Updated Rainfall Frequency Map Enhances Alaska’s Transportation Planning

Estimating how much, how long, and how often rain will occur is a valuable tool for Alaska’s transportation engineers, as well as many other technical professions. Without this data, planning for culverts, bridges, dikes, diversions, roads and other structures—especially those built over rivers or floodplains—becomes vulnerable to major setbacks and costly infrastructure damage.

As June flooding resulted in closures along the Alaska Highway, state engineers were reminded of the crises that emerge when unexpected rainfall causes vital conduits for people and goods to halt. The costs of even isolated incidents of rainfall-related infrastructure failure are also significant. In 2003, unexpected storms in Colorado triggered a culvert failure causing $4.2 million in damages. On a statewide level, these costs are even more concerning. Ohio recently received $145 million in federal aid to cover road and bridge damages from unforeseen storms in 2011.

While more robust designs can mitigate these costs, Alaska’s engineers and planners until recently relied upon precipitation inventories published in 1963 and 1965. As Alaska DOT&PF begins the process of charting new transportation corridors, predicting and planning for the intensity, duration, and frequency of future rainfall events has become even more valuable.

The Hydrometeorological Design Studies Center (HDSC) within the National Oceanic and Atmospheric Administration’s (NOAA) National Weather Service (NWS), led by Dr. Sanja Perica, continually updates precipitation frequency estimates for various parts of the United States and affiliated territories, in NOAA Atlas 14 volumes. Alaska’s portion has not been updated since the mid-1960s due to the sparse station coverage, a relatively short period of record, and great variations in topography across the state. Dr. Doug Kane, a faculty emeritus with UAF’s Water and Environmental Research Center (WERC), was looking to update Alaska’s precipitation estimates for the state’s key transportation corridors. NOAA decided to collaborate with AUTC and WERC in expanding the effort statewide.

The partnership proved adept at overcoming numerous data collection challenges unique to Alaska. Rainfall measurement gauges often suffered from wind, snow, sleet, hail, and wildlife damage. Only some of the stations had observers present, whereas many stations were unattended. This led to data quality control procedures becoming critical for working with these types of records.

Data compilation was a key facet of this work, as the team sought to evaluate a large body of existing data. Researchers gathered data from a long list of agencies including the National Weather Service, National Resources Conservation Service, U.S. Geological Survey, the University of Alaska, and many others.

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We at AUTC are strong proponents of coordinated research leading to a common goal. Rarely are we lucky enough to have a single research project that leads to a ‘Eureka!’ moment. Instead, many of our most valuable research endeavors take place through focused, sustained collaborations involving a broader program of research projects.

Our seismic program is an excellent example. Alaska has over 24,000 earthquakes annually, and while most of these occur in small or uninhabited regions, we expect the state to experience at least one magnitude 7-8 earthquake each year. A magnitude 7.0 earthquake in 2002 prompted us to question the lack of consideration of soil structure interaction in frozen ground. After a literature search produced essentially no research in this area, AUTC decided to partner with the Alaska Department of Transportation and Public Facilities to fill this knowledge gap.

We recognized that no single university had all the skills, expertise, and facilities to rapidly fill the void. So we divided the effort into multiple manageable projects. We then selected researchers who could perform these tasks and universities that had the physical resources to get the work done. Elmer Marx, a Bridge Engineer with Alaska DOT&PF, worked tirelessly with the researchers to keep their work focused on the needs of the practicing engineer. In the role of AUTC Director, I worked to coordinate the projects and ensure that members of each project knew what the other researchers were doing. The approach resulted in major changes to the State of Alaska bridge design codes and procedures, and also in the AASHTO seismic bridge design code changes. Now in its final stages, this work is among the featured stories in this newsletter.

When I sit down with Elmer and discuss how far we have come over the last five years, I’m reminded of the success yielded by a well-focused and coordinated research program. All of the products from these projects have been implemented—most before project completion. However, while I cannot state the work is complete, I can say that we are reviewing our knowledge gaps with the Alaska DOT&PF Bridge Design Section to develop a program for the next five years. We are optimistic about the outcomes.

Employing this coordinated program model used for our seismic work, I have established a new Marine North research program under AUTC. Similar to our seismic work in its aims, the goal is to work with interested parties to coordinate our research and maximize the benefits. Retreating sea ice is driving interest in offshore oil and gas in the Beaufort Sea and Chukchi Sea as well as expanding sea lanes. The interests in this issue include sovereignty, national security, increased marine traffic, commercial shipping, energy development, and the supporting infrastructure. While we don’t claim to have all the answers, we do understand transportation and logistics in the arctic, and have unique expertise in arctic marine infrastructure. Our goal is to foster research that leads to meaningful outcomes for stakeholders.

