**Millersville University of Pennsylvania**

# An Analysis of High Impact Weather Messaging and Communications

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**Abstract**

This research will explore both the effectiveness of hazardous weather messaging in reaching the public and its impact on their actions. The goal is to gain a better understanding of how to best reach the public with hazardous weather messaging and to identify which part of weather messaging compels individuals to take action to protect themselves and their property. Studies have shown that there has been a problem with the public's ability to comprehend the emergency weather messages (NWS Hazard Simplification, n.d.). Studies by the National Weather Service conducted between 2014 and 2018 have shown that a large segment of the public does not understand the importance of weather messages or the actions that they should take in response to these. A survey of students at Millersville University was conducted to gather information on weather messaging, evaluate the understanding of the terminology used in weather messaging, and recommendations for improving the messaging. Interviews were conducted with meteorology and decision-support professionals who play a role in the creation of weather messaging to better understand the current weather messaging system and its goals. The outcomes of the study will focus on the elements of the messaging that are currently effective and potential changes that could improve the current system.

## I. Introduction

On an average fair weather day, if the public wants to see what weather is in store for them, they would likely seek out this information from the news or a weather app. In the cases of impending hazardous weather, messages are sent out by the NWS and private entities, such as AccuWeather, through various mediums in an effort to share timely and critical information about an event. Whether a weather message is communicated through the news or via an alert on a phone, weather messaging is usually composed by the local National Weather Service (NWS)

Weather Forecast Office (WFO) in a region. There are three hazard levels currently being used by NWS: Watch, Warning, and Advisory. Common hazards that face the Mid-Atlantic region and central Pennsylvania include severe thunderstorms, high wind, tornadoes, dense fog, winter weather, and flooding.

However, just because the NWS is issuing weather messages, it does not mean that the public is necessarily receiving these messages. Community members may not have access to the technology that is needed to access these messages, like cell phones or TVs. There may also be those that have the means to receive messaging, but choose not to or opt-out of receiving messaging as they may find it bothersome. Even if the message(s) are received, they may not be read or understood. If the public is not receiving the information related to a hazard, they will not be able to best prepare for the impacts of the hazard. In cases of high-impact weather, such as tornadoes or flooding, if the public does not understand what actions to take then there is a chance they could be negatively impacted by the loss of property or physical harm.

This study aims to gain a better understanding of how effective the current weather messaging system is in reaching the public, if they understand the message(s), and whether the correct protective actions are taken. This research will include a review of studies on the effectiveness of hazardous weather messaging and the current changes being implemented in the language of messages. Furthermore, the study utilizes a survey of Millersville University students and interviews with professionals who are involved in weather communication and messaging. The goal of the survey is to better understand the effectiveness of hazardous weather messaging among a specific population of college students. The goal of the professional interviews is to understand what goes into creating weather messaging and the related actions.

## II. Background/Literature Review

### A. Current Issues in Hazardous Weather Messaging

The current NWS hazardous weather messaging system is the Watch, Warning, and Advisory (WWA) system that has been used for decades. Even though the public finds some of the terms confusing, the WWA system has proven to be very effective when it comes to protecting life and property. Not only does the public potentially lack a good understanding of what the terminology means, but they find it difficult to differentiate between the different messages. The NWS developed the Hazard Simplification (Haz Simp) Project in 2011 to make changes to the current system to better ensure the public is prepared and protected from hazards. The project has two main approaches: repair and revamp. Repair focuses on the minor changes that can be made to the current system, two examples of this are consolidating the number of WWA products and reformatting the WWA product text to simplify it. Revamp focuses on major changes that could be made to the current system. This could mean that the NWS may have to change policies, the current messaging paradigm, and the software used. The revamp section of the project led to the NWS conducting studies to learn of the level of understanding the public has regarding the current WWA terms, potential new terms, and the potential impacts of changing the system. The NWS concluded conducting surveys in 2018. Currently the NWS is in their second to last phase, planning for outreach and training. Beginning in 2025, the NWS will begin the final phase, development and implementation (NWS Hazard Simplification, n.d.).

### B. NWS Studies and Findings

The NWS Haz Simp team conducted a variety of studies between 2014 and 2018 to gauge public understanding of weather messaging and to also assess issues experienced by other groups like emergency managers and broadcast meteorologists related to weather messaging.

The findings of the 2014 Focus Groups were that while there was a spectrum of understanding of the WWA system and terms, the term “Advisory” was the least understood. There was also support behind moving to a hierarchical system to either replace or add to the current system that involved the use of colors, symbols, or language. Other findings concluded that there are too many WWA products with confusing text. Despite the changes proposed by these groups, many advised that major changes not be made unless there was further research and testing, along with a public outreach campaign (NWS Hazard Simplification, n.d.).

Further studies were conducted in 2015, with a Haz Simp Workshop and a Case Study Survey being conducted by the NWS. The workshop included partners like emergency managers, broadcast meteorologists, private sector partners, and social scientists. The goal of the workshop was to create prototypes to be tested to replace WWA terms and figure out minor adjustments that could be made to the WWA system to simplify messages. A variety of changes were suggested, ranging from only changing the “Advisory” term to completely remaking the system with new terminology. There was some agreement on combining or eliminating some products as well as improving the formatting and details of messaging. The participants who wanted a new system advised to use tiers of colors, words, and action-based language. The case study survey reached hundreds of professionals including emergency managers, broadcast media, and other weather, water, and climate enterprise partners. The participants were prompted to point out what worked and did not work in the hazard messaging. The findings focused on changes including the simplification of products, improvements in formatting and language used, increased coordination between NWS WFOs, consideration of more impact-based focus of WWA product definitions, and increased education and outreach no matter the extent of changes to the current system (NWS Hazard Simplification, n.d.).

In 2016 the NWS conducted a Testbed Activity where the previously developed prototypes from 2015 were tested among professionals such as emergency managers, NWS forecasters, and broadcast media. Some key findings included that action-based language did not perform well, especially among forecasters. The participants in this activity were in agreement that any other potential changes to the system should also be tested via the Testbed to understand how they would operate. In 2017 the NWS sponsored an Institutionalization Survey which had organizations from a variety of sectors to understand how dependent organizations are on the WWA system and the impact on their respective policies and operating procedures. It was found that "Warning" was most embedded in organizations policies and "Advisory" was the least. Furthermore, most respondents believed they could adjust to a change in the WAA system within a year (NWS Hazard Simplification, n.d.).

The most recent survey conducted by the NWS is the 2018 Generalizable Public Survey, which was part of the last research phase. Unlike the previous surveys, this survey was focused solely on testing public knowledge of current WWA terms and prototype terms (Figure 1). There were about 7000 individuals surveyed across the United States. The hazards tested include winter weather, thunderstorms, tornadoes, coastal flooding, flash flooding, and areal flooding. For this study, the results of only thunderstorms, tornadoes, flash flooding, and areal flooding will be examined as they are more likely to affect central Pennsylvania. When testing the public's knowledge of current terms, there was never more than 70% of participants who were able to correctly identify the terms. Some of the terms were only correctly identified by 30% of survey participants. To determine how effective the prototypes were in comparison with the current WWA system an ordered logistic regression was used to estimate the odd ratios of the prototypes relative to the current system (Eastern Research Group, 2018).

