The role of GIS in communicating hazard risk and developing an emergency alert system in Grand Canyon, Arizona

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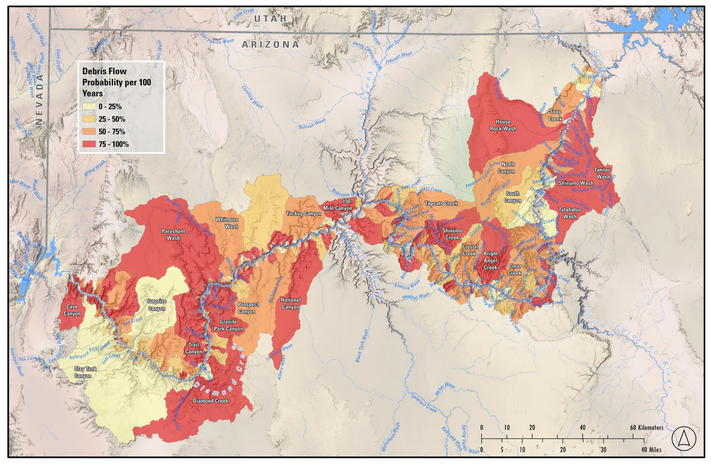
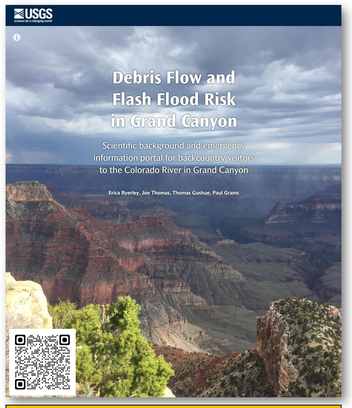
ABSTRACT

Visitors to backcountry areas of Grand Canyon National Park can now subscribe to a new emergency warning system that works in areas where cell phone signals are absent. The **Grand Canyon River Alert System** is a free, subscription-based service specifically designed to send custom hazard-related alerts to satellite messaging devices (SMDs), the first system of its kind in the nation. Visitors can also subscribe and get the alerts through a cell phone when cellular reception is available.

The Grand Canyon River Alert System (GCRAS) provides government-issued emergency alerts to wilderness recreationalists in the Grand Canyon, who are often outside the bounds of cellular signal reception. Alerts may include information on boating hazards, missing persons, critical streamflow-related operations for the Colorado River and flash flood warnings. GCRAS is a collaboration between the U.S. Geological Survey, Southwest Biological Science Center's Grand Canyon Monitoring and Research Center (USGS-GCMRC), National Weather Service (NWS), Coconino County Emergency Management (CCEM), and National Park Service (NPS), drawing on the unique capabilities and data resources of each organization.

At the core of this new alert system are authoritative geospatial data sets – developed, maintained and served by GCMRC using ESRI's ArcGIS software suite (from ArcGIS Pro to ArcGIS Enterprise) – that were used both directly in the development of alert messages received by subscribers and indirectly through geospatial analyses and relationships used to further communicate the risk associated with such events.





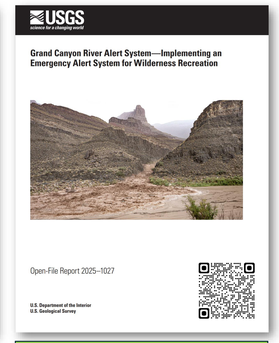
Link to the USGS geonarrative (ArcGIS Online Story Map):
https://grandcanyon.usgs.gov/gisapps/debrisflowflashfloodrisk/

Debris Flow and Flash Flood Risk in Grand Canyon Geonarrative (Story Map)

This project was focused on communicating risk associated with debris flow and flash flood events in Grand Canyon. To facilitate this the team developed a suite of informational products. Some of the same data sets that were identified and produced to help inform the emergency alert process were also used to drive a visually-stunning geonarrative – the USGS term used for Story Map products – that is a deeper dive into the science behind these events in Grand Canyon. This new online product is packed with information, images, videos and interactive maps that highlight debris flow and flash flood events, and the geospatial data used to provide more context on the potential impact these events have across this unique landscape.

The geonarrative also links out to other products we have developed as a part of our risk communication strategy, including several announcement-style write-ups for community-based publications, the official USGS news release and recently published USGS report on how the Grand Canyon River Alert System was developed and implemented, and information on how to subscribe to the alerts.

