Emergency Bridge Surveys Responding to Flash Flooding Events

BEN SHINABERY, Kentucky USA

Key words: Flood Response, Bridge Survey, Infrastructure, Natural Disaster

SUMMARY

When responding to new global climate conditions, surveyors should anticipate the need for full 3D surveys after natural disasters caused by flash flooding emergencies. In July of 2022, flash flooding swept across Eastern Kentucky, USA affecting more than 10 counties due to an estimated 0.5-meter rainfall in less than 2 days. The USA National Weather Service estimated that this volume of rainfall (600% above average) occurring in such a short period of time had a 1:1000 chance of happening in a given year. Living in the modern era, we all need to be ready for more natural disasters. The flash flooding washed through creeks and rivers while at the same time destroying roadways, bridges and homes. More than 40 deaths are attributed to this one event.

Qk4, Inc. had been surveying bridges for the Kentucky Department of Transportation under a private consulting contract comprised of 1000 individual bridges in the state inventory. Because of the experience of the Qk4 survey team and their ability to respond quickly with existing contracts, surveyors arrived on bridge sites within one week of the flooding event. With modern survey equipment such as robust GPS receivers, robotic total stations, 3D laser scanners, and drones, the survey team was able to establish geodetic survey control and collect all existing site conditions of the bridge sites in just 2 or 3 days. All features related to the bridge were precisely located including remaining bridge components, utilities, roadway, creek limits, drainage structures and more. These trained survey technicians had the exact experience necessary to accomplish the emergency response. Each survey was collected in 3D and modeled in a digital format for transmission to dozens of design engineers worldwide.

Extreme environments do not always require extreme land surveys if companies prepare for natural disasters with proper planning and technician training. Through this one flooding event, we learned that the resilience of the human spirit can accomplish great things for communities that are recovering from destruction. We may not consider land surveyors as first responders, but for the people of Eastern Kentucky, the surveyors started sustainable reconstruction of their bridges in less than a week's time. The bridges for these replacements were designed and built with a 75-year sustainable lifespan to proactively account for more flooding in the future. Thanks to the efforts of the surveyors, engineers and contractors, communities now have bridge security for their families in Kentucky.

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PROVIDENTIAL PREPARATION

In 2020, as surveyors climbed through vegetation along the banks of small drainage creeks in rural Kentucky, they never expected that providence was training them to respond to potential natural disasters to come. Using specialized land survey knowledge, Qk4 field crews collected thousands of georeferenced points with intelligent codes for the 3D digital terrain model features of hundreds of bridge sites in unknown preparation for Kentucky's worst flash flooding event of this century. Little did these surveyors know that their laser scanning and drone mapping experience would be called upon to help save a community recovering from the loss of lives, homes, safe access roads, and bridges in the Eastern Kentucky Flood of 2022.

JULY 26, 2023: THE EASTERN KENTUCKY FLOOD (Appendix A)

Between July 25th and July 30th, 2022, several complex thunderstorms developed across southeastern Kentucky, causing heavy rain, deadly flash flooding, and devastating river flooding in eastern Kentucky. These storms resulted in rainfall rates exceeding 4 inches per hour, leading to 39 deaths and widespread catastrophic damage. Hundreds of homes and parts of communities were swept away, and over 600 helicopter rescues were needed to evacuate residents. In total, 24 Flash Flood Warnings were issued, with 13 warnings, including 3 Flash Flood Emergencies, occurring during the peak of the event. Radar estimates indicated that 14-16 inches of rain fell in a narrow swath, with many areas receiving 6-10 inches of rain. The highest rainfall was reported in southern Knott County, with 14 inches between July 25th and July 29th. These rainfall values are extremely rare, with less than a 1 in 1000 chance of occurring in a given year.

The intense rainfall also led to significant river flooding, particularly in the Kentucky River and its forks, the Red River, and the Licking River. At Whitesburg, the North Fork of the Kentucky River reached nearly 21 feet before gauge failure, surpassing the previous record of 14.7 feet set in 1957. The North Fork of the Kentucky River at Jackson also set a new record crest of 43.47 feet. This river flooding caused further destruction and affected downstream areas less impacted by the initial rainfall.

SURVEYORS FIRST TO RESPOND

Because of the experience gained from years of surveying small structures in Kentucky for the Department of Transportation and an on-call survey services contract with the state, Qk4 surveyors were able to respond within three days of the flood event. Emergency responders already knew the situation was worse than ever before. Whole communities had been washed away by the torrents of water rushing down mountainsides filling up creeks and drains to beyond flood limits. Emergency services established a control center and enacted every agency to help the recovery effort.

The Kentucky Transportation Cabinet engaged the existing on-call bridge delivery contract to assess and rebuild roadways and bridges that had been washed out to create a quick design repair or replacement of unstable structures. The land survey team of Qk4 was called to collect existing conditions of the damaged sites and provide a basemap CAD drawing of the critical features needed to design sustainable replacements that would last through future storms. Every experienced surveyor mobilized with modern land survey tools to collect the ground surface, remaining structure, existing utilities, and creek hydrology. In some cases, the surveyors did not know where they would sleep because of the destruction of hotels and homes, but they went with a resilient spirit and hope that they would be able to help.

