydro Québec estimated the cost of the event to be close to $15 million.[5]

## MITIGATING THE EFFECTS OF GEOMAGNETICALLY INDUCED CURRENTS

The U.K. didn't entirely escape the effects of the storm of March 1989. During the night of the 13th/14th March, reports were received of spurious alarms from power stations, telecommunications networks, and supergrid transformers on the U.K. network. There was no actual loss of supply or tripping, but two 5-limb transformers, one on the eastern extremity of the network, and one on the western extremity, were taken out of service; the damage to these was attributed to GICs.[7]

As the electric power networks are getting more and more heavily loaded and complex, their vulnerability to geomagnetic disturbances is increasing. Following the collapse of the Hydro-Québec system, the National Grid of England and Wales (currently National Grid Electricity Transmission) undertook a risk assessment on the potential impact of solar cycle 23 and the effectiveness of possible mitigation strategies.[8] At the time the system operator was heavily dependent on reactive power compensation for the transmission of active power. The results of the risk analysis indicated that severe geomagnetic disturbance could lead to an additional reactive power loss, hence a reserve of up to 3500 Mvar may be required. Furthermore, it was established

[4] A device used to control reactive power, hence voltage, on the system.

[5] http://www.spaceweather.gc.ca/tech/se-pow-eng.php

[6] P Czech, S Chano, H Huynh and A Dutil, " The Hydro-Quebec system blackout of 13 March 1989: System response to geomagnetic disturbance", Proceedings of Geomagnetically Induced Currents Conference, 8-10 November 1989, Millbrae, California, EPRI Report TR-100450, 1992.

[7] P Smith, "Effects of geomagnetic disturbances on the National Grid System", 25th Universities Power Engineering Conference, September 1990.

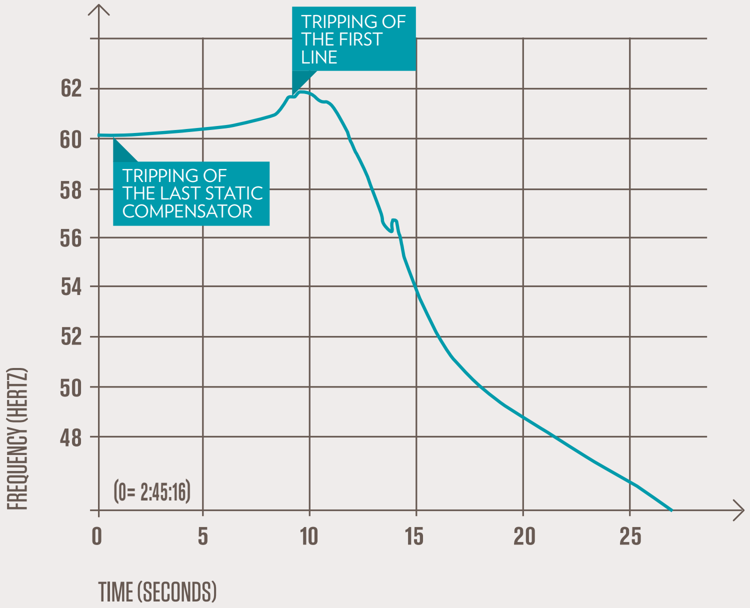


**FIGURE 3** - HYDRO-QUEBEC SYSTEM FREQUENCY DURING THE 1989 GIC EVENT[6]

AS THE ELECTRIC POWER NETWORKS ARE GETTING MORE AND MORE HEAVILY LOADED AND COMPLEX, THEIR VULNERABILITY TO GEOMAGNETIC DISTURBANCES IS INCREASING.

that transformers in the coastal regions would be the key collection points for the GIC currents, with auto-transformers experiencing the highest flows and saturation.