The surveys provided four different scenarios to assess the current and prototype prompt levels. These were (1) Warning with a downgrade, (2) Warning with an upgrade, (3) Advisory with an upgrade, and (4) Emergency with a downgrade. The survey participants were randomly assigned a prototype and either an upgrade or downgrade scenario for an initial prototype sequence. They were then assigned a different prototype and either an upgrade or downgrade scenario. After this, half of the participants were randomly chosen to give information for either the current system or the prototype they were assigned to assess if the information affected the protective responses. The protective response questions assessed how participants would react given a prompt. The action options included do nothing, monitor, prepare, take some action, and take protective action. The action options were worded to reflect the actions that would be taken for specific hazards. The likelihood that participants would take the various actions was also assessed on a scale of one (very unlikely) and five (very likely). The survey questions also asked for the demographics of the participants, including information such as the participant's location or gender. Participants were asked questions to assess how participants perceive and respond to various hazards. Furthermore, they were asked about their sources of weather information and how often they access it. In order to obtain a wide range of responses and attempt to survey multiple demographics, survey participants had to be over 20 years old, the number of survey responses from one state was limited, and a maximum of 65% of participants to be women. The surveys were randomly distributed through Qualtrics and available for about a week between February and March of 2018 (Eastern Research Group, 2018).

For the 2018 survey, the level of understanding of the different prompt levels for thunderstorms was relatively low. For severe thunderstorm watch, only 43.5% correctly identified the level. For significant weather advisory, only 24.3 % correctly identified the level, with 50.5% of participants instead selecting the definition for severe thunderstorm warning. For severe thunderstorm warning, only 56.8% correctly identified the level (Figure 2). For thunderstorms, the current system outperformed all of the prototypes, especially at the watch level, but in terms of being protective, the prototypes performed better at the advisory level (Eastern Research Group, 2018).

The level of understanding of the different prompt levels for tornadoes was still somewhat low, but compared with the other hazards assessed there was generally a better understanding. For a tornado watch, 67.3% correctly identified the level. For tornado warning, 70.6% correctly identified the level. For a tornado emergency, only 28.9% correctly identified the level, with 61.3% of participants instead selecting the definition for tornado warning (Figure 2). For tornadoes the current system outperformed Prototype 1. It was concluded that Prototypes 2 and 3 may be more effective than the current system at the watch level, but not by much. Increased monitoring was performed similarly by both the current system and the prototypes (Eastern Research Group, 2018).

The level of understanding of the different prompt levels for flash flooding was also somewhat low. For a flood watch, only 50% correctly identified the level, with 45.7% of participants instead selecting the definition of flash flood warning. For flash flood warning, 64.5% correctly identified the level. For flash flood emergency, 62.2% correctly identified the level (Figure 2). For flash flooding the prototypes were generally outperformed by the current system, especially at the watch level. However, the prototypes were more effective at promoting protective action at the advisory level (Eastern Research Group, 2018).

The level of understanding of the different prompt levels for areal flooding was fairly low. For a flood watch, only 44.4% correctly identified the level, with 38.9% of participants instead selecting the definition of flood advisory. For a flood advisory, only 42.6% correctly identified the level, with 30.3% of participants instead selecting the definition of flood watch. For a flood warning, only 43.6% correctly identified the level (Figure 2). For areal flooding, the prototypes performed mostly better than the current system, with Prototypes 2 and 4 being the most effective. However, compared to the current system Prototype 3 was less effective (Eastern Research Group, 2018).

The overall findings of the 2018 survey found that Prototypes 2 and 4 had the best performance. Despite performing better than the current system more times, there was not a drastic improvement. Prototypes 1 and 3 generally performed the worst compared to the current system. The best performing prototypes varied by hazard, with the current system or Prototypes 1 and 3 performing best. The findings from the surveys also concluded that headlines matter in how the participants responded to the various prototypes. As found in the previous research conducted by the NWS, the term “Advisory” was found to have a poor level of understanding and was outperformed every time by Prototypes 1, 2, and 4 at the advisory level. The performance of the prototypes also varied across the prompt levels. For example, while Prototype 2 performed best at the watch level relative to the current system, Prototype 4 was outdone by the current system. It was also found that Prototypes 2 and 4 were also better than the current system to compel action and increasing monitoring of the hazard. Prototype 2 was most effective at increasing preparation (Eastern Research Group, 2018).

### C. Related Studies and Findings

A 2018 paper by Taylor, et al. explored the effectiveness of weather messaging around the globe. This study focused on specific issues including changes toward impact-based weather warnings, the public’s uncertainty toward forecast accuracy, catering messaging to different groups, the role of social media, and the context in which weather messaging is used in decision-making. The challenges of weather communication and potential solutions are discussed as well. In an attempt to address these issues, the World Meteorological Organization (WMO) created the High Impact Weather initiative, whose goal is to help increase understanding of what users need in early warning systems. This study utilized a variety of methodologies from around the world, including interviews, surveys, decision experiments, stakeholder workshops, case studies, and social media analysis (Taylor, et al., 2018).

The 2018 paper by Taylor, et al. found that the intensity of the hazard being communicated can lead to differences in the intent to take protective action. Studies by Casteel 2018 and Morss et al. 2018 found that in areas prone to more tornadoes or hurricanes in the United States, people were more likely to take protective action for higher warning levels that made the impacts more important than the warning or description of meteorological conditions. The same studies also found that language meant to cause fear or play up catastrophic impacts in messaging did not lead to more action. Another important finding of this study was that the intent to take protective action was related to the trust in the forecast. There was a link between the expected severity of a hazard and a greater degree of trust in the consistency of forecasts. A challenge with this is that forecasts change over time, leading to greater forecast uncertainty and more doubt in the impact of a hazard. A partial solution to this challenge is to more effectively communicate the probabilities involved in forecasts to the public. Recent work by LeClerc et al. 2012 suggests that providing information about forecast uncertainty can lead to lower the loss in trust due to false alarms. The trust in correctly forecasting some impacts of a hazard but not others is also common. An example of this is provided in a study by Bostrom et al. 2018, which found that people who live in areas prone to hurricanes trust forecasters to predict hurricanes, but do not have as much faith in their ability to predict the exact location of landfall. The recommendations of the WMO were discussed by Taylor, et al. 2018 where the WMO suggested that hazards and forecasted information is being communicated, is accessible, and provides the public input on actions to take.

In a 2021 journal article Ernst, et al. explored how the public perceives the potential severity of a hazard based on the language or colors associated with different levels. The goal of the study was to understand the comprehension of forecasts by the public as the accuracy of forecasts is already known. The methodology of the study included a survey that asked participants to rank words and colors from lowest to highest risk. The study found that the current terminology being used by the Storm Prediction Center (SPC) can be confusing to the public and that there needs to be future public surveys to find future improvements to the language used, specifically more easily understood language. Currently, the SPC uses numerical probabilities and a five-tier scale of wording and colors. The SPC has made previous changes to their weather messaging terminology. In 2014 the SPC added two categories for lower risk hazard levels at the urging of emergency managers for emergency management purposes. To address potential concerns of confusion due to wording, the SPC then added the corresponding color and numerical scales. This four-tier system has also been adopted by the Weather Prediction Center (Ernst, et al., 2021).

Other studies, such as the study by Williams et al. 2020, explored more specific applications of public understanding of weather communication. While the SPC found greater public understanding of weather messaging when using colors and visual products, the Climate Prediction Center found the opposite, especially among non-English speakers. Numerous studies, including ones performed by Schultz et al. 201), Powell and O'Hair 2008, and Mason and

Senkbeil 2015, found that the level of the public's understanding of tornado warnings comprehension varied between 47% to 90% based on region and demographics. Studies exploring warning comprehension of other hazards also found a spectrum of understanding that varied by demographics. For example, white, highly educated, middle-aged individuals from the Great Plains region were found to have the highest tornado warning comprehension. More studies relating to understanding of warning terminology and demographics were recommended to highlight vulnerable populations who are not being as effectively communicated to as they may need to be informed in ways other than demographics. It is also recommended that more studies be done to identify the public's patterns of weather comprehension (Ernst, et al., 2021).