MODERN EFFICIENT 3D BRIDGE SURVEY

The survey crews had years of experience preparing bridge surveys and had the equipment necessary to establish coordinate control localized to each site. They had modern GNSS receivers, a robotic total station, data collectors for all crew members, and the use of laser scanning and drones for detailed scans or contextual drone mapping. On many sites, the bridge was completely washed away which made it difficult to even access both sides of the creek. The process started with the field crew arriving at the bridge site and immediately setting up a GNSS base on a primary survey control point, then setting additional control to be used as reference control but also as permanent benchmarks for future contractors. As the crew chief established control, the other crew members began taking 360-degree site photos, measuring unique site features, locating utility evidence, and talking with neighbors. While the base was still collecting its static session, the crew would run differential levels through the control for precise elevations across the site. With good control established, one field crew member set up a robotic total station for topographic data collection while the second crew member ran an RTK rover to also collect the contextual ground surface and creek locations. With both crew members working with independent survey setups, these crews started collecting the bridge site with efficiency before the close of the first day when the static GNSS session ended.

Subsequent days, the crew used the same control base location to maintain the same reference frame expecting to post-process the whole job and adjust it to real control. Elements of the site were collected with intelligent field-to-finish codes to create a digital twin for critical design decisions: direction and width of approach roadways, the cross sections of the remaining creek for volume calculations, any existing utilities that were adjacent to or along the side of the bridge, any remaining substructure or superstructure of the bridge, and the overall context and topography of the land. Those bridges that had historic significance or were complex in nature may have been laser scanned to archive the post-flood conditions for assessments to decide the viability of keeping significant bridges. Each day on the site the field crew worked within the same control established the first day on the site.

After a thorough review of the collected digital points and confidence that bridge engineers had the modeling information needed for their design, the field crews moved on to the next emergency site which may have been downstream of the same washed-out river. Crews were so efficient that they may be able to collect a site in just a couple days in most cases. The speed at which they worked was important because the response time of the engineering team started when they received the 3D model from the survey team. Field data collection was uploaded to Qk4 servers, allowing the survey CAD technicians to finish the modeling that had begun with intelligent codes. Qk4's workflow created a total of three surfaces within their delivered digital twin: an overall surface TIN model of ground features that included the bridge substructure and creek, a bridge deck model which could be a TIN or could be modeled solid CAD features that acted as the digital bridge within the CAD model, and finally, an under bridge surface model that provided a complete hydraulic opening to calculate the volume of water that would flow under the bridge. These surfaces, along with all other data collection on the site, created a full composite of the existing conditions after the flood.

THE BENEFITS OF A DIGITAL TWIN MODEL (Appendix B)

A digital survey data collection allows for the digital modeling of the full digital twin of the site and bridge. The benefits of this complete model to a bridge engineer are valuable to the extent that the existing survey provides a digital canvas to build the proposed solution. Every critical elevation, length, width, and angular skew is communicated in one digital platform. Digital twins are proven to support Finite Element Analysis (FEA) for structural integrity, facilitate complex geometry, provide detailed visualization renderings, and allow multidisciplinary collaboration tools for design teams. These CAD models allow engineers to make data informed decisions quickly and with confidence.

BRIDGE SECURITY (Appendix C)

According to recommendations of the TRIP Rural Connections Report (Sept 2024), "America's rural transportation network provides the first and last link…" for "… farm to market… access to jobs… movement of goods and people…health care and education, and provide links to social services." The bridges across rural rivers, creeks, and drains are the bridges to life and opportunity. When the July 2022 flooding washed away the bridges, it also washed away access to every basic need for those Kentuckians. For many, time was the biggest constraint to repairing and replacing this access. For any civil engineering project, the schedule begins at the point of land survey. Qk4 surveyors, through the use of the latest technology in tilting robust GNSS, robotic total stations, modern data collectors with field to finish coding, 3D laser scanning, and UAS mapping provided the land survey emergency response that put the design of recovery in motion in the days and weeks following this natural disaster.

CHANGING SURVEYING FOR THE FUTURE

Now, two and a half years after responding to the call for help, Kentuckians are still rebuilding their lives. Qk4 has been able to refine the land survey workflow even further by incorporating all the modern geospatial tools for efficient digital land survey. Our teams may never know what extreme situations we may face in the future, but we have the experience of knowing that we made a difference for thousands of lives in rural Kentucky in the aftermath of the 2022 flooding and we can have hope that our survey work in the future will impact lives for the better.

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BIOGRAPHICAL NOTES

Ben Shinabery, PLS the Land Survey director at QK4, has deep experience in the field and a passion for educating the public about land surveying. With extensive affiliations with professional surveying organizations around the world, Ben brings a unique perspective to his survey work. Whether he's surveying along remote creeks or under bridges, Ben's approach emphasizes the importance of understanding the survey data collected for engineers and why it matters.