It is of importance to note that 5-limb and single-phase transformers are much more vulnerable than 3-limb transformers. Most supergrid transformers in the U.K. are 3-limb type. The option of the installation of series blocking capacitors (which do not allow the flow of DC or quasi-DC currents) was overruled due to not being a viable mitigation strategy for the particular situation. Also an operational management strategy that would trigger action by local monitoring of GIC was discounted on the basis that the process would not be fast enough for preventive action to be taken. Instead, a predictive forecasting strategy was implemented relying on specific models of the transmission system to derive a forecast impact. This was further supported by a review of the various transmission system equipment capabilities. As a result, six strategically chosen substations were furnished with GIC monitoring equipment. The introduction of this predictive warning strategy proved to be successful in that many minor GIC events were predicted correctly and generally produced reliable forecasts two days ahead of the event.[9]

WSP | Parsons Brinckerhoff is actively supporting the work of the International Council on Large Electric Systems (CIGRE) as part of a working group tasked with the study of the geomagnetic storm environment and the formulation of a Technical Brochure that is to explain the variations in the different types of geomagnetic storm waveforms, which include electrojet storms, sudden impulses, and coronal holes. Each of these storm types has different characteristics that can affect power grids at different geomagnetic latitudes in different ways. It is intended that this study will be useful in the development of operational measures for existing power grids and for the development of future high voltage power grids.

*__Dr. Zia Emin__ is Chief Power Systems Engineer with many years of experience in power quality and switching studies. He has extensive knowledge in all aspects of power system modelling and is active in many international working groups as a member and task force leader in areas related to power quality and insulation co-ordination.*

*__Peter Smith__ specialises in power system protection and control, and system earthing and interference. He has worked in the power supply industry in both generation and transmission and was involved in the investigation of the effects of GICs on the National Grid system.*

[8,9] I A Erinmez, J G Kappenman and W A Radasky, "Management of the Geomagnetically Induced Current Risks on the National Grid Company's Electric Power Transmission System", Journal of Atmospheric and Solar Terrestrial Physics Special Addition for NATO Space Weather Hazards Conference, June 2000.

# RETHINKING URBAN ENERGY SYSTEMS IN THE WAKE OF THE LAC-MÉGANTIC RAIL DISASTER

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AS OIL TRANSPORT BY RAIL CONTINUES TO INCREASE, SO DO THE NUMBERS OF OIL TRAIN ACCIDENTS. WSP | PARSONS BRINCKERHOFF STAFF IN LAC-MÉGANTIC WORKED TO REBUILD THEIR TOWN AFTER IT WAS BADLY DAMAGED BY AN OIL TRAIN ACCIDENT.


FIGURE 1 - ORIGINATING IN NEW TOWN, NORTH DAKOTA, THE MMA TRAIN CARRYING CRUDE OIL WAS BOUND FOR SAINT JOHN, NEW BRUNSWICK

On July 6, 2013, at about 1:15 a.m., a Montreal, Maine and Atlantic (MMA) Railway train carrying 7.7 million litres of petroleum crude oil jumped the track in the Quebec town of Lac-Mégantic, unleashing a flood of burning oil into the heart of the downtown area. Dozens of buildings were destroyed and 47 people died. The building housing WSP | Parsons Brinckerhoff's office in Lac-Mégantic was damaged by the fire. In the aftermath, WSP (now part of WSP | Parsons Brinckerhoff) contributed to the town's reconstruction.

During the year-long investigation into one of the worst rail accidents in North America, the Transportation Safety Board of Canada identified 16 factors that contributed to this catastrophic incident. Beyond cause and effect, however, the increasingly controversial practice of transporting crude oil by rail was placed in the spotlight.

As oil transport by rail in North America is reported to have increased by 4,000 percent over the last five years[1], the investigation also points to an increase in oil train accidents resulting in highly toxic and damaging results. With train tracks cutting through city centres, the eminent question on how to ensure public safety is pushed to the forefront.

Communities around the world affected by rail shipments of crude oil need to address and incorporate resilience into the development of their built environments. The MMA train's last stop before Nantes, where the train lost control and crashed in Lac Mégantic, was Montréal, the second largest city in Canada. The same train also passed through other major cities in North America such as Minneapolis, Chicago, Detroit, and Toronto, to name a few (see Figure 1).

## REBUILDING LAC-MÉGANTIC

*We acquire the strength we have overcome.*

*~Ralph Waldo Emerson*

As sorrow subsided in the aftermath of the accident, discussions on rebuilding the town centre took shape. The question of "rail or no rail" was briefly debated, but the majority of residents remained adamant that no rail should pass through downtown again.