Link to the USGS news release:
https://www.usgs.gov/news/state-news-release/new-backcountry-alert-system-warns-grand-canyon-visitors-about-flash-floods



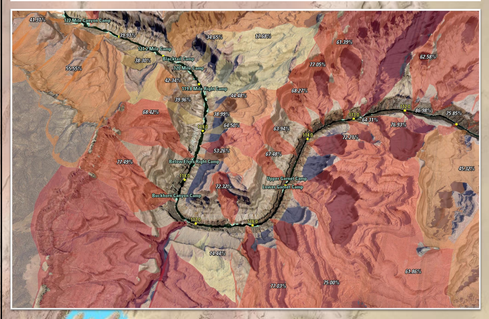
Link to the USGS report:
https://pubs.usgs.gov/publication/ofr20251027

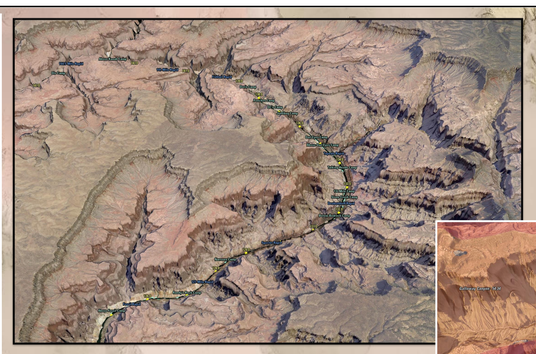
Geospatial data and analysis

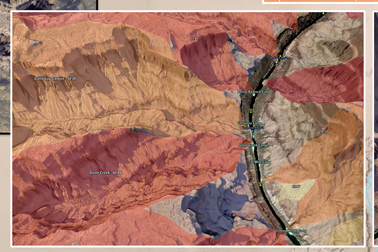
The GCMRC geospatial team reviewed past studies of debris flow events and revived published work on debris flow probabilities for ungauged tributaries in Grand Canyon (Griffiths and others, 2004). This entailed joining the probabilities with 740 tributary watersheds that terminate at the mainstem of the Colorado River in Grand Canyon. Then, a spatial overlay of geomorphic units with river campsite polygons yielded the percentage of each geomorphic unit type within each campsite.

Weather-related risks to people in the Grand Canyon can be particularly high at debris fans where tributaries enter the Colorado River corridor, and concurrently, where many people recreate and camp. Some geomorphic unit types have inherently more risk associated with them. For example, a debris fan would have more potential for risk in times of flooding than a separation bar (sandbar) that is further from the mouth of a tributary that is flashing. Intersecting tributary watersheds with river campsites yielded the debris flow probability at each campsite. This geospatial analysis was conducted to supply supportive information to the public regarding where debris flow and flash flood events occur and what areas can be impacted.

- Existing GCMRC geospatial data sets used include the Colorado River Mile System, river campsites, geomorphic map units for the Colorado River corridor, and unique geographic placenames for river rapids and tributary drainages in Grand Canyon.
- River mile and tributary name datasets were shared directly with NWS for developing weather-related alerts, and by NPS for alerts including obstructions to river travel and missing persons.
- Custom alerts issued with commonly recognized places and distances along the Colorado River for those with backcountry experience in Grand Canyon.
- Information provided in the alerts can also be referenced in published river guidebooks to obtain a better understanding of where events may be happening.
- Use of these geospatial data sets to inform weather-related forecasts and in location-based messaging makes the GCRAS a novel form of communicating risk for backcountry travel.