### D. Current Changes and Plans

To address the issues in communication when it comes to hazardous weather messaging changes are being made, especially at the NWS. A change the NWS has already made is to adopt the "What, Where, When, Impacts" bulleted format for their long-duration products like temperature, visibility, wind, and marine hazards. The short-term products also use a bulleted format, but the format is "Hazard, Source, Location" bullets, for impact-based warnings. This format was also later applied to Flash Flood Warnings. For the more severe and extreme events, the NWS is issuing Wireless Emergency Alerts by using specific tags. As of July 2021, the NWS uses a similar system of tags to better communicate the severity of thunderstorms. Starting in 2019 the NWS has also started consolidating marine, flood, and temperature products (NWS Hazard Simplification, n.d.).

As a part of the NWS revamp process, the term "Advisory" is going to be removed from the WWA system and instead, plain language headlines will be used. The headline "Special Weather Statement" is also going to be removed. These terms will not entirely be removed, with advisories instead going to only contain descriptive information. There are no plans to change the terms or criteria for “Watch” and “Warning”. In order to make time for changes being planned, changes will not occur until 2025 (Figure 3) (NWS Hazard Simplification, n.d.).

Based on the findings of the 2018 survey, the NWS was advised to develop a prototype that combined the best aspects of Prototypes 2 and 4. Potential issues with this is that Prototype 2 varies nouns and Prototype 4 varies adjectives. It was also recommended that new prototypes cater to specific hazards too. While this survey yielded useful results into which terms perform best, it is recommended that when a new prototype is developed that further research and discussions be had to assess how it will impact operations. The last recommendation was to slowly implement changes and to test the new system on hazards that were not previously included (Eastern Research Group, 2018).

## III. Methodology

Based on the findings from the NWS highlighting the issues with the current WWA system, this research aims to determine if similar results would be found among a population of Millersville University students. The survey did not evaluate the comprehension of multiple WWA terms or the reasoning behind the lack of comprehension of WWA terms or the contents of hazardous weather messaging. The survey has three main goals, to evaluate how many individuals are receiving hazardous weather messages, the assess the level of comprehension and prior knowledge relating to the contents of the messages, and to seek out feedback on the current weather messaging system. Since one of the main ways that hazardous weather messaging is distributed is via alerts and phone apps, college students would provide a representative measure of how effectively electronic weather messaging reaches the public as they are a group that is dependent on their phones. A survey was conducted through Qualtrics to determine the effectiveness of weather messaging among Millersville University students. The survey was approved by Millersville University's Institutional Review Board and distributed to students with majors in Meteorology and Emergency Management. This group was selected since not only will most of the students be involved in weather communication to some degree in their post-college careers, but they are more likely to understand the information conveyed in weather messaging. They would also be a good resource for identifying improvements to the current system. The survey asked participants to identify if they were between 18 and 22 years of age or older than 22 years old to distinguish between traditional and nontraditional college students. The next set of questions were designed to gather information on if and how the respondents receive hazardous weather messaging. This was to first identify if weather messaging is reaching a majority of this population, as that is the first hurdle to cross in being able to communicate hazards. The next set of questions were to gauge the understanding of the current terminology used in weather messaging and if respondents understood the appropriate actions that should be taken. The final part of the survey was to provide respondents with the ability to share their opinions on the current weather messaging system and provide potential suggestions. After the survey period ended, the results were analyzed to find trends in the effectiveness of communication of hazardous weather messaging.

Along with trying to better understand the public's perspective through surveys, this research sought out the applications and issues with the operational and professional side of hazardous weather messaging. Interviews were held with Jonathan Guseman (Warning Coordination Meteorologist, NWS State College), Michael Charnick (Science and Operations Officer, NWS Cheyenne), and Amber Liggett (Communication Analyst, Groundswell Consulting Group). The interview questions focused on their current or past roles related to hazardous weather messaging along with changes in the current system that they recommended. The professionals interviewed were also asked about the feasibility of the applications of some of the recommendations from survey respondents.

## IV. Data

### A. Survey Demographics and Multiple-Choice Responses

The Qualtrics survey was distributed to approximately 200 students, with responses from 52 students. Every survey respondent provided an answer to all of the multiple-choice questions, but not every respondent responded to the open-ended questions. The majority of the survey respondents were traditional college students (age 18-22), with 19% of survey respondents being over 22 years of age (Figure 4).

When asked about how the respondents primarily receive weather information, a wide variety of answers were provided. The majority responded that they primarily receive their weather information through weather apps, with 53% selecting this option. The next most popular choice (38%) included receiving weather information from the NWS, TV, radio, and private weather companies like AccuWeather. The remainder of respondents answered that they received their weather information through social media or other methods (Figure 5). The next question focused on if the respondents receive emergency weather alerts that the NWS issues on their primary devices, whether that be a phone, TV, or radio. The majority of the respondents answered that they did receive these alerts, with 88% receiving the alerts (Figure 6). Next respondents were provided with an example of a hazardous weather message for a flood warning and were asked to identify what is meant by a flood warning. Seventy-five percent of respondents chose the correct answer, which is that flooding is imminent or occurring. The rest of the respondents chose the definitions for flash flood warning or flood watch. No respondents chose the answer “Flooding is not expected to be bad but may cause inconvenience” (Figure 7). The following question asked respondents to choose which actions they would take in response to receiving the flood warning from the previous question. The best answer provided was “Get to high ground and avoid driving in water more than a couple inches deep”, which was selected by 71% of respondents. The next most popular answer was “Be alert and cautious to potential flooding” with 17% of respondents selecting this choice. 8% picked “Stay alert to possible changes” and 4% of respondents selected “Return home and stay indoors” (Figure 8). The final multiple-choice question asked if the respondents felt that they would benefit from a source with information on what actions to take based on the weather event. The majority responded that they would benefit, with 73% answering yes. The remainder of respondents answered that they do not think that they would benefit from a source, but their reasoning was divided. About half of the respondents who answered no selected that they felt the current system works well enough and the other half answered no because they lack a strong opinion on whether a change is necessary (Figure 9).

### B. Survey Open-Ended Responses

The remainder of the survey consisted of two open-ended questions that were both optional. The first open-ended question prompted respondents who had answered yes to the previous question to answer how they feel that weather information would best be conveyed to the public. Thirty-six respondents provided responses to this question. Common themes of suggested improvements involved the method of delivering the message, including visualizations, use of social media, contents of the message, and format of the message. Another recurring response included recommending that the NWS or Federal Emergency Management Agency (FEMA) develop an app to make their weather messages more accessible. Some responses recommended finding a better balance between providing details and being brief enough to be able to take fast action if needed. Others recommended that after a weather message or alert has been issued that follow-up messages with further instructions be issued or include an emergency contact for potential questions. A large number of the responses simply suggested step-by-step or more clear instructions or to further emphasize the severity of the hazard to prompt protective action.

The last question in the survey allowed the respondents to suggest any changes they think should be made to the current weather messaging system. The question received relatively few responses, with only 15 respondents replying. One respondent answered that because there is doubt in the accuracy of warnings, improving the accuracy would help the public to better rely on weather messaging. Another respondent suggested providing more information when it came to floods. Once again visuals and using social media were suggested to improve the current system. Many respondents felt that the WWA system was outdated or confusing, so they recommended changing to simpler terminology. One response suggested that the NWS has more freedom in drafting weather messages to better tailor them to their audience. Another respondent suggested that during severe weather events the public should be notified even if they have notifications turned off.