[1] http://thinkprogress.org/climate/2015/02/16/3623379/oil-train-derails-in-canada/

FIGURE 2 - WSP LAC-MÉGANTIC OFFICE WAS LOCATED IN THE RED BRICK BUILDING ON FRONTENAC STREET (JULY 2013)


FIGURE 3 – NEW COMMERCIAL COMPLEXES ON PAPINEAU STREET (WINTER 2014)

THE PROPOSED GREEN CITY PLAN FOCUSES ON CREATING A RESILIENT AND MORE EFFICIENT URBAN ENERGY SYSTEM.

The assets of the Montreal, Maine and Atlantic Railway, which declared bankruptcy after the derailment, were bought by Fortress Investment Group which struck an agreement with the town of Lac-Mégantic by promising not to transport dangerous goods through its downtown core until at least January 1, 2016. The firm is to invest $10 million to repair its Canadian stretch of tracks. It will also contribute to the cost of a feasibility study examining a rail bypass around the town, a popular but hefty option with an estimated price tag of $50 to $175 million.

The subject of building a "resilient" town is a recurring theme for the residents, if not a beacon of aspiration to guide the future planning and rebuilding process. Over a hundred businesses were destroyed, displaced, or rendered inaccessible and many residents had been left homeless, losing their livelihood, and their possessions. To this date, toxic remnants of the accident continue to block access to the town's centre. The buildings that remain standing erect are slated for demolition due to contamination. Among the many challenges is funding the cost of decontamination and reconstruction.

## A RESILIENT AND SUSTAINABLE URBAN ENERGY SYSTEM

WSP | Parsons Brinckerhoff's Lac-Mégantic office was located in a building on Frontenac Street (see Figure 2) which had to be demolished as part of a government initiative to mitigate health hazards and risks. Contributing to the town's reconstruction effort, WSP | Parsons Brinckerhoff Project Manager Mario Blais and his team in Lac-Mégantic proposed a concept for the town, the Lac Mégantic: Green City Plan.

This innovative yet sensible proposal focuses on creating a resilient and more efficient urban energy system by enhancing the city's ability to generate and manage energy in a more sustainable manner. The proposed Green City Plan would support the town's enormous job of rebuilding by establishing a large utility management tunnel under the street. The utility tunnel would function as a multi-network gallery of energy underground, where all community energy cables, wires, pipes, ducts, and other networks would pass through without interference. This would include a hydrothermal energy system for space conditioning (heating/cooling). The tunnel would be designed large enough to hold all the various utilities and to accommodate maintenance and other workers. This would allow power, heat, and other utilities to be more easily connected without the need for digging up the street, for example, when new buildings need to be connected to the grid.

The proposed system would have the ability to identify the heating and cooling needs of all buildings that are connected to the network and respond accordingly, thereby managing and exchanging the town's local energy resources and reducing its dependency on fossil fuels. The system would be sustainable, accessible, and efficient; and most importantly it would mitigate the impact of future disruptions. In this Green City Plan, central heat would be generated from a proposed hydrothermal power plant at the nearby Chaudière River, of which Lake Mégantic is the source. Other renewable energy sources and sustainable practices would include:

- Biomass energy used for additional support;
- Use of solar power to optimize operations; and
- Energy recovery from recycled greywater.

While elements of the Green City Plan are in use in major cities, such a plan is unprecedented in smaller towns and communities such as in this region.

## CONCLUSION

Lac Mégantic is slowly but surely rebuilding; and WSP | Parsons Brinckerhoff has led four projects, ranging from construction of new commercial complexes on Papineau Street (see Figure 3) to reconstruction of businesses and institutional buildings, all beginning with sludge and debris removal.

Resilience is the building block of any community. Communities around the world need to incorporate resilience into the development of their built environments. In the words of Lac Mégantic newspaper editor Rémi Tremblay, *"Le centre-ville du Lac Mégantic pourrait devenir un exemple de relève à tout le moins pour l'Amérique du Nord où de nombreuses petites villes sont traversées par une voie ferrée et par des convois de pétrole et de matières dangereuses."* ("Downtown Lac Mégantic could become an example for North America, at least, where rail lines and convoys of petroleum and other hazardous materials traverse through town centres.")

