NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

Due to netc@ctcandassociates.com **by January 25, 2019**

I. PROBLEM TITLE

Modeling Combined Coastal and Inland Impacts from Extreme Storms on Transportation Infrastructure

II. RESEARCH PROBLEM STATEMENT

Emergency managers face challenges in understanding, communicating, and planning for potential weather-related hazards, including hurricanes, nor'easters, and one-hundred and five-hundred year flood events. Preparedness typically emphasizes the last event encountered, resulting in an overly simplistic model that underestimates or overestimates the potential impacts of future hazards. Risk assessment models (e.g., basic HAZUS) that emphasize accumulated damages in economic terms do not provide actionable data regarding specific local concerns, such as access by emergency vehicles and potential communications disruptions. Qualitative methods conventionally used to identify these issues, however, lack the specificity necessary to incorporate the managers' knowledge into hazard models (e.g., exact geographic location of the vulnerability or source of cascading consequences). Existing data points and damage curves that may be sufficient for generalized or aggregate analysis (e.g., 'basic' loss estimation with HAZUS) are often not applicable at granular scales to serve the needs of facility and emergency response managers, or those with responsibility for critical infrastructure links.

III. RESEARCH OBJECTIVES

This research will develop a method to collect rich, actionable, qualitative data from critical facility managers and infrastructure owners that can be utilized in combination with hydrodynamic, wind, and precipitation models to assess potential hazard consequences in real time as a storm moves into the region. Research will:

- Comprehensively investigate hazards and impacts in Southern New England using the most advanced storm prediction models, coastal storm surge, wave, and hydrological models.
- Transition new modeling capabilities to the real-time storm modeling used by DHS: ADCIRC-Surge Guidance System (ASGS) and Coastal Emergency Risks Assessment (CERA).
- Integrate enduser concerns as model outputs. Qualitative and quantitative concerns will be collected directly from endusers of the models, making model outputs directly relevant. Impact data will be collected directly from endusers of the models using a methodology that allows critical facility managers' and infrastructure owners' expertise about impacts to be integrated in the same way that "damage functions" are traditionally utilized to model potential structural damages.
- Develop visualization tools that use geographic points representing specific pieces of infrastructure which can be indexed directly into storm models. Detailed 3D

visualizations of structures and objects such as buildings and bridges, will allow for rapid assessment by the user. For example, the combined storm hazard and impact modeling system will be able to not only predict that roads are blocked, but where, when, and how they are blocked (e.g., coastal or inland flooding, or wind damage) as a storm unfolds. This is especially evident in multi-day events with overlapping response and damage mechanisms.

IV. COST ESTIMATE

The budget for this project will be approximately $175,000.

V. RESEARCH PERIOD

This project will take approximately 18 months to complete, including preparation of a Draft Final Report and its review by the NETC project Technical Committee (90 days), and the preparation and printing of the Final Report.

VI. URGENCY AND PAYOFF POTENTIAL

A description of the urgency of the need for this research in relation to the transportation needs of the six New England States and, if possible, the potential for payoff in benefit/cost terms.

TK

VII. PRELIMINARY LITERATURE SEARCH

To avoid duplicating research already published or in progress, the submitter of the Problem Statement will perform a brief literature search prior to submitting the Problem Statement. This literature search can be conducted using the Transportation Research Board's TRID database, available at https://trid.trb.org/. The TRID database contains information on completed research as well as research in progress.

Attach a brief summary (1-3 paragraphs) *of the results of this literature search to the Problem Statement. The summary should describe how the subject of this Problem Statement would differ from or add to existing studies.*

Emergency and infrastructure facility managers face challenges in understanding and communicating hurricane hazards (Morrow et al., 2015). Robust emergency management and resiliency planning starts with identifying the problem, which includes understanding impacts, risks, opportunities, and associated vulnerabilities (Moser and Ekstrom, 2010;Preston et al., 2010;Bierbaum et al., 2013). However, preparedness typically emphasizes the last event encountered, which often leads to the underestimation of the risks of future hazards (Adger et al., 2013;Kellens et al., 2013). Traditional risk assessment models (e.g., basic HAZUS) that emphasize accumulated damages in economic terms or use generic damage functions do not provide actionable data regarding specific local concerns, such as potential damage to a given facility's emergency generator (Paul et al., 2018). Qualitative methods typically used to identify managers local concerns, however, lack the specificity necessary to incorporate such local concerns into hazard models (e.g., exact geographic coordinates of the vulnerability or cascading consequences), resulting in concerns that can be described, but not modeled. The modeling of hazard impacts for individual pieces of infrastructure and facilities requires data at a resolution that is both specific to the facility and provides specific actionable outputs that are relevant to emergency and facility managers.