Appendix A

NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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News Headlines
- Widespread Flooding Occurred Across Kentucky in Mid February 2025. See the Details Here.
- Winter Weather Safety Resources

11 AM UPDATE: WINTER WEATHER RETURNS WHILE FLOODING LINGERS IN SOME AREAS.
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Historic July 26th-July 30th, 2022 Eastern Kentucky Flooding

Jackson, KY
Weather Forecast Office

Weather.gov > Jackson, KY > Historic July 26th-July 30th, 2022 Eastern Kentucky Flooding

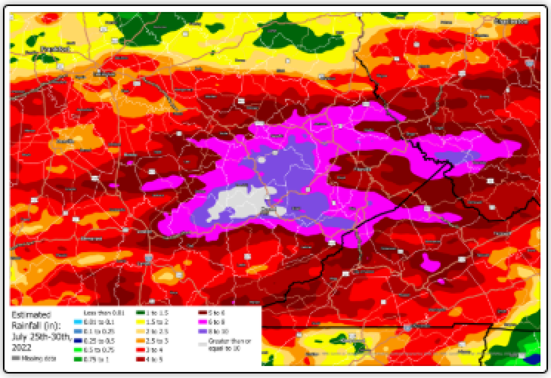
Current Hazards | Current Conditions | Radar | Forecasts | Rivers and Lakes | Climate and Past Weather | Local Programs

Overview

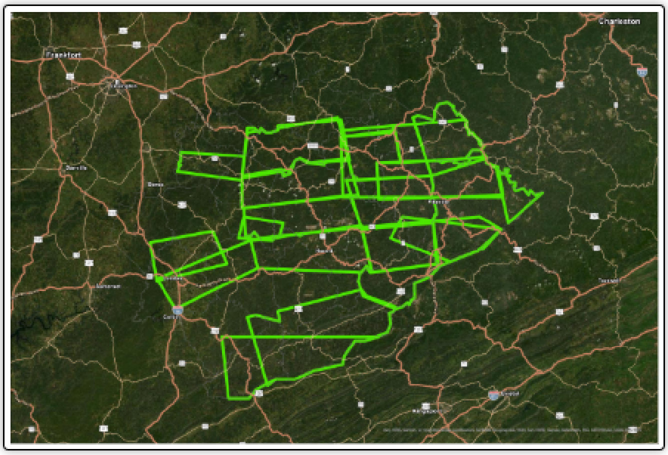
Between July 25th and July 30th, 2022, several complexes of training thunderstorms developed south of I-64 and brought heavy rain, deadly flash flooding, and devastating river flooding to eastern Kentucky and central Appalachia. These thunderstorms, at times, caused rainfall rates in excess of 4"/hr across complex terrain that led to widespread devastating impacts. While it did not rain continuously during this 4-day stretch, the overwhelming amounts of rain and resultant flooding led to 39 deaths and widespread catastrophic damage. Entire homes and parts of some communities were swept away by flood waters, leading to costly damage to infrastructure in the region. Over 600 helicopter rescues and countless swift water rescues by boat were needed to evacuate people who were trapped by the quickly-rising flood waters. In total, 24 Flash Flood Warnings were issued between July 26th and July 30th. Between the evening of July 27th and the mid-morning hours on July 28th (the peak of the event), 13 warnings were issued, 3 of which were upgraded to a Flash Flood Emergency.

Radar-based rainfall estimates suggest that upwards of 14-16" of rain fell during this 5-day period in a narrow swath, with many more locations receiving 6-10" of rain. Most of this rain fell during the night of July 27th into the morning of July 28th, which is when the most devastating impacts were felt. The highest totals occurred across an axis that stretches from northern Clay and southern Owsley counties, east through southern Breathitt and northern Leslie counties, into Perry, Knott and Letcher counties. The highest rainfall total report was from southern Knott County, where 14.00" fell between July 25th and July 29th. This site, a cooperative (COOP) observer at Carr Creek Lake, reported 6.71" from 7am July 28th to 7am July 29th, following a report of 6.50" at that site on the previous day. Another COOP site in Buckhorn reported 8.00" of rain for the 24-hour period ending 7am on July 28th. The rainfall total in Buckhorn from July 25th to July 29th was 11.76". These rainfall values occurring in such a short period of time are incredibly rare: there is less than a 1 in 1000 chance for this much rainfall over five days in a given year.