***Mario Blais**, a Mechanical Engineer with over 32 years of experience, has managed the Lac Mégantic office of WSP | Parsons Brinckerhoff for 11 years. His areas of expertise include energy, heating/cooling, and ventilation and he has led several major industrial, commercial, municipal, and institutional projects.*

***Suzie Kim** is the Communications and Marketing Coordinator for WSP | Parsons Brinckerhoff and is based in Montreal, Canada.*

# RESILIENCY IN THE CENTRAL UNITED STATES

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## THE CENTRAL REGION OF THE U.S. EXPERIENCES FLOODS, TORNADOES, DROUGHT AND OTHER NATURAL DISASTERS WITH INCREASING FREQUENCY.

This article is about resiliency activities in the WSP | Parsons Brinckerhoff's central region of the U.S. (see Figure 1). The central region is the part of the United States that is bisected by a big river (the Mississippi), adds two hours to a non-stop transcontinental flight, is home to farmers and ranchers and oilmen and more farmers, and has "towns" such as Chicago, IL; Indianapolis, IN; Minneapolis, MN; New Orleans, LA; and St. Louis, MO, popping up amid seas of wheat and corn and oil rigs. It's quiet here, save for the occasional natural disaster of a drought, flood, fire, tornado, or small earthquake.

These types of disasters have been occurring long before the discussion of resiliency and climate change adaptation rose to prominence, but as the frequency and severity of these events appear to be increasing, a different response to rebuilding our communities is needed. A resilient community is one that can take a major disaster or crisis and turn it into a short-term inconvenience and a longer-term opportunity. Resiliency isn't a new concept; rather it stitches together existing programs and strategies such as asset management, emergency response, design standards, technology tools, environmental considerations, public investment, and others, to prepare communities for physical and institutional infrastructure challenges due to a disaster. Resiliency planning focuses on fostering effective communication and coordination among existing responding government institutions and departments, and ensuring design standards that make our communities safer in the event of a disaster.

## RESILIENCY PLANNING FRAMEWORKS

As noted, resiliency planning covers a multitude of issues, and there are a number of ways to respond and prepare. For example, hazard mitigation plans have been promoted by FEMA since 2000; sustainability, with its focus on environmental enhancement, is another approach for making buildings more resilient; and climate change adaptation plans are emerging as a new way to look at resiliency. There is overlap

**50**

STATES HAVE FEMA-APPROVED HAZARD MITIGATION PLANS

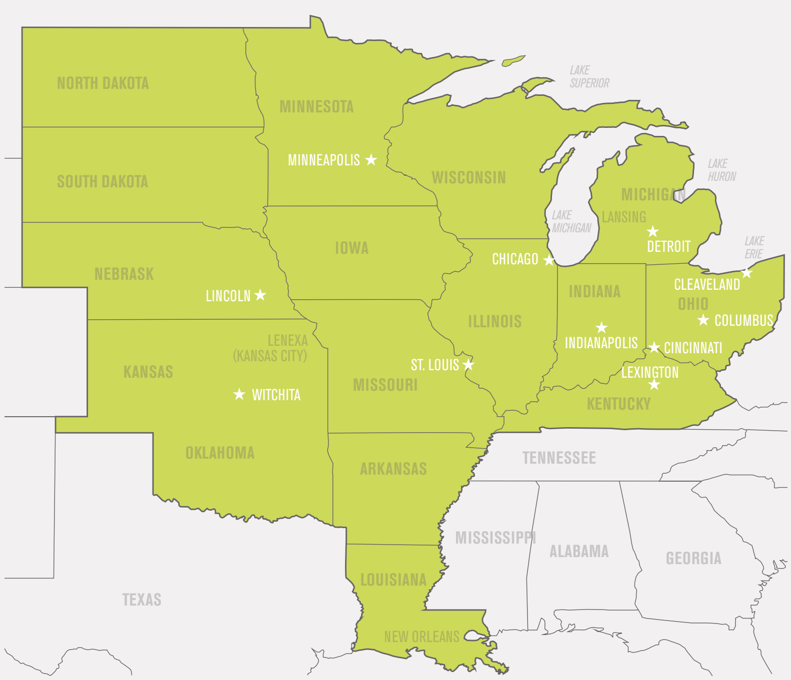


FIGURE 1 – WSP | PARSONS BRINCKERHOFF'S CENTRAL REGION AND OFFICE LOCATIONS

[1] www.fema.gov/multi-hazard-mitigation-plan-status. Accessed March 12, 2015.