### C. Interviews

The purpose of conducting interviews of professionals involved in weather communication was to gain perspective on how the current weather messaging system operates the way it has and to learn about the current changes the system is undergoing. The interviews were conducted individually via email and all received the same questions.

All of those interviewed were first asked to provide their current positions and any roles they have had relating to hazardous weather messaging. Jonathan Guseman is currently a Warning Coordination Meteorologist at the NWS State College, Pennsylvania. Jonathan Guseman's roles relating to hazardous weather messaging include serving as the primary liaison between his office and their partners, which include emergency managers, local broadcast meteorologists, Pennsylvania Department of Transportation, and state police. Jonathan is also in charge of the warning services for central Pennsylvania. Michael Charnick is currently a Science and Operations Officer at the NWS in Cheyenne, Wyoming. Michael Charnick's roles relating to hazardous weather messaging include communicating both daily and hazardous weather to both partners and the public. These hazards are communicated through various mediums such as social media, TV, radio, and newspaper depending on the situation. Amber Liggett is currently a Communications Analyst for Groundswell Consulting Company as a Federal contractor for the National Oceanic and Atmospheric Administration (NOAA). Amber Liggett's current role involves communication within and outside of NOAA and social media. In a previous role, Amber Liggett was a freelance broadcast meteorologist at WHTM-TV. This role included communicating hazardous weather events with the public both live on TV and online through social media posts. In addition, Amber Liggett also served as a Public Information Officer at the Pennsylvania Department of Health. This role included partnering with the Pennsylvania Emergency Management Agency (PEMA) during hazardous weather events and creating messages to provide the public with weather safety tips for the hazard.

The next question that the professionals were asked was about what challenges they face relating to creating hazardous weather messaging. Jonathan Guseman shared the challenges related to making sure that both partners and the public understand and receive the information in a timely manner. He also brought up that it is important to obtain feedback from the public and partners to make sure that they are being provided with the information that they need when they need it. A challenge that Michael Charnick mentioned is knowing which visual products work best with messaging, especially since studies have been inconclusive as to what visuals would be most effective. Amber Liggett discussed two challenges in hazardous weather messaging. One challenge is keeping people's attention to the message by balancing the amount of information and recommended actionable steps to take, especially when faced with word limits. The other challenge that Amber Liggett pointed out was the issue of not knowing whether or not people understand the contents of messaging.

Questions also focused on whether they have or are involved in any of the changes focused on messaging related to high-impact weather events. Jonathan Guseman and Michael Charnick answered yes and provided examples of some of these changes. Jonathan Guseman shared how NWS as an organization is constantly adapting their messaging and related products based on the feedback they receive from their partners along with shifting their messaging towards probabilistic messaging. Michael Charnick shared how each weather event introduces the challenge of how to choose which visualizations would best be incorporated. Michael Charnick also brought up the shift toward probabilistic messaging. The professionals were asked what changes they personally think would lead to a more ideal weather messaging system. Jonathan Guseman answered that one method is to work with emergency managers to create Hazardous Weather Action Plans. These plans would include contact information of professionals who could be contacted to answer questions about what actions to take for specific hazards. Michael Charnick answered that using an evidence-based approach to decide which graphics to use and at what times to use them. The graphics should be chosen based on which ones will motivate action the most over aesthetic appearance.  He further pointed out that there are many graphics that can be useful, but potentially in limited ways. Jonathan Guseman elaborated on some of the issues surrounding the use of graphics. Similarly to weather messages, the public may misinterpret or not understand the meaning of the graphic. For example, in Figure 10 there is information about the conditions that may lead to wildfire spread but does not explicitly show which locations are at high risk, which may lead to public misinterpretation. There is also the issue with trying to use graphics on social media since the graphics may not reach the public in a timely manner due to social media algorithms. When meteorologists are creating graphics, it is difficult to find the right balance between the amount of text and visuals in a single message. He also pointed out that visuals may not be able to be distributed over all mediums and not be accessibly by those who are visually impaired.

At this point of the interviews, the professionals were provided with some of the suggested improvements from the survey of Millersville University students. Some of the suggested changes included the creation of a NWS or FEMA app, using imaging (graphics and radar), more social media, tailoring messaging more specifically to individual areas or hazards, changing the formatting of messages, and allowing severe/life-threatening alerts to bypass disabling notifications. The professionals were asked their opinions on whether or not these suggestions should be implemented or not. Jonathan Guseman's response focused on the need to have a consistent and coordinated message and the importance of the public to have multiple methods of receiving weather messaging as the public may receive messaging from other agencies, especially regarding travel impacts. Michael Charnick responded that one of the suggestions related to the development of a NWS app to distribute messaging was not possible. Michael Charnick pointed out that while social media and tailored messaging can be helpful, the content still needs to focus on the specifics. Michael Charnick added that the NWS is aware that the public and other groups that use their data know that there is useful information out there, but they do not know where to find it or look for it. Amber Liggett also shared some insight on why a NWS app will not be made, as the NWS is a public entity and does not want to compete with private companies who also have weather apps. She agreed that visuals and graphics would likely benefit message comprehension as she has found that it helps in depicting climate change impacts. Similarly to Michael Charnick, Amber Liggett agrees that social media can be a useful tool as there are different ways to share information on different platforms, but it takes more effort to stay current and reach the target audience. Amber Liggett agreed that it would benefit the public to tailor messaging to individual communities based on their most common hazard and to have emergency alerts bypass any settings to disable them on phones as they could contain life-saving information.

The final question for the interview was if they had any other information on the effectiveness of hazardous weather information that they wished to share. Jonathan Guseman brought up how it is not feasible to tailor messages to every specific user, but with the help of partners like emergency managers and the media, they can find better ways to reach most people. Also, the NWS is making changes to its website to make it easier for mobile users to navigate since they will not be creating an app. While the NWS does not have an app, FEMA has an app where the public can receive alerts for severe weather warnings. Jonathan Guseman pointed out that while there will be more use of visual and graphical messaging, there will still be text-based messaging to cater to more users. Michael Charnick's response focused on the need to continue studying what users like to see in weather messaging and what they find useful, as well as involve other professionals in weather messaging, like social scientists, graphic designers, and data scientists.

## V. Discussion and Summary

The need for adjustments and changes to the current hazardous weather messaging system has been made apparent through research conducted by those in NWS and academia, including what was accomplished for this study. This research has shown that there are a variety of issues with the current weather messaging system, with some of the core issues being a lack of public understanding of terminology such as advisory, formatting of messages, the terminology and language used with the message, and the lack of visuals in messaging. The lack of clear communication between the public and those creating weather messaging has contributed to these issues. Moving forward there needs to be improved communication and feedback relating to weather messaging, as suggested by the NWS studies and interviews conducted for this study. This will allow for improved public comprehension and understanding of both terminology and message contents to detect potential improvements to the system. The importance of communication between the NWS and its partners who are dispersing weather messaging was also pointed out by Jonathan Guseman, as it would be difficult for the public to understand the message and take the best actions to protect themselves if there is conflicting information from different sources. This also relates to the use of social media as an online source for distributing hazardous weather messaging. Social media is an effective way to reach a large segment of the public, but it also allows for the spread of misinformation easily. To avoid the spread of misinformation, a consistent message should be distributed by credible sources.