Existing data points and damage curves that may be sufficient for generalized or aggregate analysis (e.g., 'basic' loss estimation with HAZUS) are often not applicable at granular scales to serve the needs of facility and emergency response managers. While "direct damages" are relatively easy to quantify and "indirect impacts" can be quantified through a variety of economic modeling techniques, the "intangible consequences" that decision makers and society face after a storm are best suited to qualitative data-collection approaches (Becker et al., 2015). This project developed a method to gather rich, actionable, qualitative data from critical facility managers that can be utilized for risk assessment and emergency response. These data provide additional granular detail regarding impacts to enhance Disaster Risk Reduction (DRR) and other participatory risk assessment processes.

Disaster Risk Reduction (DRR) is the systematic practice of evaluating and reducing risks posed by natural hazards such as storm surge associated with hurricanes (Thomalla et al., 2006). A 'context first' DRR approach encourages decision makers to start with the adaptation problem itself (e.g. the need to maintain communications) and then appraises adaptation strategies through hazard impact models (Reeder and Ranger, 2011). DRR assessments also employ risk-based approaches, which take the climate hazard as the starting point of analysis and introduce impact models to an assessment through experts that provide the likelihood and consequence of a particular climate-related event (see for example (Holper et al., 2007;Port of Dover, 2015;Port of Felistowe, 2015)). These kinds of DRR assessments most commonly rely on models that predict the impacts of a simulated climate event through engineering approaches based on characteristics of exposed assets (e.g. elevations of coastal homes) and storm hazards (e.g. wave height). Some DRR assessments use vulnerability curves to evaluate physical damage and degree of loss estimations based on flood depth or wind speed at a structure's location (Aerts et al., 2018) while others use fragility curves to predict the probability of similar storm forces causing a specific damage level on an asset (Porter, 2015).

Fragility and vulnerability curves are based on expert opinions, empirical methods, analytical methods or a hybrid of these approaches (Schultz et al., 2010). They may be developed for a particular structure or used to make generalized predictions. Empirical curves use observational data from natural or scientific experiments to predict impacts of hazards while analytical curves use engineering principals of assets and hazards to predict impacts. Methods chosen to build a vulnerability curve depends on the information available and the requirement for a precise output (Schultz et al., 2010). Hybrid curves combine multiple data types to compensate for shortcomings of individual approaches (Porter, 2015). However, in many cases, fragility and vulnerability curves do not account for more detailed qualitative or quantitative storm concerns that may be raised by stakeholders of interconnected systems, such as facility managers in a particular region (Schneider and Schauer, 2006).

Further, many human responses to disasters cannot be reliably output by fragility and vulnerability curves due to the unpredictability of human behavior even though these responses significantly impact damage to and recovery of a system (Aerts et al., 2018). Thus, decision makers are calling for the development of new methods to understand how their concerns may be triggered by storms so that they may find ways to reduce vulnerability and increase resilience (EPA 2008;Becker et al., 2013).

Emergency and facility managers face unique challenges in this regard, as the infrastructure that is relied on to recover from major storm events may itself be vulnerable to storms. Incorporating their concerns (e.g., the short-circuiting of a hospital's generator) into scenario plans through participatory processes such as workshops can improve the accuracy (White et al., 2010) and usefulness of storm models (Messner and Meyer, 2006), and is an essential component of hazard management (Eakin and Luers, 2006). Many DRR methods, including HAZUS, specifically recommend accounting for expert's local concerns when developing detailed storm impact models (Vickery et al., 2006). However, most flood risk assessments use single average fragility and vulnerability curves, ignoring the qualitative concerns of many decision makers. Incorporating these concerns into quantitative DRR assessments can increase their relevance at a finer geographic scale (Brecht, 2007).

VIII. RESEARCH KEY WORDS

Provide a list of key words that can be used to conduct an additional search of the TRID database for related research. To the maximum extent possible, key words should be selected from the Transportation Research Thesaurus (http://trt.trb.org/).

Risk Assessment, Built Environment, Disaster Preparedness, Emergency Management, Hazard Evaluation, Hazard Mitigation

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TWO DOT ENDORSEMENTS ARE REQUIRED (To be signed by separate individuals.)