On a more somber note, Michael Downing, one of our Board Members passed away in May, after a battle with cancer.
A good friend and mentor, Mike was Chief Engineer with Alaska DOT&PF for 10 years. Mike took pride in the Department’s research program, and his support greatly aided my job as Research Manager and the results we delivered for Alaska. I always appreciated Mike’s perception and willingness to be proactive on any issue facing the Department. He used research as a means of moving us forward by improving our work.

Every researcher knew Mike would ask one simple, but insightful question about a research proposal: “How is this research going to change the way we do business?” Answer this question correctly, and you were likely to receive funding. Fail to answer this question, and your chances were slim. This insight made Mike a valuable member of the AUTC Board, and was the reason I asked him to serve. I could count on him to keep our program on target.

Mike, we will all miss you. Thank you for all that you have given us and especially for all that you have given me.

AUTC Alumni Spotlight

- **Name:** Jonathan Hutchinson
- **Institution:** University of Alaska Fairbanks; College of Engineering and Mines
- **Degree:** B.S. Civil Engineering (’09)/M.S. Civil Engineering (’11)
- **Current Job at Alaska DOT&PF:** Engineering Assistant 2, Aviation Design Section, Northern Region

Jonathan Hutchinson is wrapping up his first year on the job as an Engineering Assistant in the Aviation Design section at the Northern Region offices of the Alaska Department of Transportation and Public Facilities.

Hutchinson received a B.S. in Civil Engineering from the University of Alaska Fairbanks in 2009, focusing his course work on geotechnical and structural engineering. He participated in the annual ice arch construction and the steel bridge team competition—fabled engineering traditions at UAF. As an undergraduate, he was involved in several transportation related research projects at UAF: hydrology and water sampling work along the Steese Highway; silt sample collection for a frozen silt anchor study, and a summer internship with Alaska DOT&PF’s Central Region.

Nearing Hutchinson’s graduation, Dr. Andrew Metzger, AUTC researcher and Assistant Professor of Civil and Environmental Engineering, approached him about joining ongoing research on maritime structures by pursuing an M.S. degree. So he entered the program and began summer work on an AUTC project examining the dynamic responses of pile-guided float structures. He subsequently joined another of Metzger’s AUTC projects, this one examining the loading environment of state ferry and marine landing structures in Washington and in Juneau, where Hutchinson was involved. He was also able to apply this work as one year of experience toward the Project Engineer certification requirements.

Hutchinson’s job in the Northern Region Aviation Design section has a varied pace. His work is relatively calm in the winter, as he begins setting up contracts, pushing-out designs, and planning for multiple summer projects. Things speed up in the summer, as he arranges field work and travel, coordinates projects, and keeps up with mapping, design, and contracting duties. He cites organizational skills as a key asset in this work, as he manages more contracts than engineering students typically expect. Among his favorite job perks are the extensive field duties, entailing flying to remote locations and villages to meet with locals and the interesting experiences that come with this aspect of his work. While he was well-prepared for this work by the rigor and workload of UAF’s engineering program, he has found that writing and communication skills are becoming much more important for his work on a daily basis.
AUTC addresses many research issues on a project-to-project basis. Other issues, however, are much more complex and multi-faceted, requiring a program of projects to address them. Updating national and state bridge seismic design codes is just such an issue.

Alaska’s engineering and transportation professionals have many questions about how bridge structures can better withstand earthquakes in a state that is both the most seismically active and frigid in the U.S. Through a program of nine projects with four research partners addressing structural, soil, and software assisted analyses issues, a research effort five years in the making is now bearing fruit. Leveraging a $1.7 million portfolio of match-funded projects (U.S. DOT RITA, Alaska DOT&PF, and AUTC), the collaborative effort enhances the predictive capabilities of designers, their software, and analysis. Its results are now being written into improved seismic design standards at the national and state level.

Alaska’s bridges are vital links to goods and services, often with no alternatives. Because removing a bridge from service is not an option, and replacement takes years, designing bridges to maintain service life after an earthquake is a necessity. This program of projects addresses the two parameters engineers consider when designing bridges for earthquakes: structural capacity and seismic demand.

**Structural Capacity**

The structural capacity, or resistance, is the structure’s ability to resist a seismic load. Four AUTC research projects examining structural capacity have focused on steel reinforced concrete columns and all-steel structures similar to those used in Alaska.

AUTC’s partners at North Carolina State University (NCSU), led by faculty member Dr. Mervyn Kowalsky, utilized NCSU’s Constructed Facilities Laboratory (CFL). They used this unique set of testing and instrumentation equipment to study the behavior of bridge structures during earthquakes, and better understand bridge seismic performance limit states addressing the force a structure can withstand and still retain its strength after a seismic event—for seismic and temperature conditions typical of Alaska.