[2] www.georgetownclimate.org/about-us

[3] https://www.whitehouse.gov/the-press-office/2014/12/03/fact-sheet-16-us-communities-recognized-climate-action-champions-leaders

between these approaches but all aim to create better communities (see Figure 2).

### HAZARD MITIGATION PLANS

In 2000, the Federal Emergency Management Agency (FEMA) began promoting the implementation of plans for hazards (defined by FEMA as natural or man-made disasters). These hazard mitigation plans outline goals, objectives, and specific actions a community can take to reduce risk and future losses from hazards, and are required to be updated every three years. All 50 states and 5 territories have FEMA–approved plans and, as of March 2015, there are 12 states that have Enhanced State Mitigation Plans. This classification means that these states have demonstrated a comprehensive mitigation program and are eligible for additional funding in the event of a disaster. Five of these states are in the central region - Kentucky, Iowa, Missouri, Ohio, and Wisconsin[1]. At a local level, there are numerous local governments still in need of plans or updates (as of a September 30, 2014 FEMA assessment). Figure 3 is adapted from the FEMA assessment.

### CLIMATE CHANGE ADAPTATION PLANS

In terms of climate change adaptation:

- A recent study by the Georgetown Climate Center[2], an organization that works to strengthen state and federal climate partnerships, noted that three central region states (Michigan, Minnesota, and Wisconsin) are implementing state-led climate change adaptation plans.
- In December 2014, Dubuque (IA), the Mid-America Regional Council (KS and MO), Minneapolis (MN), Oberlin (OH), and the Sault Ste. Marie Tribe of Chippewa Indians (MI) were all recognized by the Obama administration as Climate Action Champions[3] for the work done on greenhouse gas reduction and adaptation strategies.
- In 2008, the Chicago Climate Action Plan was adopted and, in 2012, the city reported that its greenhouse gas emissions were eight percent less than the 2005 baseline.

Many communities throughout the central region have floodplain management plans or emergency response plans, and some are developing plans that consider sustainability and livability as concerns. These plans help communities and states address some aspects of resiliency. Some planning has been done, but there are opportunities for WSP | Parsons Brinckerhoff to contribute to and support resiliency efforts.

## RESILIENCY PLANNING IN THE CENTRAL REGION

This is not a full accounting of activity, but a review of some of the completed and on-going projects to address resiliency:

- Parsons Brinckerhoff (now part of WSP | Parsons Brinckerhoff) worked with the Minnesota DOT on a systems level vulnerability assessment, prioritization process, and scenario-based adaptation analysis as part of the 2013-2014 Federal Highway Administration (FHWA) Climate Resilience Pilot Program. The work focused on the issue of flash flooding; it was innovative in that it incorporated change in peak design flow and other engineering considerations in the vulnerability assessment, and included a cost/benefit analysis in the 11 step adaptation process.
- The WSP | Parsons Brinckerhoff St. Louis office has done extensive work for the Boone Hospital Center in Columbia, Missouri. The project incorporated sustainability throughout the designs of a new patient tower, parking garage, and campus site. An emphasis was placed on environmental stewardship, primarily through better stormwater management (native plants, on-site retention), strategies that help resolve community flooding. ›