Galloway Canyon Flash Flood, August 2024

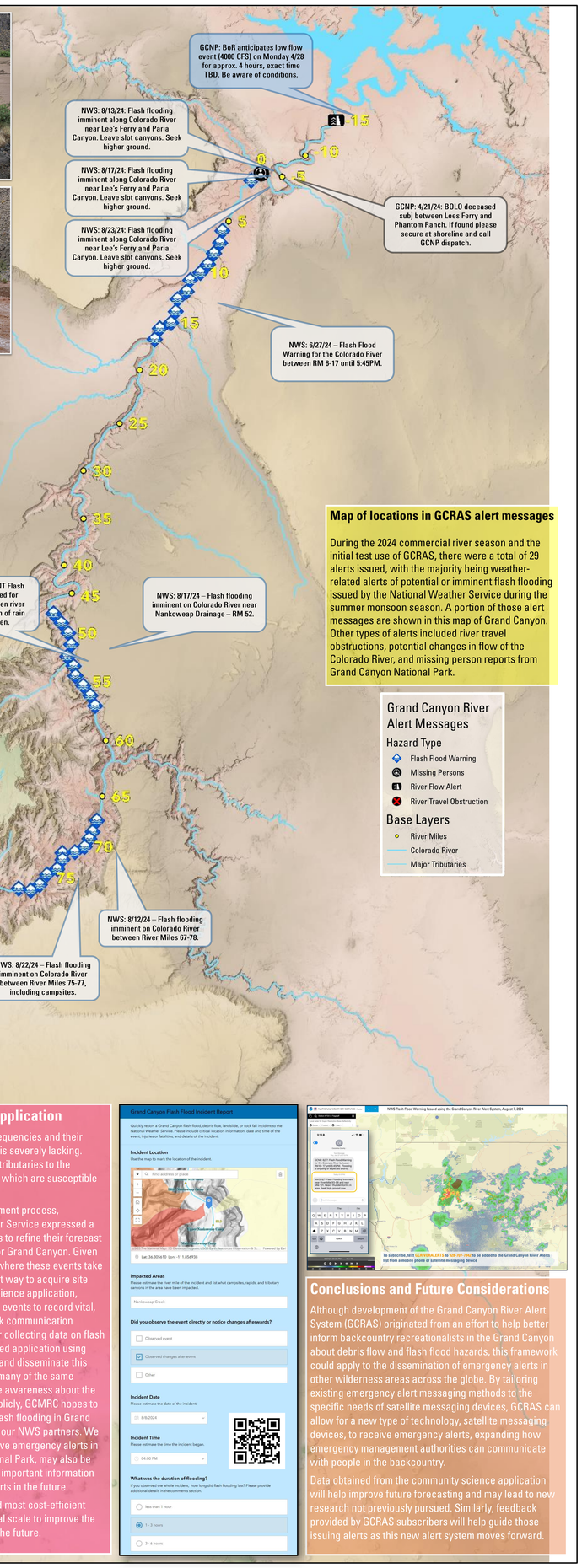
Left: 3D Oblique view of Middle Granite Gorge of the Colorado River in Grand Canyon

Below, Left: 3D oblique view looking upstream with Galloway Camp and Duebendorff Rapids in view. Named tributary canyons and debris flow probabilities labelled in white.

Below, Right: 3D oblique view looking across the Colorado River and into Galloway Canyon and Stone Creek.

Right, Top: River runners on a private boat trip in Grand Canyon witness the flash flood while scouting the "new" Duebendorff Rapid.

Right, Bottom: Moments later, a USGS – GCMRC Sediment Monitoring trip runs Duebendorff Rapids. For reference, the boat in this photo is a 37-foot motorized raft.



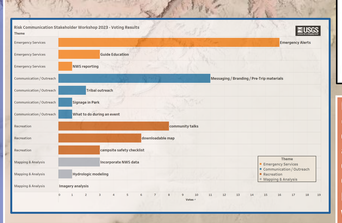
Map of locations in GCRAS alert messages

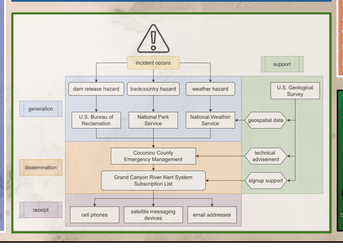
During the 2024 commercial river season and the initial test use of GCRAS, there were a total of 29 alerts issued, with the majority being weather-related alerts of potential or imminent flash flooding issued by the National Weather Service during the summer monsoon season. A portion of those alert messages are shown in this map of Grand Canyon. Other types of alerts included river travel obstructions, potential changes in flow of the Colorado River, and missing person reports from Grand Canyon National Park.

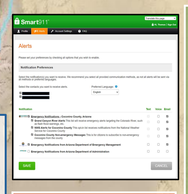
Implementing the Grand Canyon River Alerts System

The Grand Canyon River Alert System (GCRAS) emerged out of a growing awareness of the intersection between weather-related hazards, visitor-use patterns, and advances in satellite communication technologies. In September 2023, the USGS organized a Colorado River user stakeholder workshop to help identify the most effective methods of presenting debris flow and flash flood hazard information. Participants included staff from Federal agencies (USGS, NPS and NWS), local emergency management officials (CCEM), Tribal representatives, environmental advocates, private boater association members, and commercial river guides. Stakeholders were split into the following breakout groups that aligned with the stakeholders' expertise: emergency services, recreation, mapping and analysis products, and scientific communication and community outreach. After the breakout sessions concluded, the top three communication ideas from each breakout group were reported to the larger stakeholder group and participants voted to rank potential communication strategies and products by perceived importance and effectiveness. Developing an emergency alert system designed for satellite messaging devices received the most votes.