Every system will have its pros and cons, making it impossible to create a perfect system that would work for all hazards or all people. There will always be a technological barrier when it comes to reaching every member of the public, especially in cases of power outages as a result of the hazard. There will also be people with disabilities having difficulty in understanding weather messaging, or those who may not understand English. One way to help bridge the gaps in understanding which was proposed by participants of the NWS studies, the survey, and the professionals interviewed was to incorporate more visuals in weather messaging. The one downside of visuals was brought up by Michael Charnick, who pointed out that while visuals can prove useful, the usefulness varies by visual. Some visuals will work better for some circumstances or hazards than others, but this issue still needs to be researched. While clear communication can always be improved by those creating hazardous weather messages, more needs to be done to better educate the public. This research focused mainly on how the current weather messaging system caters to the public, but there is also a lot to learn from why the public lacks a basic understanding of weather messaging and terminology. It would be beneficial for the adoption of a better weather messaging system to improve the understanding of the gaps in weather education, along with how to best educate the public. Educating the public could be in the form of outreach by local WFOs or including a unit on weather basics in the school curriculum.

There are a variety of proposed changes to the current weather messaging system. Popular ideas include changes such as including visuals and modifying the language used. As pointed out by Michael Charnick, visuals can be very helpful in understanding weather messaging, but knowing which type of visual is best to use can be difficult. Visuals can be subjective and the viewer may not fully understand the message that they are trying to get across. Language can also be subjective. Some argue that hazard scales that use terminology such as moderate, high, extreme, etc. would be a better system, but it may be difficult to understand what a “moderate” hazard entails compared to an “extreme” hazard. Some of the changes proposed by students from the survey already exist, so it appears that many of the respondents and therefore potentially the public are unaware of the tools and services available to them. Many respondents of the student survey proposed a NWS or FEMA app to receive weather messaging on their phones. While a NWS app will not be developed, there already exists a FEMA app for this exact purpose, but many were unaware of its existence.

There are some other issues that were raised in this research, including considering how changes to the current weather messaging system will be impacted. Not only does new or changed terminology need to be better understood by the public, but it also must be functional for operational meteorology purposes. Also, the impact of change on businesses and organizations must be considered. The timing of changes is an important factor, as making changes to the system too quickly may lead to further confusion and lack of understanding. It is also important to understand the role that demographics play in the comprehension of various hazards and terminology. Locations that experience certain types of hazards are more likely to understand the severity of the hazard compared to a location that rarely experiences the same hazard. This means that some locations may need more education and outreach to understand a hazard and what actions to take compared to other locations. This can be especially applicable to vulnerable populations who lack the resources to have a full understanding of weather terminology or access to the needed technology.

While many necessary changes are being made by the NWS to address issues with the current weather messaging system with the Haz Simp Project, there will always be room for improvements and adjustments. Only within recent years did individuals start receiving weather messaging on their cell phones. In the next few decades, there could be new forms of technology and communication that will provide alternative ways of receiving weather messages, bringing a new set of potential issues. The weather messaging system is one that requires constant upkeep and feedback to provide the best information to the public on how to keep themselves safe in hazardous conditions. Moving forward, along with continuing research on public comprehension of weather messaging, there needs to be more efforts on educating the public.

## VI. Future Work

Further research into the effectiveness of hazardous weather messaging is certainly needed and could be accomplished by conducting a more extensive survey with a larger and more diverse group of respondents from a variety of geographic regions, age groups, educational experiences, etc. Furthermore, a study that analyzes the differences in how different age groups or generations receive and comprehend hazardous weather messaging would provide valuable supplemental information to this research. The survey of Millersville students focused on the effectiveness of hazardous weather messaging among a younger population who grew up with cell phones. Most have the ability to receive the latest weather information and messaging, whereas those in older age groups relied on less instantaneous forms of communication to receive their weather messaging, such as through TV or radio. A more in-depth analysis of the impact of education on weather topics on the way information is comprehended would improve the understanding the existing gaps in hazardous weather messaging. The lack of prior knowledge from the public is likely a key issue when it comes to comprehending the hazard and the contents of messaging. The 2018 study by the Eastern Research Group showed the low levels of understanding hazard terminology, exploring the ways to improve public education on these topics would likely result in greater effectiveness of hazardous weather messaging.

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**Appendix A**

| Level | Current System | Prototype 1 | Prototype 2 | Prototype 3 | Prototype 4 |
|---|---|---|---|---|---|
| Watch level | X Watch | X Outlook | X Notice | Possible X Event | Possible X Conditions |
| Advisory level | X Advisory | X Warning | X Alert | Moderate X Warning | Level Orange X Event |
| Warning level | X Warning | X Warning | X Warning | Severe X Warning | Level Red X Warning |
| Emergency level | X Emergency | X Warning | X Emergency | Extreme X Warning | Level Purple X Warning |

Note: The "X" is a placeholder for hazard-specific description. For example, for winter weather, the watch level becomes "Winter Weather Watch."

**Figure 1**: This table shows the four prototypes for a potential weather messaging system developed by the NWS. The prototypes were tested in the 2018 survey to determine the level of understanding for the current system and determine potential replacements to the current terminology (Eastern Research Group, 2018).

| Survey | Term Tested | Percentage Correct | Term Tested | Percentage Correct | Term Tested | Percentage Correct |
|---|---|---|---|---|---|---|
| Winter Weather, Mild | Winter Storm Warning | 43.1% | Winter Weather Advisory | 14.5% | Winter Storm Watch | 70.6% |
| Winter Weather, Cold | Winter Storm Warning | 43.8% | Winter Storm Advisory | 17.4% | Winter Storm Watch | 68.9% |
| Thunderstorms | Severe Thunderstorm Watch | 43.5% | Significant Weather Advisory | 24.3% | Severe Thunderstorm Warning | 56.8% |
| Tornadoes | Tornado Watch | 67.3% | Tornado Warning | 70.6% | Tornado Emergency | 28.9% |
| Coastal Flooding | Coastal Flood Watch | 41.6% | Coastal Flood Advisory | 44.4% | Coastal Flood Warning | 55.6% |
| Flash Flooding | Flood Watch | 50.0% | Flash Flood Warning | 64.5% | Flash Flood Emergency | 62.2% |
| Areal Flooding | Flood Watch | 44.4% | Flood Advisory | 42.6% | Flood Warning | 43.6% |

**Figure 2**: This table shows the percentage of survey participants who correctly identified the correct WWA term when prompted (Eastern Research Group, 2018).