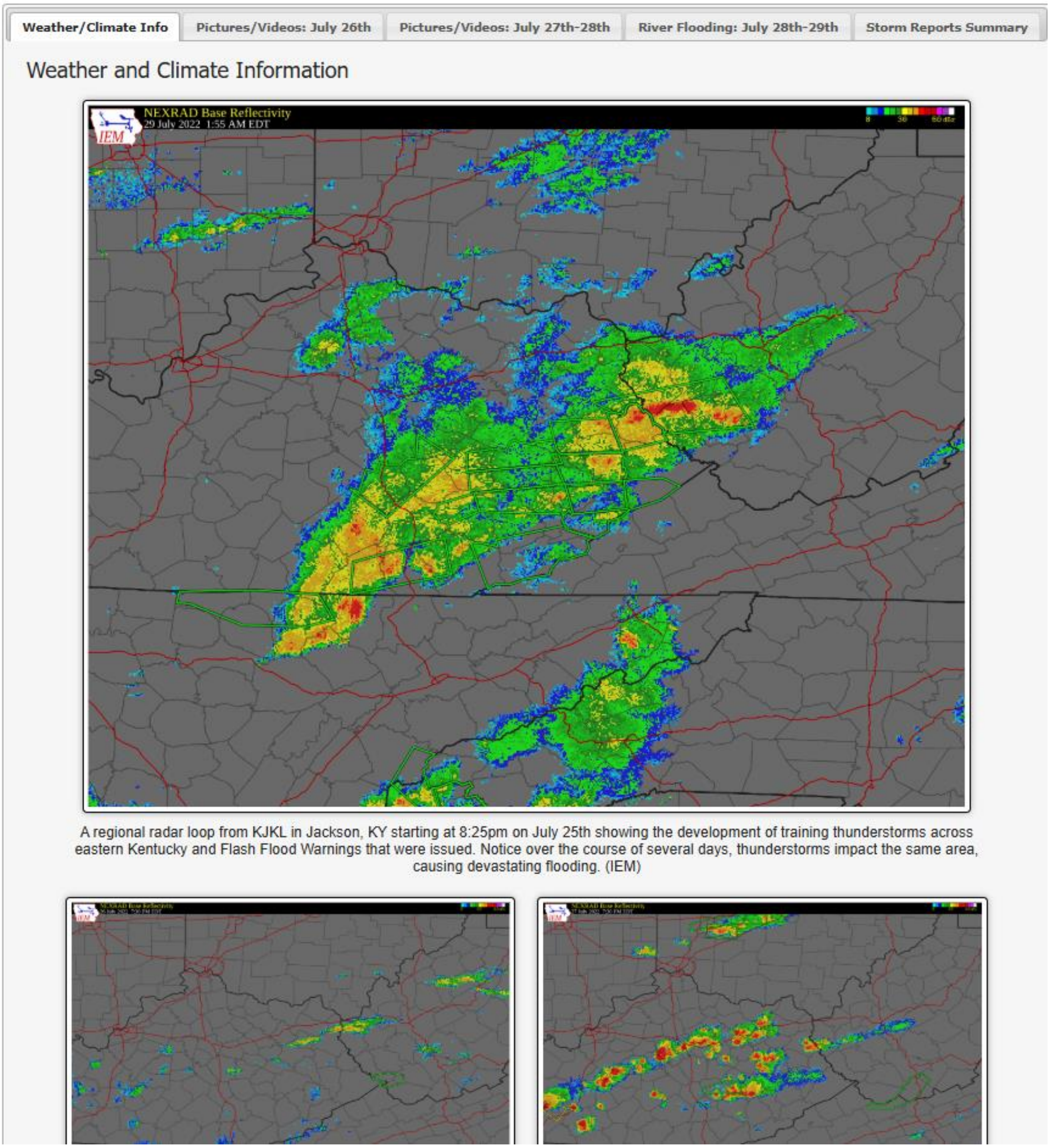
The incredible rainfall also led to significant rises and flooding on many rivers in eastern Kentucky including on the main stem of the Kentucky River; North, Middle and South forks of the Kentucky River; Red River and Licking River. At Whitesburg, the North Fork of the Kentucky River swelled well above major flood stage, reaching close to 21' before gauge failure (the previous flood of record was 14.7' in 1957). The North Fork of the Kentucky River at Jackson also reached major flood, setting a new record crest of 43.47' (the previous record was 43.1' set in 1939). The river flooding caused a second round of destruction for communities in the region, and caused flooding in downstream areas that did not receive as much rainfall.

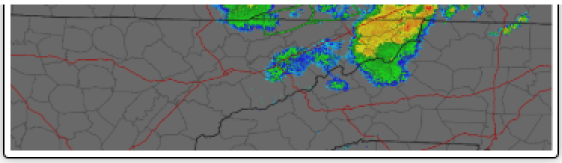


Estimated rainfall totals from July 25th through July 30th, 2022 via NCEP Stage IV precipitation data.

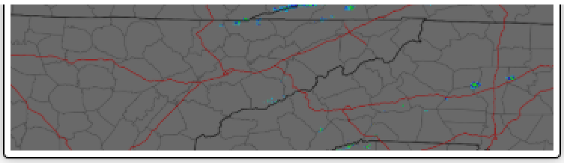


Flash Flood Warnings issued by NWS Jackson, KY from July 26th through July 30th, 2022. **Three of these warnings were "Flash Flood Emergencies."** This type of Flash Flood Warning is reserved for catastrophic flash flooding events.