IX. ENDORSEMENT BY THE SPONSORING DOT (To be signed by the DOT representative to the NETC Advisory Committee through whom the Problem Statement is submitted.)

By signing the endorsement, the DOT representative is certifying that:

1. *The Problem Statement follows the required format.*
2. *The required literature search has been conducted.*
3. *The Problem Statement addresses a transportation issue of relevance to NETC and does not duplicate another Problem Statement being submitted at this time.*

____________________________________ ____________________

Name DOT

Signature Date

X. ENDORSEMENT BY A SECOND EMPLOYEE OF THE SPONSORING DOT who agrees to chair the project's technical advisory committee (TAC) if the Problem Statement is selected for funding. (To be signed by a DOT staff person who has technical knowledge of the project topic and is committed to the research outcome.)

DOT Technical Endorsement*: I agree to chair the project's Technical Advisory Committee if this Problem Statement is selected for funding by NETC.*

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NOTE: To expedite the processing of Research Problem Statements, NETC requires submittal by e-mail (netc@ctcandassociates.com**) by January 25, 2019.**

NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

I. PROBLEM TITLE

Communicating the effect that Climate Change has on Transportation Infrastructure

II. RESEARCH PROBLEM STATEMENT

New England State Transportation Agencies have been dealing with major infrastructure damage brought on by extreme events (precipitation, wind, storm surge, sea level rise). New construction projects that are designed to proactively adapt to this change have higher costs. There is a need to increase support from the public, state legislators, and other funding decision makers for state expenditures related to adapting transportation infrastructure to climate stressors.

III. RESEARCH OBJECTIVES

- Determine existing messaging efforts to communicate transportation-specific climate change risks
- Identify appropriate audience and evaluate successful practices for educating (e.g. general public , executive officials)
- Develop education tools and key messages relevant to New England for use at rest stops as an example.

IV. COST ESTIMATE

$75,000

V. RESEARCH PERIOD

18 months

VI. URGENCY AND PAYOFF POTENTIAL

A 2018 study by the National Institute of Building Sciences determined that for every $1 spent on mitigation, $4-$6 in post-storm cleanup and rebuilding is saved. Mitigation represents a sound financial investment. Funding decision makers and taxpayers don't often understand the future savings from mitigation related to losses from flooding and wind damage.
Resilience projects (or projects that include resilience) will seek funding soon and indefinitely in the future (for example, 10-year plans by state transportation agencies). Funding these projects will need support from the public and/or local leaders. This research will provide educational tools to increase awareness and understanding on why

budget requests for today's investment in infrastructure will provide a long-term benefit to the New England transportation agencies.

VII. PRELIMINARY LITERATURE SEARCH

As state transportation agencies begin to plan for and adapt to climate change, the issue on additional funding will need to be addressed. Studies on how states have increased taxes and fees with public support are minimal. The subject of this problem statement would differ from most by addressing the need to have support for funding infrastructure that is resilient to a changing climate.

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Missouri University of Science and Technology. (n.d.). Developing a Robotic Simulator and Video Games for Professional and Public Training (WD-2). Retrieved from https://inspire-utc.mst.edu/researchprojects/wd-2/

Minooei, F., Sobin, N., Goodrum, P. M., & Molenaar, K. R. (2018). Managing Public Communication Strategies in Accelerated Highway Construction Projects. *Transportation Research Record*, *2672*(26), 1–10. https://doi.org/10.1177/0361198118759943

National Institute of Building Sciences. 2018. *Natural Hazard Mitigation Saves: 2018 Interim Report*.

NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

Due to netc@ctcandassociates.com by January 25, 2019

I. PROBLEM TITLE

Incorporating Climate Change into asset management and long-term planning

II. RESEARCH PROBLEM STATEMENT

Current transportation management practices tend to be more reactive than proactive particularly at this time when most public agencies are facing funding shortages. Transportation agencies must respond to immediate needs and problems. However, by only being able to respond to existing concerns, this prevents managers from being able to look at the long-term big picture needs of communities and transportation projects especially as the background climate state will be changing. Currently there is no good framework for incorporating long-term climate change impacts into the decision making process for transportation infrastructure.