The NCSU team tested steel-reinforced concrete columns to measure how strength increases in the -40 degree temperatures common to Alaska. Using cyclic testing to mimic an earthquake, they pushed and pulled upon bridge columns to measure their maximum deformation capacity.

Researchers found these cold conditions increased concrete strength by 30-40 percent and steel by 10 percent. A similar project utilized advanced non-contact sensor technology placed directly on structures to measure how the specimen’s load history impacts the strain it can withstand. The results show the deformation a bridge pier can withstand and remain in service after an earthquake.

The team also studied all-steel bridge piers. In Alaska, these often serve as detour bridges, temporary work structures, bridges in remote locations, and marine structures like marginal piers and ferry terminals. Engineers are skeptical of their structural ductility (ability to withstand large deformations) and propensity to fail during seismic events. However, all-steel structures present an attractive construction option if built to reliably withstand large earthquake demands. This project tested structures built under current specs, and also tested reinforcement methods to improve ductility, helping refine Alaska standards for all-steel piers.

Alaska DOT&PF, consultants, and contractors benefit from the all-steel option. Testing identified previous designs problems and made required standards more reliable and cost-beneficial. New designs require minimal cast-in-place concrete, labor, and shipping costs—especially valuable in remote locations where these costs soar. Also, new designs exhibit quickened assembly time that reduces traffic delays. Most importantly, they are more reliable and ductile.

NCSU also looked at designs of steel pipe piles filled with reinforced concrete. Steel pipes can serve as the formwork and permanent casing for columns in a variety of ground conditions. They offer lower levels of environmental impact than conventional foundations. This type of bridge system also exhibits high ductility. This ongoing study is identifying materials strains at various performance limit states for more efficient and better performing designs.
Seismic Demand

Other projects investigate the seismic demand put on Alaska’s infrastructure. The demand, or load, is the force acting upon a structure. For example, what happens to a bridge foundation during an earthquake if it is built on a frozen crust of ground on a layer of liquefiable soil?

University of Alaska Fairbanks Civil Engineering Professor Dr. Leroy Hulsey, University of Alaska Anchorage Associate Professor of Engineering Dr. Joey Yang, and a team at UAA managed five overlapping projects addressing soil liquefaction (which occurs when an earthquake causes soil to lose its strength and behave like a liquid) and the frozen soil impact on bridge substructures. They also examined the mechanical properties of naturally frozen soils.

They looked at how temperature cycles, soil liquefaction, and frozen soil impact the seismic demand on structures. One study offers the first quantified evaluation of loads imposed on bridge foundations by a frozen crust with liquefaction and lateral spreading. The team validated a computer model that simulates a pile foundation’s response to seismic events in arctic conditions. Results show that pile performance is very sensitive to crust conditions, and the pile’s internal forces like bending moment and shear force vary by roughly 50% when the crust freezes. The team expanded these experiments to include partners at China’s University of Science and Technology Beijing. Shown above, researchers utilize a large-scale shake-table testing facility in China. (Photo Courtesy: J. Yang, UAA/AUTC)

Implementing the Results: National and State Standards

AASHTO’s seismic bridge design guide (2011 AASHTO Guide Specifications for LRFD Seismic Bridge Design, 2nd Edition) governs aspects of seismic bridge design. Findings from this suite of projects have been integrated into and sections 7 and 8, addressing structural steel and reinforced concrete components. They include language on several specific components, such as the mechanism for calculating the strength capacity of concrete filled steel pipes, and the design of column-to-beam joints. At the state level, Alaska’s seismic bridge design protocol is being rewritten to include these advances through Alaska DOT&PF.

By enhancing these design guides with research developed in the nation’s coldest and most seismic design environment—Alaska—DOT’s nationwide save potentially hundreds of millions through improved bridge design. These cost savings include prevented bridge failure, improved maintenance, replacement, retrofit, and other costs associated with bridge management. Most importantly, public safety will benefit as well.
This winter, the U.S. Coast Guard cutter Healy drew international attention for a somewhat harrowing incident in the Bearing Sea. The ship was called on to escort a Russian tanker through more than 300 miles of ice on its way to Nome, Alaska. After a vital fuel delivery was cancelled due to severe winter snow storms, the emergency fuel delivery to this remote Alaska community underscored the growing need for Arctic Marine capacity and infrastructure.

Because the US’s two other ice-breaking ships were either being repaired or de-commissioned, the Healy was and is currently the only ship with this capability. Moreover, Alaska’s arctic waters are under-developed, lacking vital land-based and off-shore infrastructure to support commercial, transit, military, search and rescue, and other maritime activities.

As these needs persist, lawmakers, government, and private industry are pushing for more infrastructure investment. With this backdrop, the Institute of Northern Engineering and AUTC created a new research initiative: the Marine North research program. Utilizing unique expertise in cold regions engineering and maritime infrastructure, the program will align current research specialties with emerging stakeholder research needs.