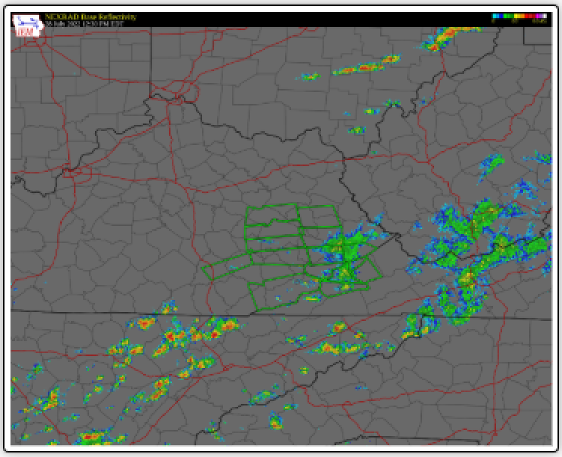




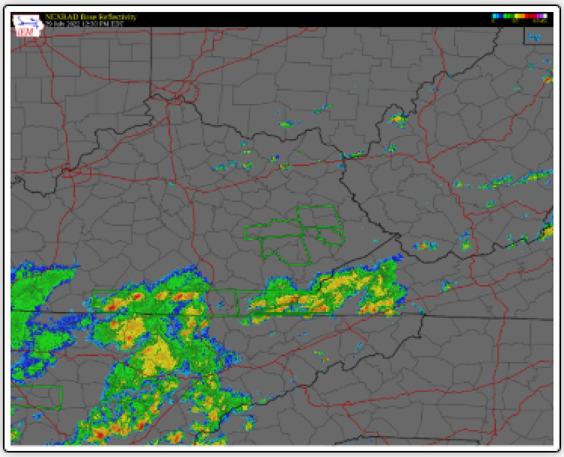
Radar loop from KJKL in Jackson, KY on July 26th (IEM)



Radar loop from KJKL in Jackson, KY on July 27th (IEM)



Radar loop from KJKL in Jackson, KY on July 28th (IEM)

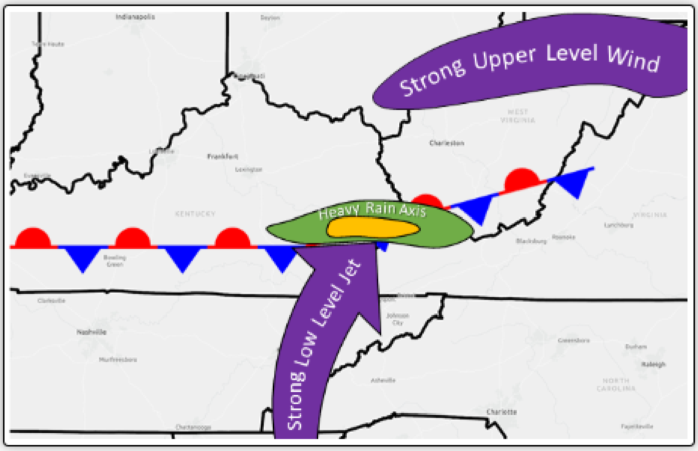


Radar loop from KJKL in Jackson, KY on July 29th (IEM)

Light rain was falling late on July 25th and into the early morning of the 26th, before heavier rain entered the region around 6am on the 26th. An axis of training thunderstorms impacted parts of eastern Kentucky and southern West Virginia through the day.

After a nearly 24-hour break from heavier, widespread rain (though a few thunderstorms did still impact the area) another round of training thunderstorms set up across eastern Kentucky during the evening of July 27th, warranting numerous Flash Flood Warnings and leading to the devastating impacts and loss of life.

The training thunderstorms lasted for hours during the night of July 27th into the early morning of July 28th. These storms began to taper off just before 12pm on July 28th. Another round of thunderstorms then impacted the already-soaked region late that night into the morning of the 29th, adding insult to injury.



A conceptual model for the meteorological setup of the flash flooding event that occurred from July 26th to July 30th, 2022 in eastern Kentucky. This setup is described in further detail in this paper written by Moore et al. (2003) in the AMS Weather and Forecasting journal.

The heavy rain fell north of a stationary front that was anchored across southern Kentucky. Strong low level winds (around 5,000 feet AGL) brought in copious amounts of low-level moisture, which interacted with the stationary front and the upper-level jet stream to produce repeated thunderstorms over the same areas for more than 6 hours - several days in a row. These thunderstorms caused an intense swath of heavy rainfall. Most of the area saw at least a few inches of rainfall, with a narrow band of 10 to 14" observed in east-central Kentucky.