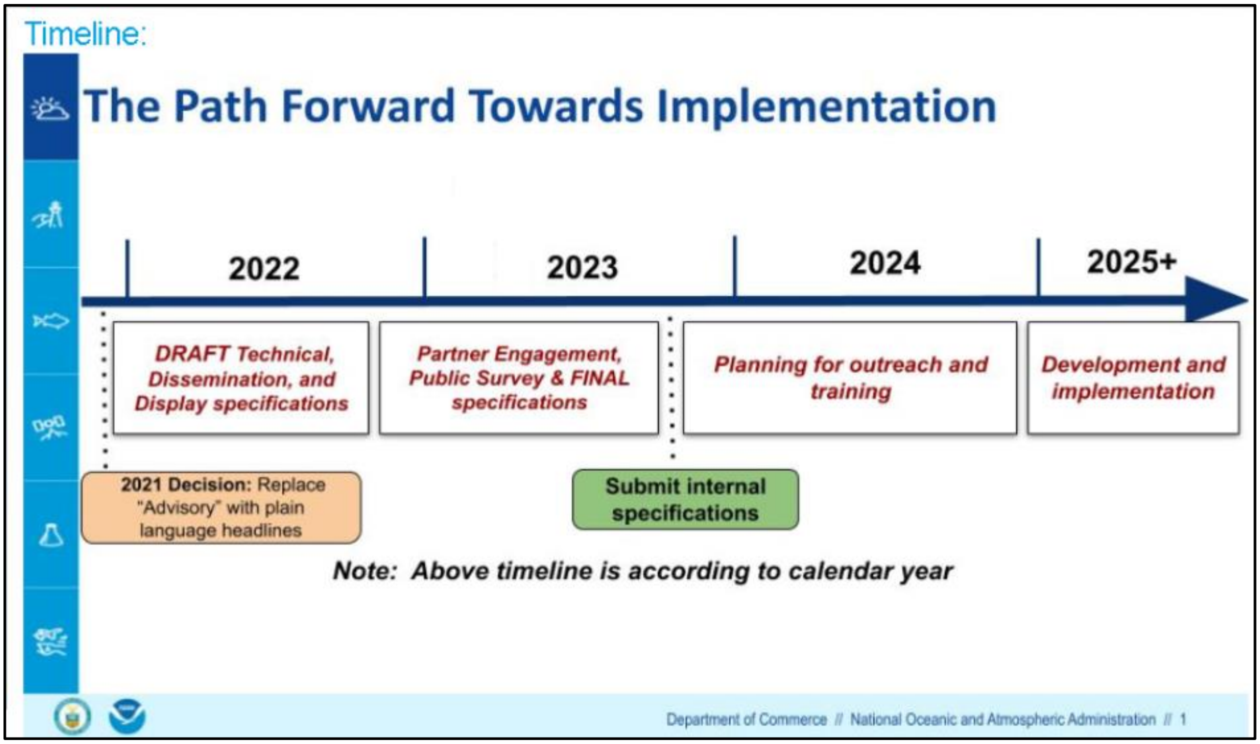


**Figure 3**: A timeline from 2021 to 2025 and beyond depicting the planned actions by the NWS to adapt the current hazardous weather messaging system. (NWS Hazard Simplification, n.d.).