Building off the stakeholder workshop, the USGS established a working group of those who would be responsible for data sharing, alert development, and alert dissemination to implement an emergency alert system specific to the needs of SMDs and backcountry visitors in Grand Canyon. The group included USGS, NWS, CCEM and NPS staff. The USGS provided expertise in satellite communication technology and applied geospatial data analysis that integrated river campsites, tributary drainages, geomorphic units at campsites, and the Colorado River Mile System to produce more meaningful datasets to be used in the alert system (Gushue, 2019). NWS and CCEM staff provided expertise in emergency alert creation and dissemination. NPS employees provided knowledge of backcountry hazard message development and backcountry recreationalist education.

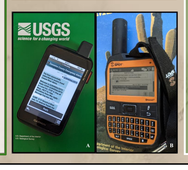






Message design and character count are critical for effective dissemination of alerts to SMDs, and character count also varies depending on the manufacturer of the device and the service provider.

When developing GCRAS, SPOT and Garmin inReach devices were tested, which use the Globalstar and Iridium satellite networks, respectively.



System Framework

The GCRAS framework uses a modified subscription list method for sending alerts with a defined character count, short-code signup capability, and a focus on synthesized information. Although GCRAS caters to the specific needs of SMDs, it is also compatible with standard cellular devices and email addresses, enabling emergency alerts to be received by individuals who are not in the backcountry, such as family members and managers of commercial guide companies.

GCRAS is designed to be flexible and compatible with as many devices and service providers as possible; it primarily does this by meeting the needs of devices with the lowest character count per message limitations. By doing so, GCRAS can easily incorporate existing and future forms of satellite-based communication, such as emerging low-earth-orbit cellular technology.

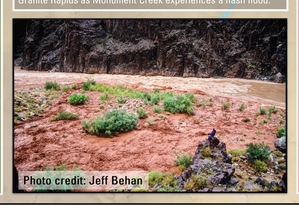
GCRAS implements a short-code signup method. Short codes are low character count words or phrases that when received by a specific phone number trigger an action, such as subscribing or unsubscribing from a list. By sending an outbound short code from an SMD to the GCRAS signup phone number, the SMD is initiating contact and can therefore receive inbound messages from that same number. The GCRAS short-code signups and emergency alert disseminations are conducted by the same phone number.

GCRAS messaging is provided by NWS or NPS officials to CCEM depending on the nature of the event. In general, weather-related hazards are provided by NWS, while public safety and Colorado River boating hazards and flow information are provided by NPS. All alert messaging is communicated to CCEM, which ensures that the message meets GCRAS specification, including character count and message relevance. CCEM then disseminates the alert message to the GCRAS subscription list.

Granite Rapid at the mouth of Monument Creek, River Mile 93

Above: Imagery map showing the extent of Granite Camp boundary and the Monument Creek debris fan. Notice the overlap of these boundaries and drainage visible in the 2021 high-resolution imagery.

Below: River runners scout the potential changes occurring in Granite Rapids as Monument Creek experiences a flash flood.



Grand Canyon Flash Flood Application

Institutional knowledge of flash flood frequencies and their impacts on recreation in Grand Canyon is severely lacking. There are approximately 740 ungauged tributaries to the Colorado River in Grand Canyon -- all of which are susceptible to flash flooding during any given year.

During the risk communication development process, collaborators from the National Weather Service expressed a need for more data on flash flood events to refine their forecast models and issue more precise alerts for Grand Canyon. Given the extreme terrain and remoteness of where these events take place, the team determined that the best way to acquire site observations is through a community science application, allowing people that witness flash flood events to record vital, first-hand information. As part of our risk communication strategy, GCMRC identified a method for collecting data on flash flood events by developing an ESRI-based application using ArcGIS Online and Survey123 software and disseminate this new mobile-based application through many of the same communication channels used to create awareness about the GCRAS. In releasing this application publicly, GCMRC hopes to gather crowd-sourced information on flash flooding in Grand Canyon and share that information with our NWS partners. We anticipate that those signing up to receive emergency alerts in the backcountry of Grand Canyon National Park, may also be some of the same individuals collecting important information that will help us improve upon those alerts in the future.

This application represents the best and most cost-efficient method for acquiring data at the regional scale to improve the accuracy of forecasting flash floods in the future.

Conclusions and Future Considerations

Although development of the Grand Canyon River Alert System (GCRAS) originated from an effort to help better inform backcountry recreationalists in the Grand Canyon about debris flow and flash flood hazards, this framework could apply to the dissemination of emergency alerts in other wilderness areas across the globe. By tailoring existing emergency alert messaging methods to the specific needs of satellite messaging devices, GCRAS can allow for a new type of technology, satellite messaging devices, to receive emergency alerts, expanding how emergency management authorities can communicate with people in the backcountry.

Data obtained from the community science application will help improve future forecasting and may lead to new research not previously pursued. Similarly, feedback provided by GCRAS subscribers will help guide those issuing alerts as this new alert system moves forward.