Climatological Context for This Devastating Flash Flooding Event

- The rainfall totals observed between these dates across eastern Kentucky were over 600% of normal.
- While most of the region was drier than normal going into July, this amount of rain in such a short period of time would overwhelm any area, simply due to the very high rainfall rates.
- NWS Jackson set two records for 24-hour rainfall: July 26th's observation of 2.11" broke the previous record of 1.78" set in 1993, and July 27th's observation of 4.11" broke the previous record of 1.37" set in 2014.
- A COOP site in Buckhorn Lake (which has records dating back to 1961) measured 8.00" of rain in a 24-hour period, which beat the previous record of 1.80" at that site. That value is also the most rain the site has ever observed. The 4-day total from July 26th to July 29th at Buckhorn was 11.76", also a record for that amount of time.
- The Carr Creek Lake COOP (which has records dating back to 1981) reported 6.71" in the 24-hour period ending 7 AM on July 29th, after receiving 6.50" in the previous 24-hour period ending on July 28th. The 4-day total from the 25th to 29th was 14.00".
- The estimated peak rainfall totals of 14-16" from the 26th through 29th are historically unheard of. There is less than a 1 in 1,000 chance of that amount of rain falling in any given year over a 4-day period.

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Appendix B

Bridge modeling uses software and algorithms to create virtual blueprints, helping engineers design, analyze, and visualize bridge structures.

What is bridge modeling?

Bridge modeling is the process of using specialized software to create digital blueprints of bridge structure Sophisticated algorithms and modeling techniques are used to replicate the physical attributes and behavior o bridge elements in a virtual environment. The goal is to help engineers design bridge models, perform structura analysis, and visualize models in the context of their natural and built environments to share with project stakeholders.

Connecting the world with 3D bridge modeling software

Bridge modeling software provides a digital canvas for building detailed models, simulating how they'll operate in real-life stress conditions and adjusting blueprints to reflect those insights long before construction begins. This is done using tools such as:

Parametric modeling: enables the creation of intelligent, customizable 3D models and quick adjustments and iterations based on changing design parameters and requirements.

Finite element analysis (FEA): Engineers can assess structural integrity by simulating real-world conditions, analyzing factors such as stress, load distribution, and material behavior.

Clash detection: identifies conflicts or interferences between design elements, preventing potential construction issues.

Visualization tools: provide realistic visualizations for better understanding and communicating design intent to stakeholders.

Bridge modeling software revolutionizes construction with intelligent 3D models, stress simulations, conflict detection, an seamless collaboration. NavisWorks rendering of the M4 motor in London courtesy of Atkins.

Complex geometry handling: capable of facilitating intricate bridge designs, including curved structures, complex shapes, and unconventional geometries, with accurate modeling and analysis.

Collaboration tools: facilitates collaborative work among multidisciplinary teams, allowing seamless communication and coordination among project architects, engineers, and contractors.

When construction begins, blueprints and models serve as digital twins for virtually validating concepts, managing the construction process, allocating resources, and conducting ongoing maintenance after delivery.

The data that bridge modeling software aggregates makes it an effective hub for project stakeholders to access and review variables in virtual plans, edit models remotely in real time, and get disciplines (architects, engineers, contractors) on the same page.

Benefits of 3D bridge modeling software

Computer-aided design impacts several stages of a bridge construction project. The best way to understand its importance is to highlight where bridge modeling software comes into play, such as:

Data-informed negotiations

CAD models can be referenced during negotiations to clarify project specifics and ensure the client's expectations and the contractor's proposed process are aligned.

Connected workspaces

During construction, CAD models serve as a digital canvas for managing a bridge project through completion and as a workspace where stakeholders can share ideas and interact with data in real time.