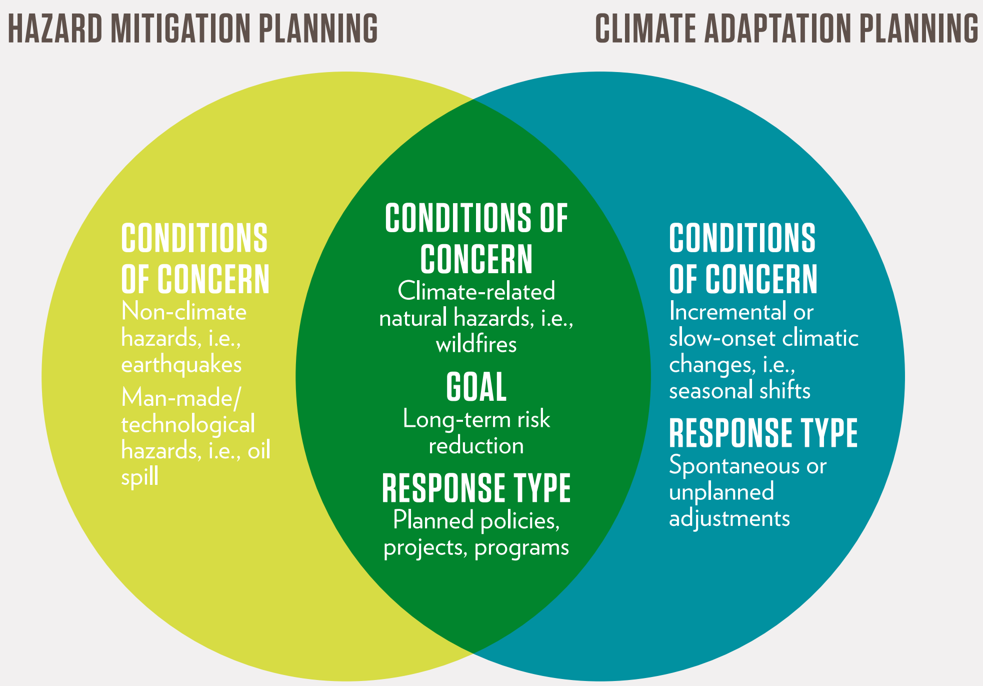


FIGURE 2 – INTERSECTION OF HAZARD MITIGATION AND CLIMATE ADAPTATION PLANNING (source: http://www.icleiusa.org)

# $4

ONE ANALYSIS INDICATES THAT $1 OF RESILIENCY INVESTMENT PRIOR TO A DISASTER CAN SAVE $4 IN RECOVERY, REPAIR, AND REHABILITATION COSTS POST-DISASTER.

- After four hurricanes between 2005 and 2008 prompted Louisiana to focus on disaster response and resiliency, the state established the Louisiana Resiliency Assistance Program (LRAP), part of Louisiana State University. The LRAP team funds a variety of services to help communities recover from disaster, and in 2013 it assisted 30 communities with planning, training, and funding.
- Louisiana also developed a Coastal Master Plan in 2012, after recognizing that the loss of 1,800 square miles of wetlands and natural coastal barriers since the 1930s had something to do with the amount of damage done to its communities and economic livelihood by hurricanes and the Deepwater Horizon oil spill in 2010. This plan is being updated for 2017.
- At the regional level, some metropolitan planning organizations (MPOs) are beginning to address resiliency, but these responses vary.
  - The Chicago Metropolitan Agency for Planning (CMAP) is incorporating resiliency and climate change adaptation into its long-range transportation plan.
  - The Association of Central Oklahoma Governments (ACOG) coordinates the region's 911 emergency response phone system.
  - Other MPOs are addressing resiliency as a response to trauma.
- CMAP is also assisting communities with preparing applications for the National Disaster Resilience Competition. Funded by the Department of Housing and Urban Development, this nearly $1 billion competition invites the 67 units of government that experienced natural disasters during 2011