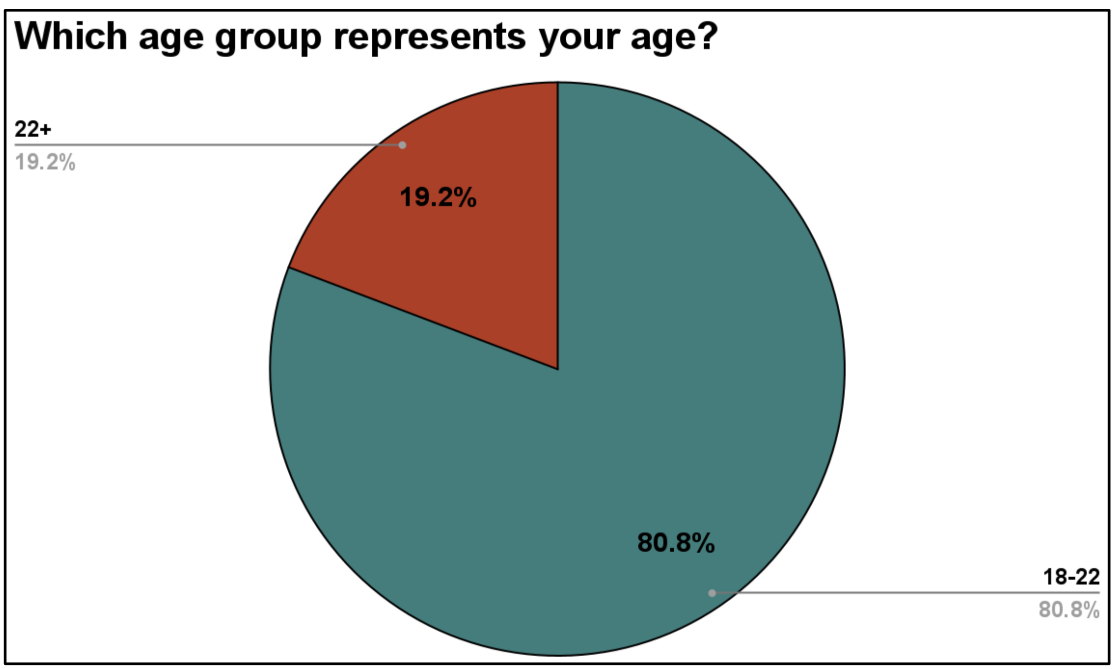


**Figure 4**: A pie chart depicting the results of Question 1 from the survey of Millersville University students.

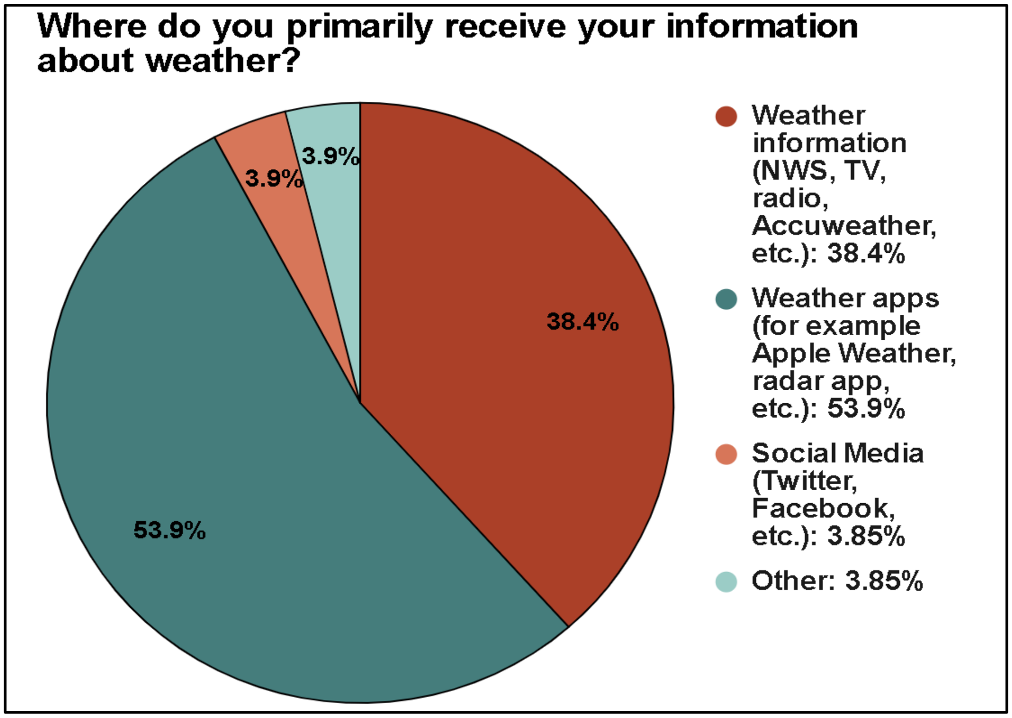


**Figure 5**: A pie chart depicting the results of Question 2 from the survey of Millersville University students.

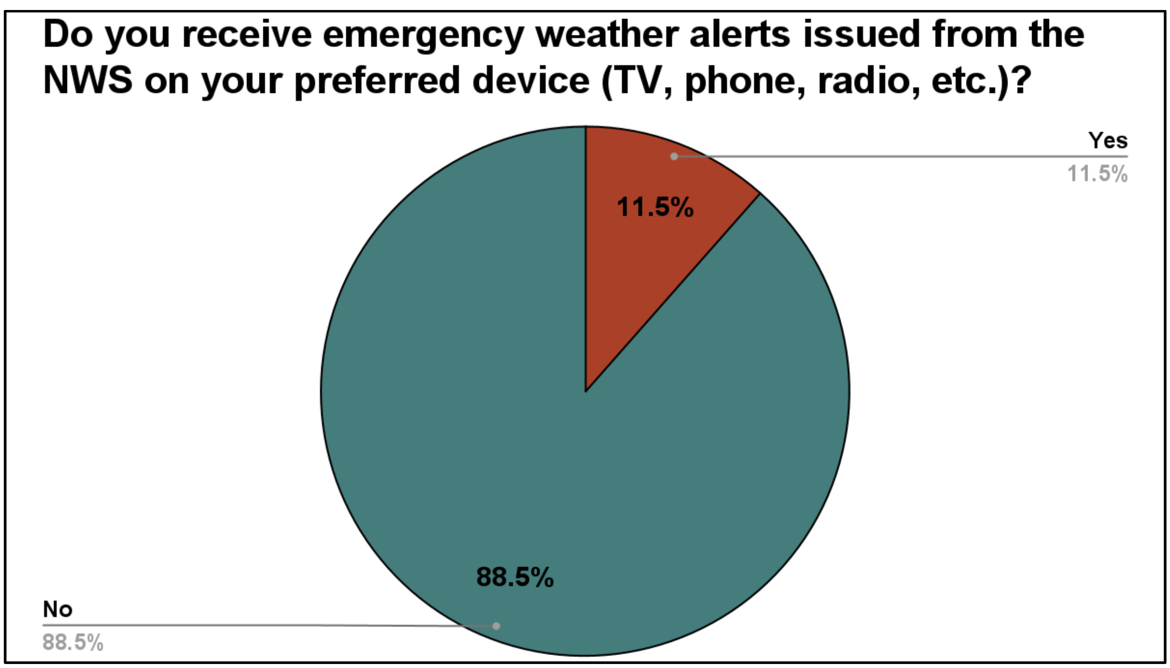


**Figure 6**: A pie chart depicting the results of Question 3 from the survey of Millersville University students.

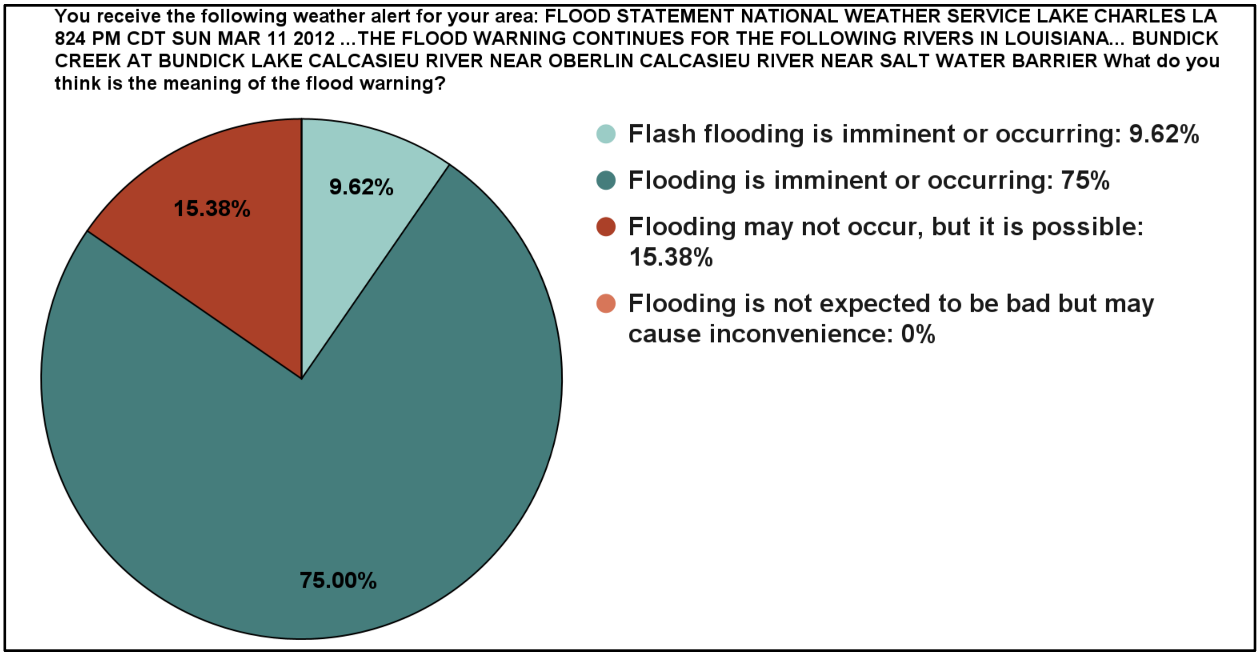


**Figure 7**: A pie chart depicting the results of Question 4 from the survey of Millersville University students.

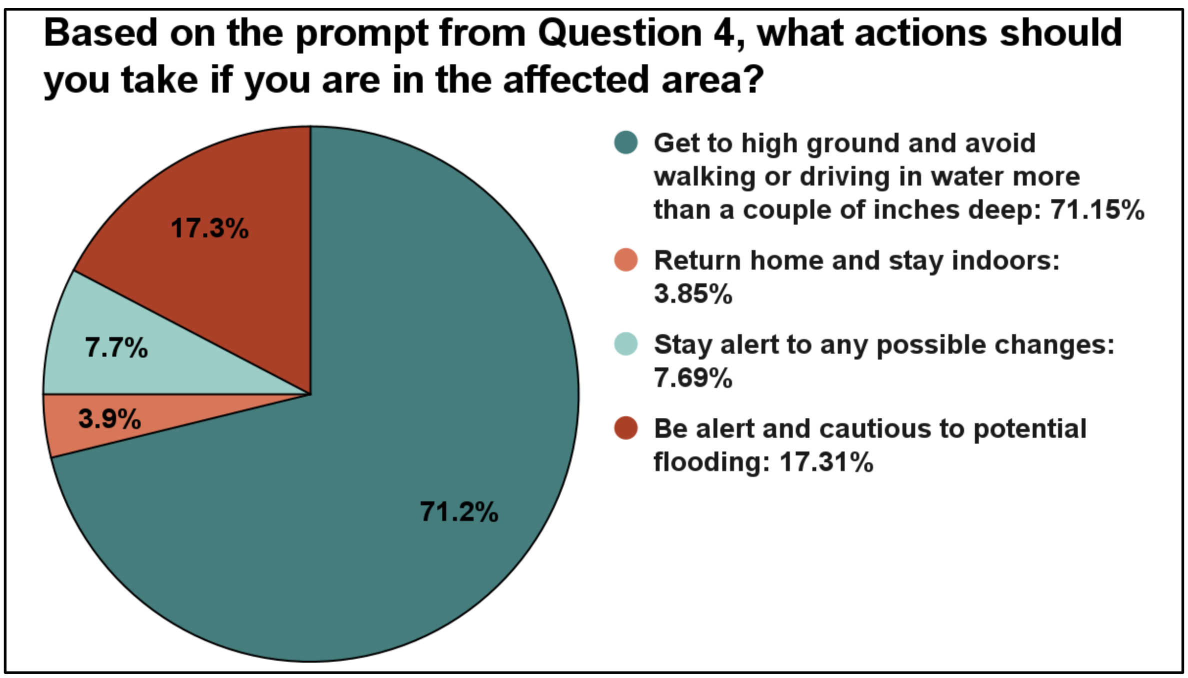


**Figure 8**: A pie chart depicting the results of Question 5 from the survey of Millersville University students.

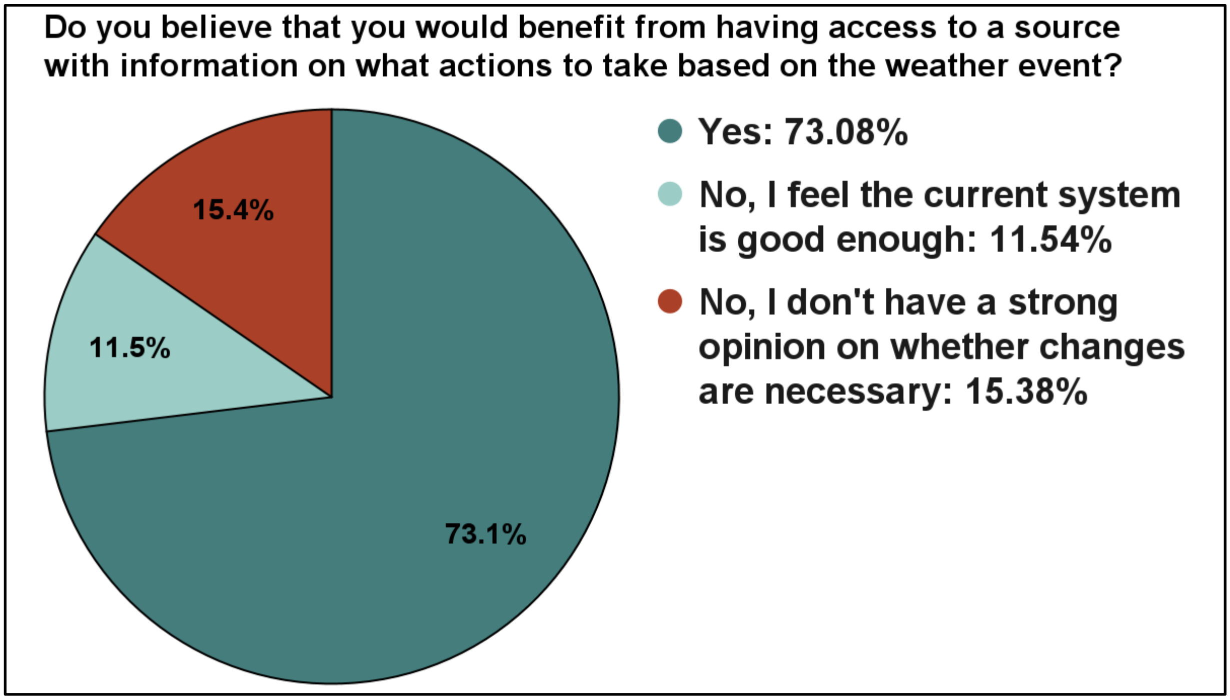


**Figure 9**: A pie chart depicting the results of Question 6 from the survey of Millersville University students.

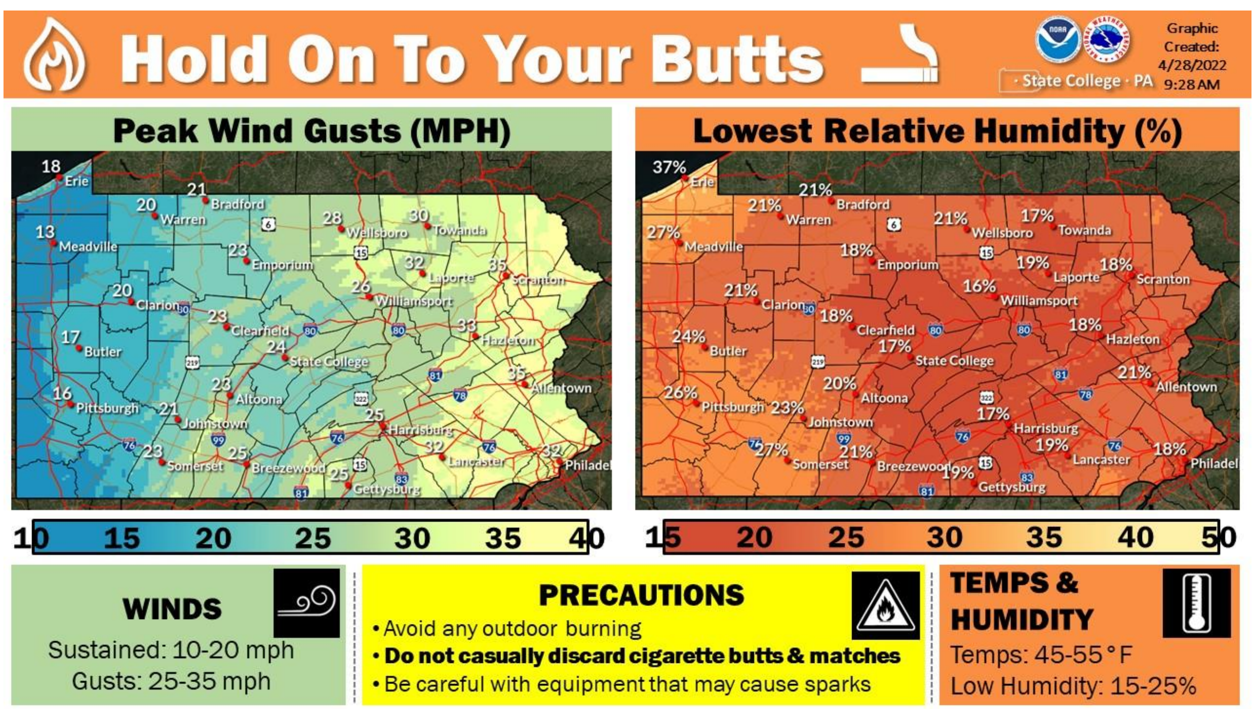


**Figure 10:** Maps showing the Peak Wind Gusts and Lowest Relative Humidity for Pennsylvania and textboxes that provide wildfire precautions (NWS State College).

**Appendix B**

Survey Questions

| |
|---|
| Question 1: Which age group represents your age? |
| Question 2: Where do you primarily receive your information about the weather? |
| Question 3: Do you receive emergency weather alerts issued from the NWS on your preferred device (TV, phone, radio, etc.)? |
| Question 4: You receive the following weather alert for your area:<br>FLOOD STATEMENT NATIONAL WEATHER SERVICE LAKE CHARLES LA 824 PM CDT SUN MAR 11 2012 ...THE FLOOD WARNING CONTINUES FOR THE FOLLOWING RIVERS IN LOUISIANA... BUNDICK CREEK AT BUNDICK LAKE CALCASIEU RIVER NEAR OBERLIN CALCASIEU RIVER NEAR SALT WATER BARRIER<br>What do you think is the meaning of the flood warning? |
| Question 5: Based on the prompt from Question 4, what actions should you take if you are in the affected area? |
| Question 6: Do you believe that you would benefit from having access to a source with information on what actions to take based on the weather event? |
| Question 7: If you answered yes to the last question, how would the information best be conveyed in your opinion? |
| Question 8: If you have any suggestions of changes that could be made to the current weather messaging system, please elaborate below: |

Interview Questions

| |
|---|
| Question 1: What is your position? |
| Question 2: What roles do you perform in your current (or past) position that relate to messaging about high impact weather events? |
| Question 3: If you have (or had) a part in creating messaging, what challenges do you face? |
| Question 4: Are you currently involved in any of the changes focused messaging about high impact weather events? |
| Question 5: What changes do you think would lead to a more ideal system of sharing information about high impact weather events and related public messages? |
| Question 6: Some of the suggested changes I've received from my survey of Millersville students includes the creation of a NWS or FEMA App, using imaging (graphics and radar), more social media, tailor messaging to individual areas or hazards more, changing formatting of message, and allowing severe/life threatening alerts to bypass disabling notifications. What are your opinions on whether or not these should be implemented or not? |
| Question 7: Do you have any recommendations on studies or papers about the effectiveness of weather messaging? |