III. RESEARCH OBJECTIVES

This project will evaluate current strategic planning practices and identify inconsistencies. This project will develop a framework on how to include climate change in the strategic planning process. The goal of this research would be to develop a framework transportation managers could follow for assessing the longer horizon climate change issues (e.g. Sea level rise) and their impact on the region to determine how to proceed with building new infrastructure or maintaining/fixing old infrastructure. An example would be a case where a bridge needs to be updated/rebuilt. The engineers plan to build a bridge to withstand the next 100 years. However in the 50-year time horizon sea level rise will so high that the community and roads will no longer exist. Does it make sense to build that bridge with such a long life span, when it may make more sense for communities to plan their retreat.

IV. COST ESTIMATE

$100,000.

V. RESEARCH PERIOD

24 months.

VI. URGENCY AND PAYOFF POTENTIAL

Urgency is considered lower as there is a need to understand the reliable information that transportation managers can use from a technical perspective and what long-term projections mean for organizations. The payoff could be large as future investments would be made more wisely. This would also tie in-to the current asset management work that is now being required of State agencies by FHWA.

VII. PRELIMINARY LITERATURE SEARCH

VIII. RESEARCH KEY WORDS

Provide a list of key words that can be used to conduct an additional search of the TRID database for related research. To the maximum extent possible, key words should be selected from the Transportation Research Thesaurus (http://trt.trb.org/).

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NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

Due to netc@ctcandassociates.com by January 25, 2019

I. PROBLEM TITLE

Collection, curation and overview of existing Sea Level Rise and related flooding datasets

II. RESEARCH PROBLEM STATEMENT

Sea level rise is an emerging design consideration for transportation agencies and practitioners in New England. While a considerable amount of research has been rapidly developing and being published, much of this work has been piecemeal and funded by individual cities/organizations and is not always widely disseminated or shared with other interested groups for use and consideration in the design phase of projects. A guide is needed for practitioners as a quick reference to identify studies and sea level rise projections that may be relevant for their area.

III. RESEARCH OBJECTIVES

Create a white paper and online document archive which identifies all existing studies and datasets addressing rates of sea level rise along the New England Coast. This reference will outline existing reports and publications regarding sea level rise projections and their potential impact on coastal inundation and flood levels. It will need to summaries the data assumptions, methodologies, and projections. This white paper will include simple large-scale estimates of sea level rise (e.g. NOAA's Bathtub modeling) and well as detailed city studies. One key aspect of this document is that practitioners will easily learn more about the uncertainty in sea level rise, and at least be able to determine the conservative measure for future change, if not a detailed explanation of uncertainty. Also, as new studies become available this will be a document that can be updated regularly and where people can submit their information.

IV. COST ESTIMATE

$100,000.

V. RESEARCH PERIOD

24 months.

VI. URGENCY AND PAYOFF POTENTIAL

Transportation agencies, and more importantly the design staff, need easy and quick access to current sea level rise projections, and it is important so that they do not continuously re-invent the wheel or spend significant time trying to locate relevant information..

VII. PRELIMINARY LITERATURE SEARCH

There are a lot of sea level rise and related flooding studies being done across multiple agencies, non-profits, and universities. However there is no complete reference of relevant documentation for New England. Here are a list of some of the reports that could be included in such a white paper. This report would summarize the differences of these existing datasets, their different methodologies, and qualitative explanations for their uses and potential missing uncertainties.

NOAA's Digital Coast Sea Level Rise Viewer
https://coast.noaa.gov/digitalcoast/tools/slr
Data and specific stories could be helpful

From First Street Foundation: Rising Seas Swallow $403 Million in New England Home Values
https://assets.floodiq.com/2019/01/a22bd29b007a783c7d3fa7f5c4531c9a-ne-homevalue-loss-slr.pdf

Flood iQ Website Uses data from multiple agencies and maps flood risk for home owners.
https://floodiq.com

Massachusetts Sea Level Rise and Coastal Flooding Viewer
https://www.mass.gov/service-details/massachusetts-sea-level-rise-and-coastal-flooding-viewer

NOAA Office of Coastal Management DIGITALCOASTL Visualizing the Impacts of Sea Level Rise in Delaware
https://coast.noaa.gov/digitalcoast/stories/slr-delaware.html

Risk finder and map for Sea Level Rise in 2100 for US Cities from Surging Seas at Climate Central.
http://sealevel.climatecentral.org
This work is based on the academic publication from:
Tebaldi et al. (2012) Modeling sea level rise impacts on storm surges along U.S. coastlines.
Strauss et al. (2012) Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States.
Kopp et al (2014) Probabilistic 21st and 22nd century sea level projects at a global network of tide-gauge sites.