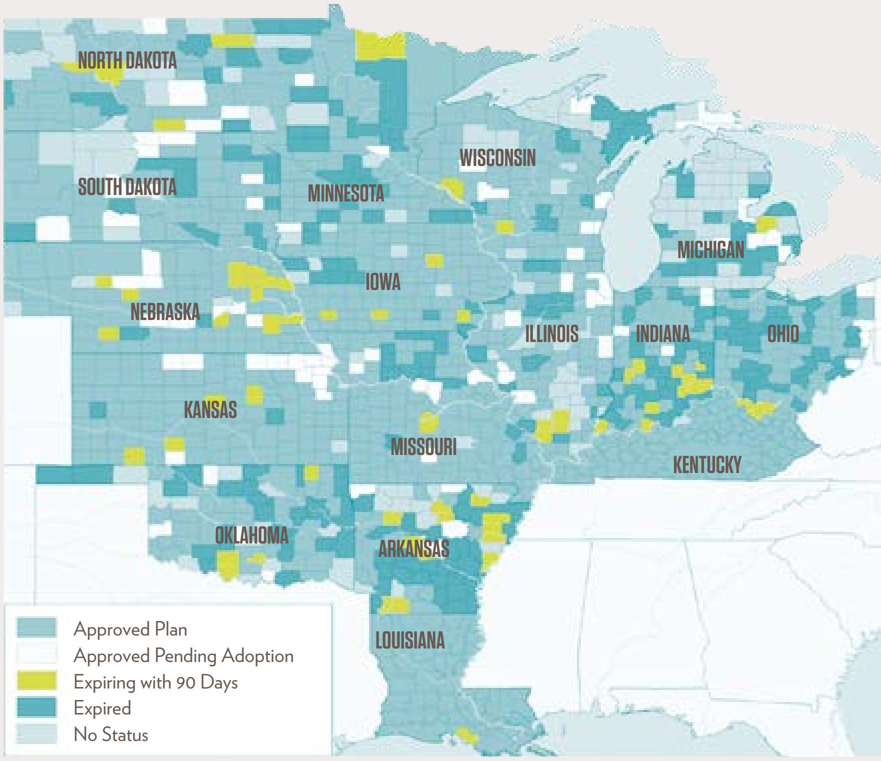


**FIGURE 3 – STATUS OF LOCAL MITIGATION PLANS IN THE CENTRAL REGION** (Status of Local Multi-Hazard Mitigation Plans, September 14, 2014)

to 2013 to compete for funds to help them rebuild and increase their resilience to future disasters.[4]

- In September 2014, Cook County, Illinois, approved the largest multi-jurisdictional hazard mitigation plan in the U.S. to date. This is to address natural hazards that the county frequently experiences, like flooding, extreme cold temperatures, snow and heavy storms, which endanger lives, and damage and destroy property. The plan defined current conditions, assessed risks, and provided the policy direction for improvements. A total of 115 planning partners were involved in the effort, including 113 of Cook County's 134 municipalities.[5]
- Norman, Oklahoma, lies within what is called "Tornado Alley", a geographic region where tornado activity is predominant. The National Institute of Standards and Technology (NIST) had the only Midwest session of its workshop in Norman - it's a series on developing a disaster resilience framework. NIST, as part of the U.S. Department of Commerce, is focused on developing standards for resilient building and infrastructure, so that communities can rebuild more rapidly and at lower cost. In addition, the University of Oklahoma has established the Resilience Development Institute, with its inaugural training conference scheduled for April 2015.
- The cities of Tulsa, St. Louis, and Chicago have received funding from the Rockefeller Foundation's global '100 Resilient Cities' initiative. The funding establishes a Chief Resilience Officer position in each city to lead the resilience efforts, and provides expertise to assist in developing strategies for each municipality to become more resilient. This also entails ideas for innovative public and private sector tools that can assist with implementing the strategies. The Rockefeller Foundation's definition of resiliency is broader than just addressing infrastructure, it is also concerned with social stresses (inequality, crime, poverty) in communities.

## CONCLUSION

Experience suggests that developing strategies to prepare for and mitigate the effects of disasters can save both money and lives. One analysis indicates that $1 of resiliency investment prior to a disaster can save $4 in recovery, repair, and rehabilitation costs post-disaster. Resiliency is an emerging issue and WSP | Parsons Brinckerhoff is assisting communities in resiliency planning by providing innovation and expertise in the many infrastructure areas in which we work.

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[4] www.hudexchange.info/cdbg-dr/resilient-recovery/

[5] www.cookcountyil.gov/2014/09/11/cook-county-board-approves-largest-hazard-mitigation-plan-in-the-u-s/

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