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State legislators want Alaska to begin researching, planning, and constructing roads, airports, maritime, and terrestrial infrastructure. In an April statewide public opinion piece, state legislators Bob Herron and Reggie Joule, leading members of the Joint Alaska Northern Waters Task Force, outlined four recommendations:

- Forward base the Coast Guard in the Arctic,
- Fund additional icebreakers and other ice-capable vessels,
- Develop ports and safe harbors in the Arctic, and
- Support coastal search and rescue coordination centers.

While each of these recommendations entails its own list of unique considerations, the third—developing ports and safe harbors—is an issue that has received a growing level of attention among federal and state agencies in recent years. It is also an area of research in which AUTC has unique expertise in researcher Andrew Metzger, Assistant Professor of Civil and Environmental Engineering at UAF.

Metzger will lead the new Marine North research program. It will focus on marine transportation in northern latitudes, and all engineering aspects surrounding it. The program will provide technical support for policy development and will address the research needs of government and private industry stakeholders. These include:

- The oil, gas, and mining industries;
- Financial services firms;
- Federal agencies such as the Department of Homeland Security (DHS), Department of Defense (DOD), and Department of Interior (DOI); and
- State agencies like the Alaska Department of Transportation and Public Facilities, the Department of Environmental Conservation, and the Alaska Department of Commerce, Community, and Economic Development

It will capitalize on UAF’s historically unique expertise in arctic issues like frozen ground engineering and arctic marine infrastructure. It will also leverage collaborative relationships with the Geophysical Institute and International Arctic Research Center at UAF. The effort will expand these research capacities to potentially include areas related to planning, design, construction, and maintenance of arctic marine infrastructure.

As Alaska’s existing arctic maritime infrastructure, and lack thereof, has drawn more national interest in recent months, a variety of stakeholders have already sought AUTC’s expertise. This Spring Metzger gave a presentation on the issue for a gathering of the American Society of Civil Engineers, and last July he was invited to present his assessments at the U.S.
The researchers aimed to make the data adequate for statistical analysis through merging records from nearby stations, performing various quality control tests, and detailed investigation of suspicious values. Using up-to-date modeling and computer techniques, they improved the quality of precipitation frequency estimates contained in the original publications. The project moved engineers from utilizing hand interpolations to determine location-based rainfall estimates to sophisticated computer-assisted techniques incorporating a more detailed and thorough collection of figures. This resulted in more accurate, efficient estimates.

The differences in estimates between these are attributed to a number of factors, including improved frequency analysis approaches and interpolation techniques. In addition, the increase in the number of stations—including high-elevation stations and more diverse topography—and periods of record across all durations used in frequency analysis were significant improvement factors.

The team determined which of the data sets from Alaska's more than 1,600 gauges could be merged together to yield useful results. Their reliance upon longer rainfall records enables better estimates and improved statistics. The precipitation frequency estimates with accompanying information are available at NOAA's online interface. With a zoom-in map function, well-displayed graphs, and the ability to generate point-and-click location specific data on the fly, this functionality is a dramatic improvement from the original product. Before this project, engineers relied upon a series of printed isopluvial maps from the 1960s.

Online users and engineers move a cursor anywhere in Alaska, and click on a location. Then, the system generates rainfall frequency estimates specific to that exact coordinate. The user can click to view these figures in tab or full-frequency color graph format. It also displays upper and lower bounds of 90% confidence intervals, helping engineers improve risk analysis by incorporating uncertainty into existing estimates. Users can also click to view a variety of supplemental data including cartographic maps, high resolution grids estimating a range of durations and frequencies, and accompanying documentation describing the whole process in detail. The format also gives temporal distribution, seasonality analysis, and data source and watershed information—all for a specific location.

The project has garnered significant interest from a number of stakeholders. In January, the Alaska Center for Climate Assessment and Policy (ACCAP) invited researchers led by Dr. Perica to present a live webinar for more than 80 people. In February, Dr. Kane gave a presentation at the Department of Interior's North Slope Science Initiative (NSSI), and a graduate student gave a seminar on her role in the project to WERC colleagues at UAF. In March, team members were invited to present their work in Juneau to more than 100 attendants at the annual meeting of the Alaska Section of the American Water Resource Association (AWRA), and Dr. Sveta Stuefer headed this presentation.

Beyond these audiences, anyone can access the updated rainfall frequency estimates online at NOAA's website, located at: hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_ak.html. There visitors can explore the variety of functions and data accessible through this user-friendly format.

Pictured above: a remote gauge station. Rainfall measurement gauges often suffered from wind, snow, sleet, hail, and wildlife damage. (Photo Courtesy: S. Stuefer, WERC)
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