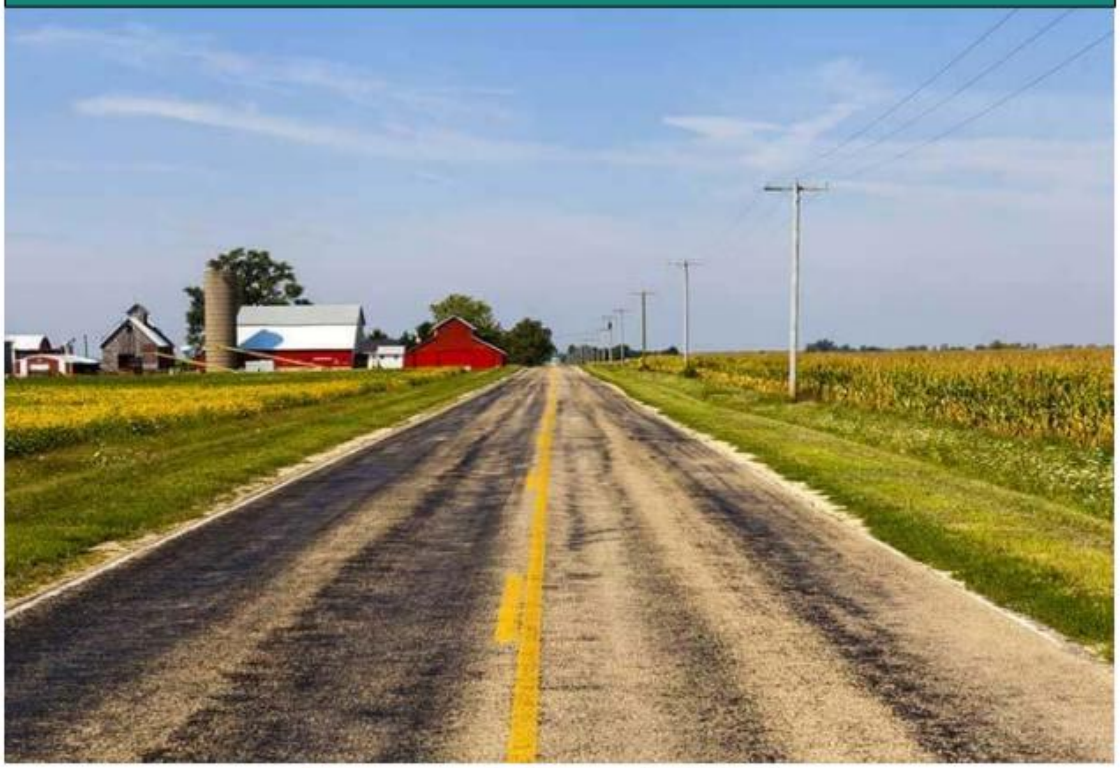
Project management

Digital models can be updated wit
real-time feedback and mark-ups t
help monitor progress when a proj
is in the construction phase.

Appendix C

RURAL CONNECTIONS:

EXAMINING THE SAFETY, CONNECTIVITY, CONDITION AND FUNDING NEEDS OF AMERICA'S RURAL ROADS & BRIDGES



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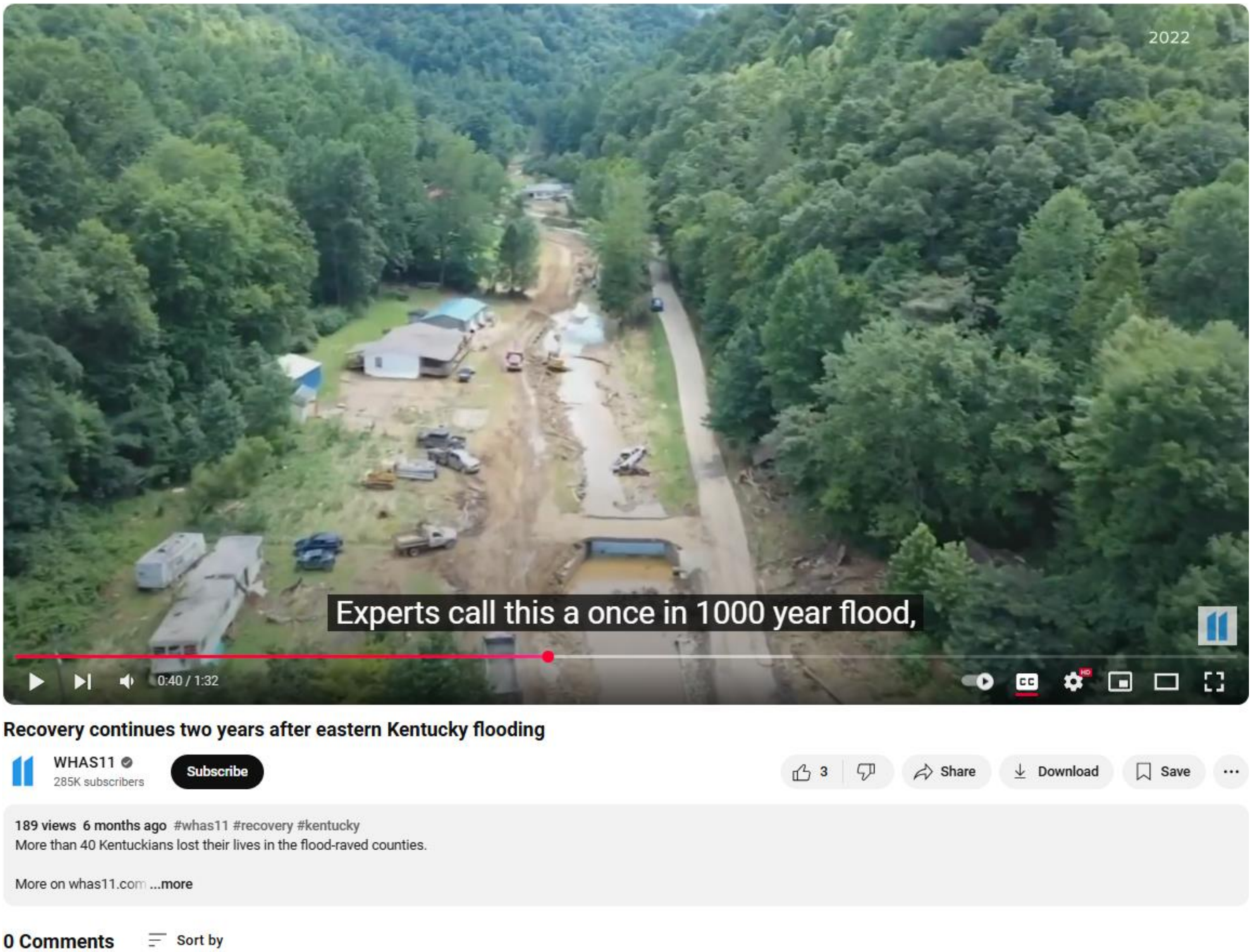
SEPTEMBER 2024

Founded in 1971, TRIP ® of Washington, DC, is a nonprofit organization that researches, evaluates and distributes economic and technical data on surface transportation issues. TRIP is sponsored by insurance companies, equipment manufacturers, distributors and suppliers; businesses involved in highway and transit engineering and construction; labor unions; and organizations concerned with efficient and safe surface transportation.