A article on how to map sea level rise based on bathtub-type modelling
Schmid et al. (2014): Mapping and Portraying Inundation Uncertainty of Bathtub-Type Models

https://www.jcronline.org/doi/abs/10.2112/JCOASTRES-D-13-00118.1

VIII. RESEARCH KEY WORDS

Design practice, sea level, best practice

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NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

I. PROBLEM TITLE

Effects of Changing Frost-Thaw Conditions on Roadway Maintenance and Seasonal Load Restriction Methodology

II. RESEARCH PROBLEM STATEMENT

Low-volume roads (LVRs) provide a critical transportation link for rural communities and commerce, but in northern regions, seasonal freeze-thaw conditions effect the ability of vehicles to use these roads without causing damage. Heavier vehicle weight limits (winter weight premiums, WWPs) are sometimes permitted during the frozen period because the road has increased strength and stiffness. However, during early spring, temporary weight reductions (spring load restrictions, SLRs) are generally applied because those frozen roads weaken as they thaw, becoming highly vulnerable to damage from heavy trucks, or even entirely unusable. The challenge is to protect infrastructure and minimize maintenance costs, but also to allow commerce as much as possible during the spring thaw and strength recovery period.

Freeze-thaw patterns are changing and that change is causing increased damage to roads. As state transportation agencies begin to plan for and adapt to climate change, current WWP and SLR policies will need to be clarified and simplified, while at the same time being flexible from year to year due to changing environmental conditions.

III. RESEARCH OBJECTIVES

The main goals of this proposed project are to:

- Inform policy change on WWP and SLR decision-making.
- Establish a correlation between changes in freeze-thaw and winter pavement distress.
- Develop initial guidelines on approximate cost implications of changes in damage and resulting repair/maintenance.

IV. COST ESTIMATE

$150,000

V. RESEARCH PERIOD

24 months

VI. URGENCY AND PAYOFF POTENTIAL

As the climate changes, transportation agencies are performing additional maintenance and repair but do not have any additional programmed budget for this. More accurate seasonal load restriction guidelines would reduce the need for some of that maintenance and repair. Additionally, prediction of future changes in freeze-thaw patterns will enable transportation agencies to better plan for potential cost increases based on changes in pavement deterioration curves.

VII. PRELIMINARY LITERATURE SEARCH

Several studies have been conducted to establish guidelines for setting seasonal load restrictions. Some agencies have used quantitative approaches to monitor spring thaw processes, such as measuring pavement deflections with a falling weight deflectometer, and/or installing sensors beneath roadways to monitor subsurface temperature and/or moisture profiles during the winter freeze and spring thaw periods. Such research has been reported by Van Deusen et al. (1998), Ovik et al. (2000), Kestler et al. (2007), Tighe et al. (2007), Marquis (2008), Eaton et al. (2009), Bradley et al. (2012), and Miller et al. (2013).

The subject of this Problem Statement would differ from and add to existing studies by addressing changes in freeze-thaw patterns that will result from a changing climate. In northern New England, the frozen period has already shortened by approximately one week, and within 20 years, the typical winter freeze period is estimated to shorten by an additional two weeks (Daniel et al., 2017). It is possible that these regions could routinely have no frozen period by 2070. In addition, many of the New England areas with posted roads are well known for their year-to-year variability, which will likely increase in the future. As state transportation agencies begin to plan for and adapt to climate change, these critical issues will need to be addressed in order to rationally apply WWPs and SLRs, and to more efficiently plan for roadway deterioration and repair costs.

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Kestler, M., R. Berg, B. Steinert, G. Hanek, M. Truebe, and D. Humphrey. 2007. *Determining When to Place and Remove Spring Load Restrictions on Low-Volume Roads: Three Low-Cost Techniques*. Transportation Research Record: Journal of the Transportation Research Board, No. 1989, pp. 219–229.

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Ovik, J., J. Siekmeier, and D. Van Deusen. 2000. *Improved Spring Load Restrictions Guidelines Using Mechanistic Analysis.* Report No. 2000-18. July. Minnesota Department of Transportation, St. Paul, MN.

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Van Deusen, D., C. Schrader, D. Bullock, and B. Worel. 1998. *Springtime Thaw Weakening and Load Restrictions in Minnesota*. Paper No. 98-0621. Transportation Research Record: Journal of the Transportation Research Board, No. 1615, pp. 21–28.

NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

Due to netc@ctcandassociates.com by January 25, 2019

I. PROBLEM TITLE

A suggested title in as few words as possible.

Climate Change Effects on Inland Groundwater and Implications for Transportation Infrastructure

II. RESEARCH PROBLEM STATEMENT

A statement of the general problem or need. One or more paragraphs are sufficient.

Climate change is affecting precipitation patterns as well as temperature, sea level, and the incidence of extreme weather events, and all of these changes have implications for transportation infrastructure and systems. In recent years, there have been several efforts to understand how climate change is affecting groundwater levels, particularly in coastal areas. We have evidence that groundwater levels are changing and increasingly impacting roads and other infrastructure in coastal areas as a result of sea-level rise related to climate change. However, we lack the same level of understanding of how groundwater levels may be changing in environments further inland as a result of precipitation changes and precipitation-driven flooding, and the extent to which these changes might affect transportation infrastructure. Research is needed to help transportation planners and decisionmakers understand the current state of knowledge regarding how climate change might affect inland groundwater levels, and ascertain whether those changes have the potential to reduce the service life of inland transportation infrastructure. The outcomes of this research will help elucidate the need to adjust investment priorities based on inland precipitation changes, which will ultimately inform transportation planning and asset management.

III. RESEARCH OBJECTIVES

A clear and specific statement of the objectives that are to be met by the research in order to adequately address the research problem.

The extent to which future precipitation patterns may affect inland groundwater levels is currently unknown. This project would aim to develop a preliminary understanding of the state of research that could inform this topic and potential impacts for transportation assets. Specifically, this project would aim to address the following questions:

1. What trends have we already observed relating to inland groundwater level changes, and what is the state of research between precipitation changes (related to climate change) and groundwater levels inland? This question would be addressed by analyzing data from the USGS Groundwater Watch and other data, and by conducting a literature review.

2. Which classes of transportation assets are most at risk from groundwater rise? What are the implications for risk management? These questions would be answered by conducting a literature review, outreach to transportation agency operations and maintenance staff, and analysis of results.

Using results from this research, the project would also aim to identify additional, more in-depth research needs (if any) to inform transportation decision making and investment priorities for non-coastal areas likely to experience future groundwater changes as a result of climate change.

IV. COST ESTIMATE

An estimate of the funds necessary to accomplish the objectives described in Section III.

$100,000

V. RESEARCH PERIOD

An estimate of the number of months necessary to complete the project, including preparation of a Draft Final Report and its review by the NETC project Technical Committee (90 days), and the preparation and printing of the Final Report.

20 months

VI. URGENCY AND PAYOFF POTENTIAL

A description of the urgency of the need for this research in relation to the transportation needs of the six New England States and, if possible, the potential for payoff in benefit/cost terms.

This research topic is currently a "known unknown." Recent research suggests that rising groundwater levels in coastal areas can undermine road stability and service life. Trends toward increasing precipitation are expected to continue in the New England region with climate change.[1] As a result, average groundwater levels *inland* are also likely to increase. But questions exist regarding the magnitude of those potential increases, whether those increases will be of short duration or more long term, and whether there could be major implications for roads and other transportation infrastructure in New England. It is important to gain an understanding of the extent to which this may become a concern for transportation assets in the future and to identify what additional research is needed to make changes in transportation planning, programming, and asset management. The research has the potential to significantly inform risk-based asset management planning, which is required under the performance management framework established by the Moving Ahead for Progress in the 21st Century Act (MAP-21).

VII. PRELIMINARY LITERATURE SEARCH

To avoid duplicating research already published or in progress, the submitter of the Problem Statement will perform a brief literature search prior to submitting the Problem Statement. This literature search can be conducted using the Transportation Research Board's TRID database, available at https://trid.trb.org/. The TRID database contains information on completed research as well as research in progress.

[1] https://science2017.globalchange.gov/chapter/7/

Attach a brief summary (1-3 paragraphs) *of the results of this literature search to the Problem Statement. The summary should describe how the subject of this Problem Statement would differ from or add to existing studies.*

A preliminary literature search on the TRID database and elsewhere for research relating to climate change, precipitation, and groundwater indicates that there are a number of studies on one or two of these topics in the transportation context, but there do not appear to be studies looking specifically into the links between climate change and effects of changing precipitation patterns on groundwater levels, particularly in the transportation context.

Most studies on how climate change is expected to impact groundwater focus on groundwater resource management, rather than potential impacts on infrastructure (Green 2016 and references therein). Dudley and Hodgkins (2013) evaluated historical trends of groundwater levels in New England, and found a strong correlation with stream flow but relatively weak correlation with rainfall records. Historically, snowmelt has been a major driver for groundwater levels in New England (Dudley et al., 2010). There appear to be few, if any, direct studies of predicted climate change impacts on inland groundwater levels in New England.

There are existing studies relating to climate change and the impacts of extreme precipitation events and changing precipitation patterns on transportation asset classes and systems, and in some cases, there are evaluations of adaptation options. There are also a handful of studies relating to climate change and *sea-level rise* impacts on groundwater levels and the corresponding implications for transportation infrastructure (pavements in particular). For example, Knott et al. (2017 and 2018) have examined the likely decreases in pavement service life in the future based on groundwater modeling for coastal New England areas, and potential design changes to extend service life under future groundwater scenarios. However, there seems to be a lack of study of the intersection of these areas – precipitation changes driven by climate change (with an inland/non-coastal focus in particular) and the resulting changes in groundwater levels, along with implications for transportation systems and assets.

The following studies were identified in the preliminary literature search as representative of the extent of research relating to this topic, but none of them specifically address the research objectives of this project.

- Dudley, R.W., G.A. Hodgkins, J.B. Shanley, and T.J. Mack (2010). Quantifying effects of climate change on the snowmelt-dominated groundwater resources of northern New England: U.S. Geological Survey Fact Sheet 2010-3104, 4p. https://pubs.usgs.gov/fs/2010/3104
- Dudley, R.W. and G.A. Hodgkins (2013). Historical groundwater trends in northern New England and relations with streamflow and climactic variables. *Journal of the American Water Resources Association*, 49(5), 1198-1212. https://doi.org/10.1111/jawr.12080
- Federal Highway Administration (2016). Temperature and Precipitation Impacts on Cold Region Pavement: State Route 6/State Route 15/State Route 16 in Maine. U.S. Department of Transportation. Available at https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/me_freeze_thaw/fhwahep17019.pdf

- Green, T.R. (2016). Linking Climate Change and Groundwater. In: Jakeman, A.J., O. Barreteau, R.J. Hunt, J.D. Rinaudo, and A. Ross (eds). Integrated Groundwater Management. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-23576-9_5
- Gudipudi, P.P., B.S. Underwood, and A. Zalghout. (2017). Impact of climate change on pavement structural performance in the United States. *Transportation Research Part D: Transportation and Environment*, 57, 172-184. https://doi.org/10.1016/j.trd.2017.09.022
- Knott, J.F., M. Elshaer, J.S. Daniel, J.M. Jacobs, and P. Kirshen. (2017). Assessing the effects of rising groundwater from sea level Rise on the Service life of pavements in coastal road infrastructure. *Transportation Research Record*, No. 2639(1), 1-10. https://doi.org/10.3141/2639-01
- Knott, J.F., J.S. Daniel, J.M. Jacobs, and P. Kirshen (2018). Adaptation planning to mitigate coastal-road pavement damage from groundwater rise caused by sea-level rise. *Transportation Research Record*, *2672*(2), 11–22. https://doi.org/10.1177/0361198118757441
- Lu, D., S.L. Tighe, and W-C. Xie (2018). Pavement risk assessment for future extreme precipitation events under climate change. *Transportation Research Record*, 2672(40), 122–131. https://doi.org/10.1177/0361198118781657
- Thiam, P.M., G. Dore, J-P. Bilodeau (2013). Effect of the future increases of precipitation on the long-term performance of roads. Proceedings of the Ninth International Conference on the Bearing Capacity of Roads, Railways and Airfields, 2, 545-554. https://www.ntnu.no/ojs/index.php/BCRRA/article/view/2661

VIII. RESEARCH KEY WORDS

Provide a list of key words that can be used to conduct an additional search of the TRID database for related research. To the maximum extent possible, key words should be selected from the Transportation Research Thesaurus (http://trt.trb.org/).

asset management, climate change, precipitation, groundwater, groundwater recharge, weather and climate, New England, pavement performance

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NOTE: To expedite the processing of Research Problem Statements, NETC requires submittal by e-mail (netc@ctcandassociates.com) by January 25, 2019.

