# ANALYSIS OF COLOR USAGE IN NWS FLOOD GRAPHICS

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ABSTRACT

National Weather Service weather forecasting offices (NWS WFOs) are responsible for graphically communicating hazard information and risk to the public during flooding events. As color is an important part of understanding graphics, color usage is relevant for proper risk communication. This study seeks to identify how color is used by the NWS in graphics for flooding events. In this study, graphics are cataloged for billion-dollar flooding events from WFOs across the United States between 2020 and 2022 up to 5 days prior to and during the flooding event. Both categorical and numerical information were documented for each graphic, and subsequently used in a frequency analysis. Overall, green was the predominant color used in graphics for flooding events, though yellow, orange, and red were also common. There was a wide variety of color ranges used (analogous, monochromatic, or rainbow), as well as key scale types, which describe the type of weather information the office is seeking to communicate (numeric, impact-based, or probability). This implies that while some colors themselves have a strong preferred use, the practical use of color may vary widely between offices. Future research could explore the relationship between different characteristics, such as which colors are most common in displays of weather information.

## 1. INTRODUCTION

Flooding has been documented as one of the most deadly and common disasters in the United States (Perry 2000; Wanless and Riley 2023). Furthermore, flooding events globally have become more severe and frequent (Berghuijs 2017). Meteorological communication between forecasters and the public is frequently done through visual graphics, and color plays a major part in visualizing data and spatial detail, especially in weather communication. Proper use of color can be informative for the public and lead to increased awareness and risk perception, while the misuse of color can lead to confusion and misunderstanding of risk (Rosen et al. 2024; Crameri et al. 2020). Therefore, color should be used meaningfully to communicate risk.

Weather Forecast Offices (WFOs) in the National Weather Service (NWS) are responsible for communicating flood risk information to the public to increase awareness and mitigate loss. Flood risk communication to the public is often done through maps and graphics posted by NWS offices. While color usage in national weather products has been examined, it has not been examined for NWS offices. This study seeks to capture how color is being used by the NWS in major flooding events to facilitate risk communication to the public.

## 2. LITERATURE REVIEW

There have been studies analyzing flooding risk perceptions (Kellens et al. 2011; Lechowski 2018) and assessing graphic quality pertaining to flooding (Merz et al. 2007; Moel et al. 2009; Henstra et al. 2019). Flood risk perception has generally been found to be influenced by risk estimates and previous experience with flooding. However, there have been very few studies on color usage in flood communication.

The NWS has been shown to be an authoritative source for local weather information (Carr et al. 2016). Despite this, a number of NWS products have been found to be visually confusing, partly because of color usage (Carr et al. 2016). The type of color usage in graphics has been

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shown to affect perceptions of risk, among both the public and experts (Lipkus and Hollands 1999; Gulacsik et al. 2022; Rosen et al. 2024). Color helps convey spatial detail, and members of the public have expressed interest in more local information of risk to understand how they are affected by disasters (Rollason et al. 2018). While not studied in the context of weather communication, Schloss et al. (2018) demonstrated that color mapping affects audience response timings to visual data that is unfamiliar to them. As most of the public is likely unfamiliar with meteorological details, this study may imply color mapping affects how quickly the public responds to risk graphics.

While there are few recommendations on how to use color appropriately in data visualization software tools (Zeileis and Hornik 2006), there are general recommendations for color usage seen in various studies that focus on optimizing data visualization. Generally, using more than seven colors can overwhelm the audience (Carr et al. 2016). Similarly, rainbow or jet color scales can misrepresent data and pose issues for people with colorblindness (Crameri et al. 2020). Above all else, it has been suggested that color should be used meaningfully and strategically (Archambault et al. 2015). It is beneficial to consider which color stands out the most (Archambault et al. 2015). For example, the Storm Prediction Center Convective Outlook has magenta as the highest risk color, yet people sometimes consider red to be the highest, which is actually used as the second highest risk color for this graphic (Ernst et al. 2021). This is in accordance with other studies that have found the color red to be most associated with risk (Braun and Silver 1995; Chapanis 1994; