APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) FOR TRANSPORTATION AND CLIMATE CHANGE

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REPORT NOTES AND ACKNOWLEDGMENTS

The U.S. Department of Transportation John A. Volpe National Transportation Systems Center (Volpe Center), in Cambridge, Massachusetts, prepared this report for the Federal Highway Administration's (FHWA) Office of Planning. The project team consisted of Gina Filosa and Carson Poe of the Program and Organizational Performance Division, and Catherine Duffy of URS Corporation. Mark Sarmiento of FHWA's Office of Planning provided project oversight.

The project team reviewed relevant literature and conducted an internet scan of GIS applications that relate to climate change to identify potential case studies. The case studies presented are based on telephone discussions that the project team held with project contacts, as well as relevant supplemental materials that interviewees provided. Interview contacts reviewed draft case studies to suggest revisions and provide additional information as needed. The Volpe Center project team wishes to thank the staff members from the organizations across the country that provided their insights for and review of this report. The time they graciously provided was fundamental in preparing the case studies presented. Contributors are listed in Appendix A.

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EXECUTIVE SUMMARY

Global climate change's potential impacts on infrastructure create some of the most significant and challenging issues facing transportation planners and asset managers today. Despite uncertainty regarding the scope and magnitude of future climate change effects and their associated impacts, some transportation agencies have begun to factor climate change considerations into their decision-making processes. Geographic information systems (GIS) have proven to be a useful tool in transportation agencies' efforts to analyze and address climate change as it pertains to transportation facilities and operations. As such, this report synthesizes the findings from eight case studies that describe how select organizations are developing and applying GIS tools to implement climate change mitigation and adaptation strategies.

Example observations from the case studies include:

- The use of GIS to support climate change analysis is just beginning to emerge in the transportation field. The use of GIS tools for climate change would likely become more prevalent in the transportation sector if the frequency and intensity of extreme weather events increases thus influencing transportation agencies to seek additional capabilities to spatially analyze or predict the extent and potential damage caused by these events. In the short term, using GIS to support climate change adaptation strategies will be more widespread as transportation agencies will need to develop strategies to strategies to mitigate or avoid the anticipated impacts of climate change. In areas that have established GHG emission targets, transportation agencies can utilize GIS to help identify effective transportation strategies to help reach the overall GHG reduction goals.

- While there is consensus that climate change will have impacts on the transportation system, there are many uncertainties regarding the scale and scope of those impacts. Such uncertainty presents a challenge for transportation decision-makers in determining how best plan for or adapt to climate change. GIS tools can help planners evaluate various climate change impact scenarios and identify which assets are most vulnerable to the threats posed or would be most expensive to repair or replace.

- GIS technologies can provide a visual framework for conceptualizing and understanding how transportation contributes to a region's GHG emissions profile. This ability could help lead planners to develop more effective GHG reduction policies.

- Transportation agencies may need to rely on outside sources to provide downscaled, location-specific, data that provide fine-scale climate effects projections, which are necessary to determine project level impacts. Transportation agencies should coordinate with research institutions and government agencies to identity appropriate data sources.

- Transportation agencies should promote efforts to identify areas where restoration or maintenance of ecosystems may be able to reduce highway maintenance or repair costs. This proposed activity should include developing GIS layers in coordination with state, regional, and local resource and transportation experts to locate or devise ways to locate and value these areas.

INTRODUCTION

This report describes the current practice and application of geographic information systems (GIS) technologies for integrating climate change into the transportation decision-making process. It examines how select state, regional, and local agencies are using GIS to analyze, mitigate, and adapt to the potential effects and impacts of climate change on the transportation sector.

BACKGROUND

The potential impacts of global climate change on infrastructure create some of the most significant and challenging issues facing transportation planners and asset managers today. Given the uncertainty regarding the scope and magnitude of future climate change effects and their associated impacts, the transportation community's response to climate change has broadly fallen into two categories: mitigation and adaptation. Mitigation involves developing measures aimed at reducing greenhouse gas (GHG) emissions levels associated with transportation operations. Adaptation involves measures aimed at increasing the resiliency of the transportation network or specific infrastructure assets when confronted with expected, or actual, climate change effects.

Climate change analysis, at its core, is geospatial activity. Historical weather trends and future weather predictions are mapped, as are the locations of where climate change effects are expected to most likely be expressed. In turn, hypothetical climate scenarios are portrayed on maps alongside estimations of the extent of potential impacts to human and natural infrastructure. Although Federal regulations do not currently require that transportation agencies address climate change in transportation planning or NEPA documents, the Council of Environmental Quality has recently released draft guidance on when and how Federal agencies must consider GHG emission and climate change in their proposed actions.[1] Despite the lack of Federal regulation in this area, many state, regional, and local governments have established requirements or guidance on addressing climate change as part of the transportation planning or project development process, further extending the potential utility of geospatial tools in climate change analyses.

As such, GIS is increasingly being applied at transportation agencies for climate change-related assessments. Currently, the use of GIS for these purposes is not as widespread as for other transportation-related purposes. In particular, GIS, which enables users to manage, analyze, and quickly present geographically referenced information, has been used at transportation agencies to develop and assess climate change mitigation and adaptation strategies. Since GIS can translate complex transportation data into maps or applications that are visually appealing, meaningful, and accessible to non-technical audiences, it has been a powerful resource for considering climate change's uncertain but inherently spatial effects.

In the GIS case studies that follow, climate change mitigation and adaptation are addressed separately. The GIS for climate change mitigation cases describe how select agencies have used GIS tools to analyze the GHG emissions associated with projects or transportation plans, as well as and to identify opportunities to reduce or remove GHG emissions from the atmosphere. Examples highlighted include:

- Sacramento Area Council of Governments (SACOG). SACOG developed a custom GIS model to analyze land uses and transportation systems in order to quantify transportation-related GHG emissions.

- FHWA's Carbon Sequestration Pilot. FHWA and the U.S. DOT Volpe Center used a GIS analysis to assess land cover on the National Highway System's right-of-way (ROW) to determine how much atmospheric carbon highways might sequester on a national scale.

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[1] CEQ. NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions (February 2010): http://ceq.hss.doe.gov/nepa/regs/Consideration_of_Effects_of_GHG_Draft_NEPA_Guidance_FINAL_02182010.pdf

- King County, Washington’s Carbon Sequestration Assessment. King County developed a GIS application to identify opportunities to develop carbon sequestration sites within the County road ROW, which would have served to offset GHG emissions.

The GIS for climate change adaptation cases describe how select agencies have used GIS tools to identify transportation infrastructure that is vulnerable to the climate change effects, such as sea level rise and increased frequency and intensity of storm events. Examples highlighted include:

- King County, Washington’s Dockton Road Preservation Project. King County used GIS to assess the impacts of rising sea levels to inform project design.

- Coastal Adaptation to Sea Level Rise Tool (COAST). COAST utilizes GIS to visually present the economic impacts associated with different climate change scenarios.

- Cape Cod Sea Level Rise Expert Elicitation. GIS was used to facilitate the identification of areas considered vulnerable to climate change effects.

- California Essential Habitat Connectivity Project. Caltrans has been used GIS to identify existing blocks of intact habitat need to be maintained as future wildlife corridors.

- Buncombe County (North Carolina) Multi-Hazard Risk Tool. The tool is an online mapping application used to assess and report on hazard impacts in the county.

USING GIS FOR CLIMATE CHANGE MITIGATION

The relationship between transportation and global climate change has become an increasingly important focus for the transportation community in recent years. In 2006, the transportation sector directly accounted for approximately 28 percent of total GHG emissions in the United States, making it the second largest source of GHG emissions in the country behind electricity generation. Many state, regional, and local transportation agencies analyze the GHG emissions associated with their transportation systems and develop targets and strategies for reducing those emissions. In some cases, such actions stem from legislative requirements, while others are in response to policies that agency leadership has established or interest from the public. The following cases illustrate some current efforts to use GIS to help mitigate the effects of climate change.

SACRAMENTO AREA COUNCIL OF GOVERNMENTS' GIS BASED METHOD FOR GHG EMISSION ANALYSIS

In 2006, California passed its Global Warming Solutions Act, which established plans, incentives, techniques, and regulations to reduce GHG emissions. Two years later, Senate Bill 375, which requires the California Air Resource Board (ARB) to set regional GHG targets for emissions associated with the automobile and light truck sectors, was signed into law. The ARB recently established emission targets for each region covered by the State's 18 metropolitan planning organizations (MPOs), and each MPO is now tasked with creating a "sustainable communities strategy" to demonstrate how the region will meet its GHG reduction target through integrated land use, housing and transportation planning.

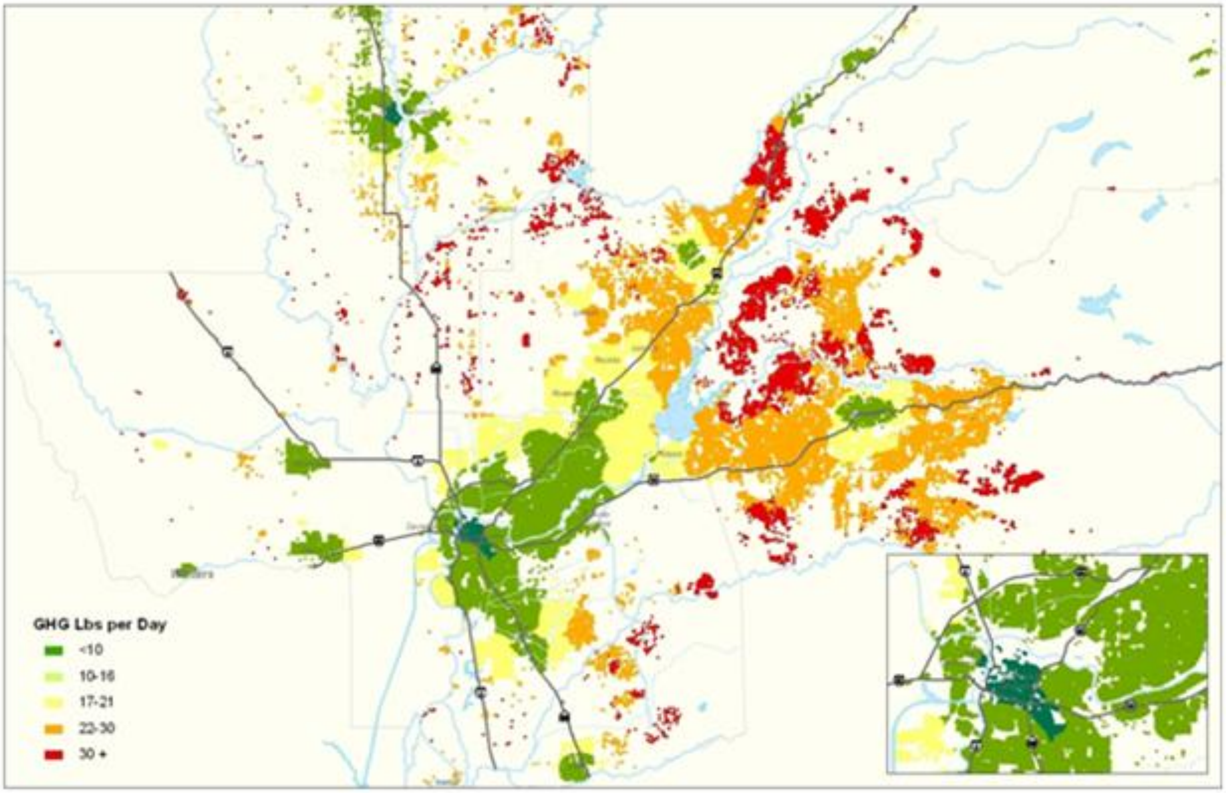
For the Sacramento Area Council of Governments (SACOG), the metropolitan planning organization (MPO) for the Sacramento region, the ARB recommended a seven percent reduction target for 2020 and a 16 percent reduction target for 2035. SACOG is currently developing a land use and transportation plan to achieve its GHG emissions targets. As part of this effort, SACOG developed a custom parcel-based travel model to analyze the relationship between land use and transportation-related GHG emissions.

Previously, SACOG's land use and transportation model used zones as the primary unit of measurement; however, that unit of analysis did not provide enough detail to assess the land use impact on travel behavior. In place of zones, SACOG developed a parcel-based travel model to better capture this relationship. The new model allows SACOG to bring the analysis into a GIS using parcel/point land use data buffered at ¼ to ½ square miles. This more detailed method allows SACOG to quantify the transportation-related GHG emissions associated with each buffered parcel, which provides a more accurate picture of the interaction between land use and transportation.

The GIS data layers used in this analysis included a parcel based land use layer for the region. This layer needed to include a regionally unique identifier that was consistent with that used in the parcel-based travel model in order to correlate the two sets of data. The travel model includes an output of vehicle miles travelled (VMT) for each parcel, that is joined with an estimate of emissions created per mile for a typically fleet of vehicles on the road for the year you are modeling. For the Sacramento region, this data is provided by the state of California and the Emissions Factors (EMFAC) model.

SACOG mapped the travel model output to visually depict where transportation emissions are highest. In the Sacramento region, these maps show a clear correlation between the built environment and GHG emissions. For example, areas located further from employment centers have higher per capita GHG emissions from transportation (see Figure 1).

Figure 1: Per Capita Transportation-Related GHG Emissions



The image highlights the correlation between land use and transportation GHG emissions.

Noting the visual power of the maps, SACOG has used them as a public involvement tool to illustrate the connection between land use and transportation planning, and educate the public on how these plans can contribute to or help reduce transportation –related GHG emissions. The maps are also used internally to identify locations to target GHG reduction strategies.

Having a better understanding of how land use decisions impact transportation-related GHG emissions enables SACOG to develop more effective GHG reduction policies. As a next step, SACOG will integrate the model with their land use model, PLACE3S. Once integrated, SACOG staff will be able to analyze the impacts that specific land use changes at the parcel level have on transportation-related GHG emissions.

FEDERAL HIGHWAY ADMINISTRATION CARBON SEQUESTRATION PILOT PROGRAM

In 2008, the Federal Highway Administration (FHWA) established the Carbon Sequestration Pilot Program (CSPP) to assess the feasibility of maintaining and measuring FHWA's Rights of Way (ROW) for carbon sequestration on a national scale. Carbon sequestration, the process of removing carbon from the atmosphere and storing it a reservoir, can be used to offset emissions, meet State greenhouse gas emission reduction objectives, or used to sell carbon credits should a carbon market be established.[2] The CSPP measured the types of land cover on FHWA unpaved ROW to determine the amount of carbon

[2] Many State DOTs recognize that ROW has values that extend beyond the safety, operations, and maintenance of highway operations. However, few have developed land-management plans that focus on the value of the ROW for wildlife habitat, nutrient reduction, and other ecosystem services. If carbon markets are established as a means to reduce greenhouse gas emissions, the carbon sequestered from the atmosphere by vegetation growing in the ROW might be sold as "credits" to companies required to reduce their emissions.

sequestered, the potential for future capture, and the corresponding potential amount of revenue for this sequestration.

FHWA used two GIS-based methodologies to analyze National Highway System (NHS) ROW: a transect analysis and a polygon analysis. For the transect analysis, point samples were generated by overlaying a 1-mile grid across the National Highway System. A point was drawn every place the grid intersected the NHS. Using a random sample of the generated points, the project team analyzed ROW property widths by drawing transect lines in the GIS perpendicular to the highway and between property boundaries. Using these lines, the project team used the National Agriculture Imagery Program (NAIP) aerial imagery to identify visually unpaved and paved areas and to estimate transect widths for grass, shrubs, trees, and grass/trees mixtures within the ROW. This sample information was used to develop estimates of land cover for the entire NHS. The second method, the polygon analysis, analyzed 300-foot diameter circle polygons around the random points chosen for the transect analysis. The project team used land cover data from the Multi-Resolution Land Characteristics Consortium's (MRLC) 2001 National Land Cover Database (NLCD) to determine the type of land cover within each of these polygons for a more refined analysis of the land cover within these points. The polygon analysis can be used as a substitute for the transect model; however, it is more appropriately used as a refining second step, once the transect analysis is completed.

The results of this analysis are available in "Estimated Land Available for Carbon Sequestration in the National Highway System," a report that FHWA and the Volpe Center jointly released in 2010.[3] This acreage total is the first known data-based estimate for highway ROW acreage for both individual states and the nation. The project team estimated the NHS ROW has approximately 91 million metric tons (MMT) of carbon currently sequestered in vegetation and is currently sequestering approximately 3.6 MMT of carbon per year, or 1.06 metric tons of carbon per acre per year. This equals the annual carbon dioxide emissions of approximately 2.6 million passenger cars. According to the researchers, the availability of ROW property data was highly variable and, thus, was the major limiter in making these estimates.

Data layers used is the GIS analysis of NHS ROW:

- NHS roadway network
- NAIP Program aerial imagery
- Property maps from Minnesota, Arizona, Montana, Washington, Utah, Alabama, South Carolina, Michigan, and Delaware DOTs
- Multi-Resolution Land Characteristics Consortium's (MRLC) 2001 National Land Cover Database
- MRLC's Retrofit Land Cover Change Data

KING COUNTY'S CARBON SEQUESTRATION ASSESSMENT

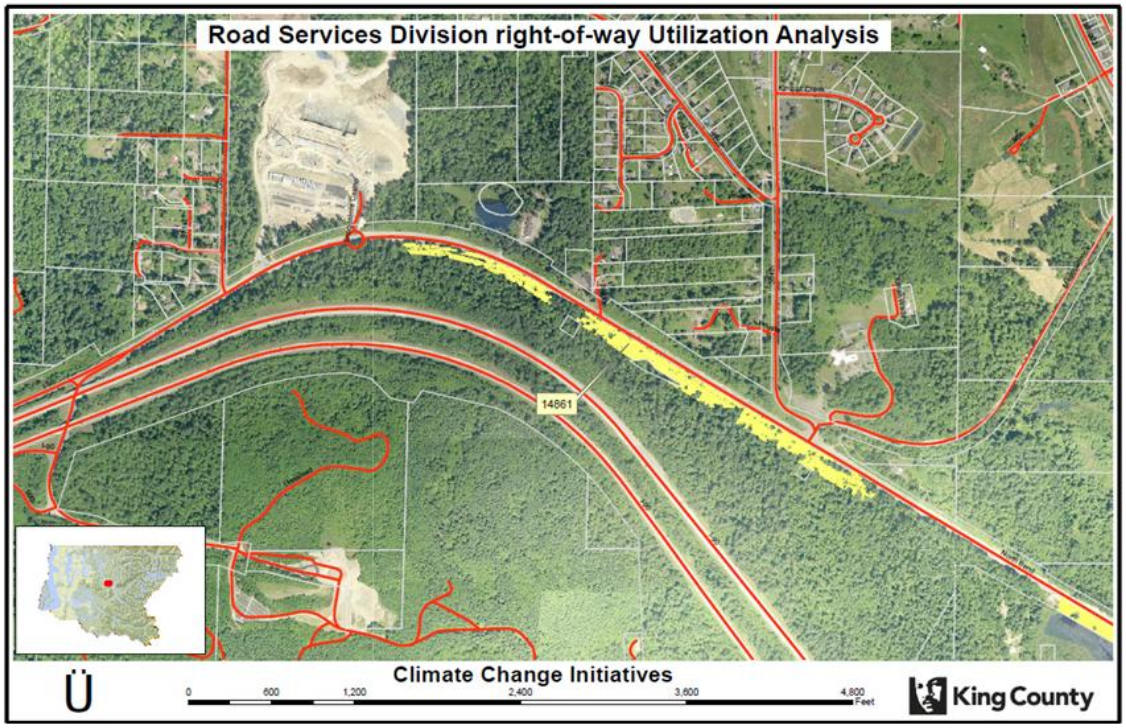
Over the past few years, King County, Washington has been developing creative solutions to address climate change and GHG mitigation. In 2006, the King County Executive, Ron Sims, issued Executive Orders on Global Warming Preparedness, which directed King County to reduce GHG emissions and prepare for anticipated climate change impacts. In response to this order, in 2008, the King County Road Services Division (RSD) developed a GIS application to examine the extent and feasibility of using undeveloped road right-of-way to provide for carbon sequestration, similar to FHWA's study, and other potential GHG reduction or low impact development measures. RSD first ran a pilot model on a township in King County, and in 2009, ran the same model for the entire county.

RSD conducted an overlay analysis to identify locations that met the agency's criteria for appropriate carbon sequestration sites (see Figure 2). The criteria included owned right-of-way land with pervious

[3] The report is available online at www.fhwa.dot.gov/hep/climate/carbon_sequestration/index.htm. As part of the overall project, the Volpe Center and FHWA also developed a Highway Carbon Sequestration Estimator as a decision-support tool to help state DOTs assess the return on investment for various carbon sequestration scenarios. The decision-support tool is available upon request by contacting Carson Poe at carson.poe@dot.gov.

surfaces, not in areas suitable for development or an areas identified as critical, and at least half an acre in size. Areas were considered critical based on data layers indicating presence of water bodies, wetlands or watercourses, landslide or erosion areas, coal mine areas, slopes over 40°, 100-year floodplain or floodway, or adjacent to RSD owned property. The team drew polygons over potential sequestration areas and calculated the area through the GIS model to determine if the area met the minimum 0.5-acre size. Land meeting all criteria except size would be considered for low impact development, but not carbon sequestration.

Figure 2: Potential ROW for Carbon Sequestration
Source: King County Road Services Division



The GIS overlay analysis identified potential carbon sequestration sites. Potential sites are highlighted in yellow on the map.

The model identified approximately 152 sites that had potential for carbon sequestration. RSD staff field-tested a representative sample of these sites in order to characterize the value/accuracy of the GIS tool and to furter assess opportunties available on these lands. Since not all of the agency's GIS data reflected current land conditions, staff reviewed aerial photographs of the locations to determine which sites appeared undeveloped and which sites may be appropriate for critical area restoration. After a review of the aerial photographs, RSD staff identified ten sample locations to visit for field verification,

The agency's site visits determined that only two of the10 most promising sites were conducive for tree planting. As a result, RSD determined that the County's undeveloped ROW areas do not provide a significant opportunity for carbon sequestration through tree planting. Although the GIS model and analysis did not result in carbon sequestration through tree planting, the sites identified may be used for environmental mitigation, low impact development and/or soil carbon sequestration in the future.

Data layers used in the GIS analysis of carbon sequestration sites:

- Known and prescriptive rights-of-way
- Developed road width
- Adjacent RSD real property
- Impervious surface areas

- Aquatic and wetland critical areas
- Aquatic and wetland critical areas buffer areas
- Landslide and earth hazard areas
- Slope profiles
- Ortho and elevation data
- LIDAR data

USING GIS FOR CLIMATE CHANGE ADAPTATION

While lowering transportation GHG emissions is an important strategy for reducing the long-term effects of climate change, mitigation will likely do little in the short-term to alter climate change processes already underway. Climate change stands to have effects on transportation infrastructure in a variety of ways. For example, increased temperatures can accelerate the degradation of infrastructure; increased precipitation may increase short-term flooding of roadways; sea level rise may inundate existing infrastructure; and, increased storm intensity and the number of events may lead to greater service disruption and infrastructure damage (U.S. Climate Change Science Program, 2008).[4] Such impacts pose safety and economic risks for the transportation sector and the public.

As a result, transportation agencies have begun to consider the effects of climate change in the way they plan, design, and construct projects. They are doing so in order to minimize impacts and increase the resiliency of the transportation system. There are five primary actions for transportation facilities and services:

- Repair and maintenance
- Reconstruction/strengthening
- Relocation
- Abandonment
- Improve redundancy

These actions differ in cost and capital investments required and have varying economic, social, and environmental implications. For example, while repair and maintenance can have low short-term capital but high long-term costs due to recurrence of the problem over the long-term. Generally, the appropriate adaptation action will depend on the specific context of the transportation facility or service being considered and the risk the transportation agency and its stakeholders are willing to accept. The highest priorities are those that face the highest risk and are of critical importance.

Transportation agencies are using GIS tools to help in the effort to identify transportation infrastructure vulnerabilities and those assets considered priorities. Such tools are also being used to evaluate potential adaptation strategies to address future climate conditions. For example, the *Impacts of Climate Variability and Change on Transportation Systems and Infrastructure – Gulf Coast Study* presents a preliminary assessment of climate change risks to transportation systems in the Gulf Coast area of the United States using a variety of GIS data sets.[5]

The following cases highlight additional examples of how GIS is being used to support climate change adaptation.

KING COUNTY'S DOCKTON ROAD PRESERVATION PROJECT

In 2009, King County, Washington began seeking ways to consider the future predicated impacts of climate change in the design of transportation projects. The County chose the Dockton Road Preservation project as a case study on how to incorporate more detailed analysis of future climate conditions in its design.

Dockton Road is located on the east coast of Vashon Island, one of the most tidally influenced locations in King County. The road, constructed in 1916, is supported by a seawall built on the beach. Over the years, bluff erosion, landslides, storm events, and associated seawall failures has resulted in frequent temporary closure of the road. The original timber seawall has now deteriorated to the point where regular, small-scale maintenance repairs are no longer effective. As a result, the King County Road Services Division is studying possible transportation alternatives to address the problem of the failing

[4] U.S. Climate Change Science Program (2008). Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.

[5] The Gulf Coast Study is available at www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf.

seawall. Since the project location is greatly impacted by coastal processes, the County is considering how climate change may affect those processes as part of the projects design.

As an initial step in its study, the Environmental Unit of the King County Road Services Division used ESRI's ArcMap as an early screening tool to assess the risk to the project area from expected sea level rise and other hydrology changes given different climate change scenarios.

The Environmental Unit engaged a consultant to help identify an appropriate sea level rise projection for the Puget Sound area. The contractor compared estimates of future sea level rise in Puget Sound developed using three different methods. The methods were:

1. An extrapolated long-term trend in local relative sea level rise based on the National Oceanic and Atmospheric Administration's (NOAA) measured water level data from 1899 to 2006 for the Seattle, Washington station.
2. A low, intermediate, and high estimate for sea level rise based on the U.S. Army Corps of Engineers (USACE) guidance in Circular 1165-2-211, *Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs.*
3. A low, medium, and high estimate for sea level rise developed by the University of Washington Climate Impact Group (CIG). The CIG method takes into account the combined effects of thermal expansion, cryospheric contributions[6], atmospheric circulation, and vertical land movement.

Based on its analysis of the different sea level rise projection methods, the County's consultants recommended using the CIG medium projection for sea level rise for the Dockton Road project. Using the recommended methodology, the consultant calculated sea level rise estimates for the years 2010 to 2100.

Figure 3: Dockton Road Screening Level Map
Source: King County Road Services Division

The figure shows where estimated sea level elevations (blue lines) intersect the road surface elevation.

[6] Melting of glaciers and ice caps is presently, and is projected to remain, the largest cryospheric contribution to sea level rise.

The calculated sea level rise estimates were entered into GIS to assess potential impacts to Dockton Road and the seawall. The screening level analysis of potential sea level rise was a simple join model of projected sea level elevation relative to the road to identify where a predicted sea level elevation would extend over the road surface (see Figure 3). The GIS analysis showed that the road and seawall were vulnerable to future sea level rise impacts. Based on this conclusion, the County decided to conduct more detailed modeling and analysis on storm wave effects and coastal flooding potential to assess the impacts on the project area.

The County is currently evaluating project alternatives, which range from a road abandonment alternative to construction of a new roadway and seawall. A preferred alternative is expected to be chosen in early 2011.

COASTAL ADAPTATION TO SEA LEVEL RISE TOOL

The New England Environmental Finance Center, with support from Battelle Memorial Institute and other organizations, developed the Coastal Adaptation to Sea Level Rise Tool (COAST) to assess the economic costs and benefits associated with particular climate change adaptive actions to assist entities in selecting appropriate strategies.

COAST is primarily a cost calculation tool that utilizes GIS to visually present the economic impacts associated with different climate change scenarios. Information on projected sea level rise and flooding, which comes from a variety of sources, including NOAA's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model and the USACE's depth-damage functions, are incorporated into an ArcGIS Arc-Globe application, to form a vulnerability data layer. This data layer, in the form of a polygon, is overlaid on mapped infrastructure assets to identify areas that are vulnerable to projected climate change impacts. The tool then calculates likely economic costs, such as infrastructure costs, lost real estate values, or lost economic output, to the area given the anticipated impacts.

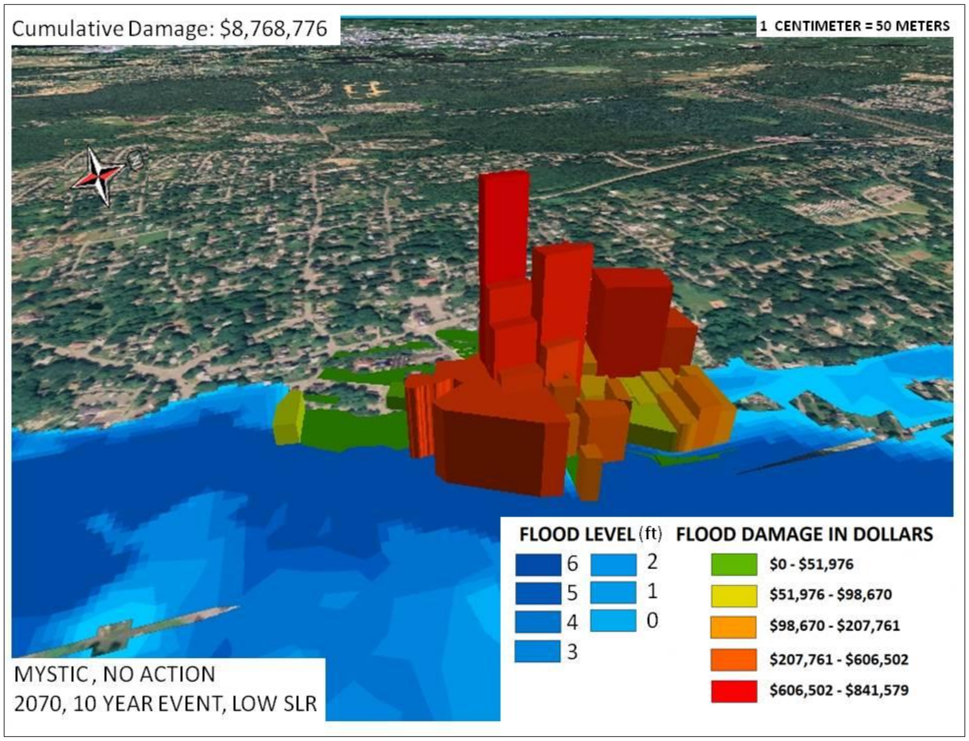
COAST can be used for both single-event modeling, where the economic impacts of a specific event, such as a hurricane, are estimated, as well as multi-decade modeling, which can estimate total expected damages from climate-change-related events over longer time periods. The tool also allows modeling of various climate change impact scenarios, such as different ranges of sea level heights and frequencies of storms.

In addition to helping assess economic impacts of climate change scenarios, the COAST tool is also used to determine the location-specific avoided costs associated with particular adaptive actions. Once an entity develops potential adaptive strategies, the information can be entered into the tool to determine the change in economic impacts associated with the various strategies.

Several municipalities are currently using the COAST approach to support their climate change adaptation planning processes. For example, Groton, Connecticut used COAST to model the economic impact, in terms of damaged real estate and building contents, from various sea level rise and storm surge scenarios at three locations. Results have been presented at climate change adaptation planning workshops to illustrate economic impacts of various adaptation strategies versus a no action approach.

As an example, Figure 4 depicts a no-adaptation-action scenario for 1 meter of sea level rise and a 10-year flood event in the year 2070, for portion of downtown Mystic Seaport in Groton, CT. The z-axis polygons represent cumulative expected lost real estate and building contents value, not discounted, of over $8 million. Adaptation actions subsequently modeled in this location included installing a hurricane barrier, elevating a road, and building dikes, each of which could provide some protection to vulnerable assets.

Figure 4: No-Adaptation-Action Scenario depicted in COAST
Source: New England Environmental Finance Center



The COAST tool was used to analyze the economic costs associated with a no-adaptation-action scenario for a portion of downtown Mystic Seaport in Groton, CT.

For Groton, CT, the tool then produced maps with reduced or eliminated polygons, for each adaptation action being considered. This is an effective way of showing up front and maintenance costs of hard-structure approaches versus expected damages from anticipated weather events. Soft-structure approaches can also be modeled, such as flood proofing, rezoning over time, and others.

Similarly, the Maine Department of Transportation (Maine DOT) is also using a variation of COAST to address cost and risk issues associated with projected sea level rise and threats to state infrastructure elements that are also designed to pass freshwater streams and rivers. More specifically, this project will help develop storm surge-sensitive design standards for large, tidally influenced transportation structures along the Maine coast.

INTERAGENCY TRANSPORTATION, LAND USE, AND CLIMATE CHANGE PILOT PROJECT ON CAPE COD

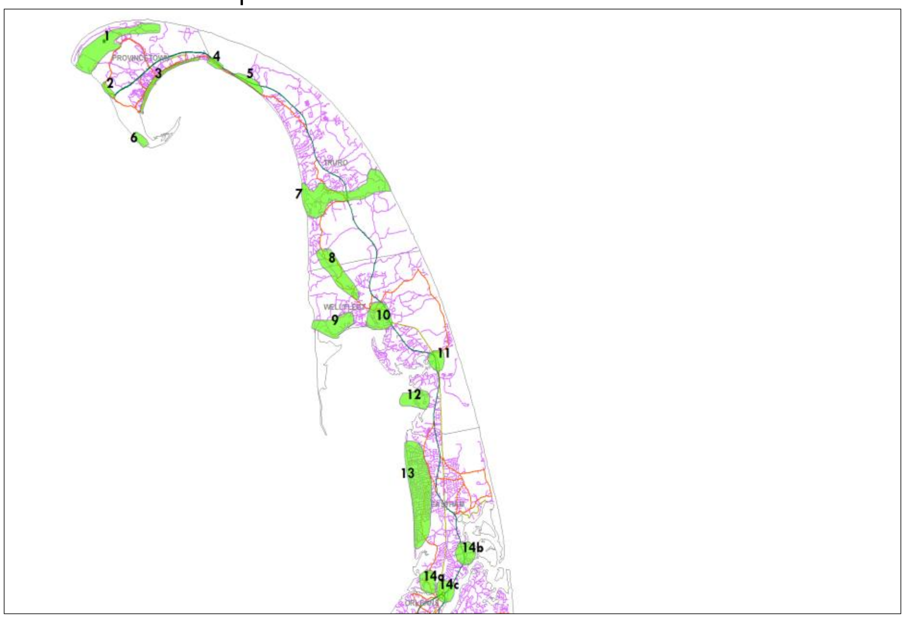
In 2010, federal, state, and local entities participated in a scenario-planning workshop to develop a transportation and land use-focused development strategy for Cape Cod that is informed by certain estimated climate change impacts and that leads to a reduction in future GHG emissions. During the workshop, groups identified suitable areas on the Cape to locate new population, employment, and transit services. The various development strategies were evaluated based on several indicators, including GHG emissions, percent of population located in areas vulnerable to sea level rise, and percent of new population served by transit.

Because SLR projections for the Cape are currently not available at resolutions needed to inform the development and evaluation of the scenarios, a consensus-based expert elicitation (EE) with coastal experts was conducted to identify areas on Cape Cod that are vulnerable to the anticipated impacts of climate change. For the purpose of the exercise, vulnerability was based on elevation, erosion potential, and exposure to storm surges and sea level rise. During the expert elicitation, the group utilized GIS and the following data layers to identify vulnerable areas:

- Digital elevation model for Barnstable County (1:5,000)
- Color Ortho Imagery (1:5,000)
- FEMA Q3 Flood Data
- Transportation infrastructure dataset

Following the EE, the areas identified as vulnerable (see Figure 5) were digitized in ArcGIS to create a vulnerable areas data layer. This vulnerable areas data layer was integrated into the scenario-planning tool to illustrate the relationship between land use decisions and climate change impacts.

Figure 5: Example Cape Cod Areas Vulnerable to Climate Change Effects
Source: USDOT Volpe Center



Areas highlighted in green were example areas identified to be vulnerable to climate change effects.

The resulting map is not a detailed or scientifically robust analysis of how and where climate change will specifically affect Cape Cod. Instead, the purpose of the map was to highlight the areas experts believed would be most vulnerable to sea level rise and associated climate change impacts in the future in order to inform the scenario planning participants. The visual representation of the vulnerable areas generated meaningful conversation among participants and helped inform their decisions on where to locate future development. The data layer was also used to evaluate the various scenarios that were developed to demonstrate how each performed in terms of the amount of population located in areas vulnerable to climate change impacts.

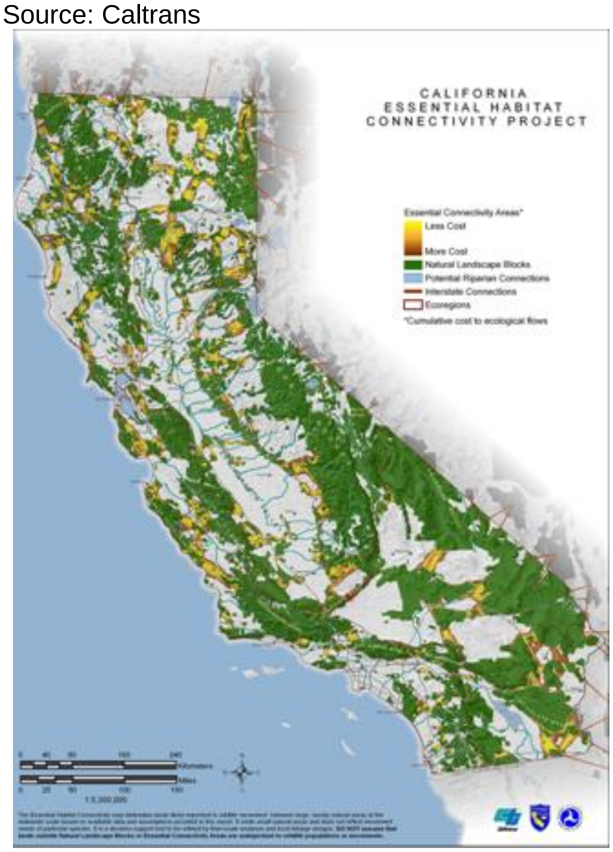
CALIFORNIA ESSENTIAL HABITAT CONNECTIVITY PROJECT

In 2008, the California Department of Transportation (Caltrans) partnered with the California Department of Fish and Game (DFG) to create a statewide Essential Habitat Connectivity Map using GIS analysis and modeling. The map identifies large, relatively natural habitat blocks, which support native biodiversity, and the corridors that are essential for ecological connectivity between the blocks. Preservation of these areas is essential to the continued support of natural communities in the face of human development and climate change. In addition to the map, the agencies created a strategic supplemental plan, which can be used to interpret the map and integrate it with transportation and land use plans.

A multidisciplinary team made of over 200 individuals from 62 Federal, state, regional, Tribal and local agencies worked together to develop the map. A technical advisory group, which consisted of a subset of the larger working group, guided decisions on the analytical approach to model statewide connectivity and to determine the relative biological value of connectivity areas. The team used the best available GIS layers as inputs into the model. Data layers used in the model include elevation, vegetation, topography, road density, and biological data collected by DFG and partner organizations.

The habitat connectivity map depicts two primary features: Natural Landscape Blocks and Essential Connectivity Areas (see Figure 6). The Natural Landscape Blocks (NLBs), which include polygons of high ecological integrity over 2,000 acres, were identified based on land conversion, residential housing impacts, road impacts, and status of forest structure. This index was modified by also considering degree of conservation protection and areas known to support high biological values.[7] Once the NLBs were identified, the group defined Essential Connectivity Areas (ECAs), which are corridors connecting the centers of NLBs. Each of the 192 ECAs was chosen using a least-cost corridor method, ecological integrity data, and buffered river corridors.

Figure 6: California Essential Habitat Connectivity Map
Source: Caltrans



The map depicts the Natural Landscape Blocks and the Essential Connectivity Areas for the state.

[7] California Department of Transportation and Department of Fish and Game (February 2010). California Essential Habitat Connectivity Project: A Strategy For Conserving a Connected California. http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=18366

In addition to creating the statewide Essential Habitat Connectivity Map, the agencies also developed a framework for mapping connectivity networks at the regional and local scale. The framework includes steps on how to consider climate change when designing linkages. Changes in temperature and precipitation will cause animal and plant ranges to shift. Enhancing connectivity and linking natural landscapes is one important adaptation strategy to conserve biodiversity during climate change.

Because models of climate change and species response to climate change are not yet accurate or detailed enough to use in designing conservation strategies, the framework instead outlines a procedure for adding additional swaths of habitat to increase the utility of corridors and linkages under and uncertain future climate. The guidance recommends an approach that identifies ecological corridors based on land facets – or areas of relatively uniform physical conditions that represent the arenas of biological activity, rather than the temporary occupants of those areas.[8]

BUNCOMBE COUNTY MULTI-HAZARD RISK TOOL

Note: This case study is based on information collected in previous conversations with the Renaissance Computing Institute (RENCI) at the University of North Carolina-Asheville (UNCA) for inclusion in two other FHWA GIS efforts: the Quarterly Webcast and Quarterly Newsletter both available at www.gis.fhwa.dot.gov/resources.asp.

Buncombe County is located in western North Carolina and includes the city of Asheville. In 2004, Asheville experienced severe flooding and a weeklong drinking water shortage following Hurricanes Ivan and Frances. Portions of the Asheville area received up to 20 inches of rain, leading to extensive flooding that inundated many roads, bridges, houses, and businesses. The Biltmore Village area, a key tourist destination and transportation corridor, was impassable for several days due to high water, affecting transportation throughout Asheville. This is just one example of the many natural hazards that affect the county. The area is also threatened by landslides, wildfire, high winds, and winter storms—all events that have the potential to adversely impact the Buncombe County transportation network, while threatening lives and property.

The Federal Emergency Management Agency (FEMA) requires the Buncombe County Emergency Operations Center (EOC) to submit a hazard mitigation plan every five years. That plan must express hazard vulnerabilities in dollar terms. When Buncombe County completed its first hazard mitigation plan, it only covered flood vulnerability as data for other hazards was limited and reviewing at-risk properties and calculating potential losses would take several days. The EOC determined that a GIS tool would streamline the process to update the hazard mitigation plan by allowing town and county planners to quickly generate maps and reports on additional hazards, such as landslides and wildfire, from their own computers without needing to first contact GIS specialists. EOC staff needed a tool that would show the extent of each hazard, the total value of property parcels at risk from each hazard, and the key infrastructure and critical resources at risk during a hazard event.

In response, the EOC partnered with the RENCI Engagement Center at the UNCA[9] to develop the Buncombe County Multi-Hazard Risk Tool (Risk Tool), an online mapping and reporting application to help assess hazard impacts in the county.[10] RENCI met with stakeholders over a six-month period to gather their input on system requirements and then took another six months to iteratively develop the application. The tool, which was first released in 2009 and is currently available to the county, its six towns, and the Asheville Fire Department,[11] now displays a map in a GIS-like interface that does not require desktop GIS software. The most recent version of the application, released February 2011,

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8 *Ibid.*

9 The RENCI Engagement Center is a unique collaboration between UNC-Asheville, multiple government agencies, and the public sector. Formed in 2006, the Center's focus is on decision-support tools related to natural hazards, community and regional planning, and economic development issues. www.renci.org/

10 The Multi-Hazard Risk Tool was developed as a Flash web application using the ESRI ArcGIS Server.

11 Access to a full version of the tool is currently password protected due to the sensitive nature of some of the data; however, a public version of the tool is available at www1.nemac.unca.edu/Renci/RiskTool/RiskToolPublic.html

includes a map interface that shows the areas affected by hazards, as well as other almost 140 data layers, including transportation infrastructure, utilities, population, and emergency responders. These data were obtained from several sources, including the North Carolina Floodplain Mapping Program, the North Carolina State Geologist's Office, and the Southern Group of State Foresters.

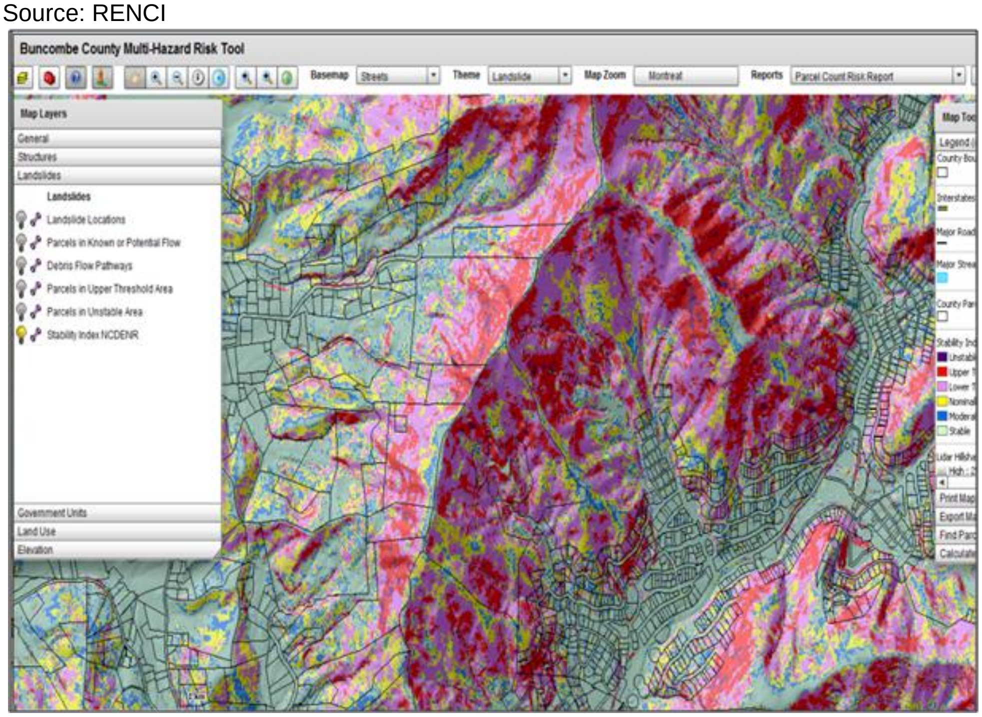
The tool has a set of reports that summarize parcel counts and values for each hazard grouped by parcel classification and vacancy status, with documentation explaining the assumptions and models used to determine hazard risk. Parcel data is updated every other week in the tool. The interface also has a toolkit with functions that allow users to identify map features, find parcels, control map layer visibility and transparency, obtain map layer metadata, calculate drive times, and create a printer-ready version of the map.

Using the Risk Tool, EOC staff can answer targeted questions such as:

- What is the total property value at risk from a 100-year flood?
- Could a flood block road access to a planned subdivision?
- Could a dam failure cause damage to a planned rail hub?
- Is there any land expected to be developed that is at high risk for wildfires?
- How many parcels have unstable land that is prone to landslides?

Although the tool is currently being used primarily for emergency response activities, it has several potential transportation applications. For example, EOC staff can now evaluate how hazards might affect roads and other transportation infrastructure that fall within a 100-year floodplain or that might be affected by a landslide debris flow (see Figure 7).

Figure 7: Landslide Risk Areas
Source: RENCI



The tool can highlight areas that might be affected by a landslide debris flow and other natural hazards.

Additionally, the tool helps planners locate communities that might be cut off from resources and evacuation routes during an emergency. Buncombe County has many communities that are built on hills and are only accessible via bridges located in adjacent valleys. By identifying bridges that lie in a floodplain or potential debris field, planners can locate these at-risk communities and communicate information to emergency management officials to help them prepare appropriate emergency response plans. Currently, tool users must visually inspect maps for intersections between hazards and transportation infrastructure, but eventually the tool will automatically generate reports that list sections of affected infrastructure.

RENCI hopes to continue to update and improve the hazard models based on new data. The flood model will be refined with building footprint data from the entire county to account for the effect of new development on floodwater flows. In the future, the team expects to update the landslide model to consider the frequency of rain events and the dam model with better engineering studies and hydrological models. The team would also like to expand the tool to consider other hazards including tornados, earthquakes, and drought events. Other potential improvements might include the use of future development scenarios to identify how growth would affect or be affected by hazards.

The tool might also be expanded to additional audiences and geographic areas. For example, RENCI is working with the Land-of-Sky Regional Council, a local government planning and development organization for the four counties around Buncombe County. The council is using the tool to develop a transportation plan for its four-county region. Furthermore, after demonstrating the tool to North Carolina DOT in a climate change adaptation workshop in March 2010 and to the North Carolina Division of Emergency Management, both agencies expressed interest in seeking funding to expand the system to other counties. RENCI has also discussed with stakeholders the possibility of integrating the ability to create mitigation scenarios into the tool. For example, the county has started buying a number of businesses located along the Swannanoa River in Buncombe County that have been flooded repeatedly. The tool could be modified to assess how removing those buildings might affect flooding downstream. As another example, a bridge in one of the county’s towns was recently replaced due to a need to widen its river passage. Some involved with the project expressed interest in being able to create models to determine how different mitigation actions would affect the transportation network and river flow. These expansions of the tool have not occurred due to funding constraints.

OBSERVATIONS AND RECOMMENDATIONS

Transportation agencies are increasingly considering climate change in their decision-making processes. Accordingly, the use of GIS to support climate change analyses in the transportation field is emerging as a common practice. As demonstrated by the reported case studies, GIS can help transportation planners and asset managers understand and respond to transportation-related GHG emissions and to the potential effects of climate change.

GIS tools can help transportation decision-makers prioritize responses to climate change.
While there is consensus that climate change will have impacts on the transportation system, the scale and scope of those impacts is unknown. Such uncertainty presents a challenge for transportation decision-makers in determining how best plan for or adapt to climate change. GIS tools can help planners evaluate various climate change impacts scenarios and identify which assets are most vulnerable to the threats from climate change or would be most expensive to repair or replace. With this information, decision makers can better develop and assess strategies to mitigate or avoid the anticipated impacts in the future.

In addition, several states and regional governments across the country have established GHG reduction goals. GIS technologies provide a visual framework for conceptualizing and understandings how transportation contributes to a region's GHG emissions profile. This, in turn, allows planners to develop more effective GHG reduction strategies to help achieve the state's overall reduction goals.

GIS can be used for both complex and less detailed analysis.
GIS can be useful across a range of analysis, from being a tool to provide an initial screen as to how climate change may potentially impact a project to more complex and detailed analyses that integrate cross-disciplinary datasets. The Dockton Road case study from King County, Washington provides an example of the benefits of a simple GIS overlay analysis to determine potential project impacts. In contrast, the COAST tool involves a more complex GIS analysis of various climate change impact scenarios and the associated costs with various approaches to adaptation.

There is a need to downscale data and to identify appropriate data sources.
Analyzing the potential impacts of climate change requires local- or regional-level information on past changes, as well as projections of future climate and related effects. For example, the U.S. Geological Survey has shown that there are important differences among coastal areas nationwide in terms of their vulnerability to coastal change due to future sea level rise. Vulnerability depends on the relative contributions and interactions of at least six variables, including tidal range, wave height, coastal slope, historic shoreline change rates, geomorphology, and historical rates of relative sea-level change.[12]

For this reason, transportation agencies may need to rely on outside sources to provide downscaled, location-specific, data that provide fine-scale climate effects projections, which are necessary to determine project level impacts. Transportation agencies should coordinate with research institutions and government agencies to identity appropriate data sources. In addition, the FHWA recently released a report, *Regional Climate Change Effects: Useful Information for Transportation Agencies*[13] that provides regional information on projected climate change effects that are most relevant to the U.S. highway system. This report is a resource that could be consulted in future GIS for transportation and climate change analyses.

A visual representation of modeling results can be useful in explaining complex and controversial findings to non-technical audiences.
Climate change is a complex, global issue. GIS can help translate climate change data and impacts into maps or applications that are visually appealing, meaningful, and accessible to a non-technical audience.

[12] Thieler, Rob *et al*. 2001. http://pubs.usgs.gov/fs/fs095-02/fs095-02.html
[13] FHWA. Regional Climate Change Effects: Useful Information for Transportation agencies (May 2010). www.fhwa.dot.gov/hep/climate/climate_effects/index.cfm

For example, agencies can use GIS to create visualizations for public outreach to illustrate the relationship between transportation systems and GHG emissions. Having a better understanding of how land use decisions impact transportation-related GHG emissions enables policy makers to develop more effective GHG reduction strategies.

Recommendations for FHWA

The use of GIS in climate change research on transportation systems is still in a nascent stage and further research and analysis are needed to support the field is needed. FHWA can consider the following actions to advance the use of GIS in climate change research and transportation planning.

- **Provide opportunities for practitioners to share information on using GIS for climate change.** In order to enhance the state of the practice of using GIS for climate change, FHWA should pursue opportunities to educate transportation stakeholders on the topic. For example, FHWA conducts a quarterly GIS webcast where transportation agencies exchange their knowledge of geospatial technologies. FHWA should reach out to state and regional transportation agencies to feature the use of GIS for climate change applications in an upcoming webcast. Additionally, FHWA could help improve the modeling or GIS capabilities of state DOT and MPO staff through sponsoring events such as peer exchanges or collaborative workshops.

- **Provide information on climate change resources and available datasets that may be useful for GIS analysis.** Analyzing climate change impacts on a regional or project level requires downscaled climate models at the same level. FHWA should identify appropriate data sources and share those with the transportation community.

- **Promote state and local efforts to identify areas where restoration or maintenance of ecosystems may be able to reduce highway maintenance or repair costs.** This proposed activity should include developing GIS layers in coordination with state, regional, and local resource and transportation experts to locate or devise ways to locate these areas.

APPENDIX A: INTERVIEW PARTICIPANTS

Name	Title	Agency
Amy Pettler	Senior Endangered Species Coordinator and Wildlife Biologist	California Department of Transportation Division of Environmental Analysis
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