NEW ENGLAND TRANSPORTATION CONSORTIUM
RESEARCH PROBLEM STATEMENT

I. PROBLEM TITLE

Changing Winter Maintenance and Road Salt Application and Impacts Costs

II. RESEARCH PROBLEM STATEMENT

Winter maintenance is a major challenge to northern states. Changing climate is likely to change salt usage and potentially post significant costs to DOTs. Impacts with associated costs include

1) Usage of salt – material costs
2) Equipment degradation – corrosion
3) Drinking water well impacts – well replacement, treatment, extension of water lines
4) Public health
5) Environmental
6) Public property – cars, trucks, etc

DOT financial planning will be improved by projections of winter weather and associated salt applications.

III. RESEARCH OBJECTIVES

This project seeks to understand how winter maintenance and associated costs and impacts are likely to change in the future.

The main goals of this proposed project are to:

- Develop data sets
  - Historic salting events over past decade of highly managed winter maintenance systems and associated salt application
  - Private and public well impacts and associated costs over time
  - Future winter weather events
- Develop models
  - Salt application as function of weather or winter severity
  - Well impacts and costs as function of salt application
- Project winter events that will trigger salt application, salt usage and associated costs and impacts over possible future climates.

IV. COST ESTIMATE

$150,000

V. RESEARCH PERIOD

24 months

VI. URGENCY AND PAYOFF POTENTIAL

Results of this research will provide estimates of cost impacts to DOTs from winter maintenance under existing management models for projected future climates. This will enable DOTs to refine long term planning for future maintenance and anticipate the likelihood of future impacts relative to impacts already experienced.

VII. PRELIMINARY LITERATURE SEARCH

Numerous studies have determined that New England winters have already changed and are projected to continue to change in the future (Hayhoe 2007, Burakowski 2008). In New England, winters are warming and the frozen period has already shortened and within 20 years, the typical winter freeze period is projected to continue to shorten in the future (Daniel et al., 2017). Winter precipitation is increasingly occurring as rain and decreasingly snowfall, particularly in northern New England and Coastal New England regions. Despite the warmer and shortened winter season, the number of freeze-thaw cycles will likely remain constant reflecting fluctuating temperatures throughout the winter, periods of near zero temperature will persist, and consecutive minor winter precipitation events will likely increase.

While most studies focus on extreme events and average conditions, winter maintenance needs to consider individual events because different types of events (i.e., Light snow, Light snow with period(s) of moderate or heavy snow, Moderate or heavy snow, Frost or black ice, Freezing rain, and Sleet) trigger differ winter maintenance responses (Ketcham et al. 1996). Any change in the magnitude or frequency of snowfall events within a certain temperature range will have significant impacts on the type, magnitude, frequency, and timing of winter-road maintenance activities (Sato 2008, Mahoney et al. 2015). When impacts for transportation and its infrastructure during the winter season are concerned, weather events occurring in the near-zero temperature range potentially are the most problematic because they include sleet and freezing rain and hybrid events with changing precipitation (e.g., rain to freezing rain to snow) can potentially cause major problems and require elevated rates of chemical treatment (Ketcham et al. 1996, Levelton Consultants 2007, CTDOT 2015). What are important to the current research needs statement are changes to the number of small, seemingly manageable events that cumulative cause major issues for receiving waters. Increasing minor "salting" events may be worse for the receiving waters (e.g., salt TMDLs and wells) than an individual heavy snowfall event due to the required level of winter-road maintenance activities (Sato 2008).

Winter maintenance impacts on receiving waters and private and public drinking water supplies are well documented (Corsi et al. 2010, Schuler et al. 2018). In the Northeast, increases in roadways and deicer use for humans have led to increased degradation of fresh water throughout the region (Kaushal et al. 2005, Pieper et al. 2018). New England DOTs are frequently responsible for implementing solutions for wells impacted by road salt including connecting to public water, drilling new well (not always feasible), and replacing plumbing/appliances. DOTs programs include MassDOT's Salt Remediation

Program, NHDOT's Well Replacement Program, the MaineDOT Well Replacement Program, and CTDOT in-house procedure for addressing road salt impacts. While anecdotal evidence suggests the frequency and costs of these programs is increasing, these impacts have not been documented. In the future, changing winters and winter maintenance may cause a significant increase in DOT winter maintenance activities that is currently unanticipated and unrecognized. Current practices may very well be unsustainable. This research will help develop information needed for the development of winter maintenance practices sustainable in the face of a changing northeastern climate.

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ICNet volunteers – Jennifer Jacobs, Charlie Hebson, Roger Appleton, Julie Eaton, Elizabeth, Nathan Robbins