Appendix D


2022
Experts call this a once in 1000 year flood,
0:40 / 1:32
Recovery continues two years after eastern Kentucky flooding
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More than 40 Kentuckians lost their lives in the flood-raved counties.
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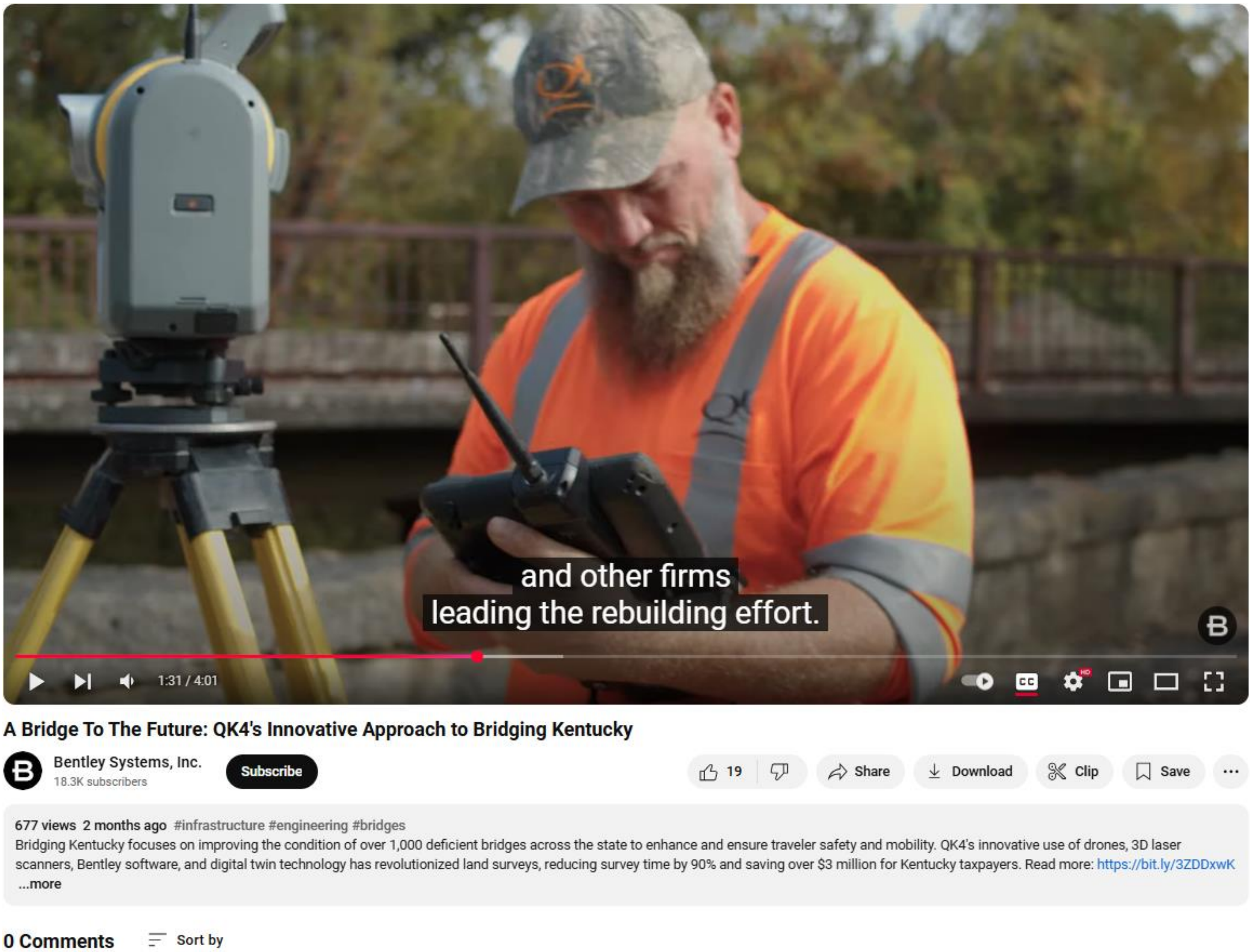
Appendix E



and other firms
leading the rebuilding effort.
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A Bridge To The Future: QK4's Innovative Approach to Bridging Kentucky
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Bridging Kentucky focuses on improving the condition of over 1,000 deficient bridges across the state to enhance and ensure traveler safety and mobility. QK4's innovative use of drones, 3D laser scanners, Bentley software, and digital twin technology has revolutionized land surveys, reducing survey time by 90% and saving over $3 million for Kentucky taxpayers. Read more: https://bit.ly/3ZDDxwK
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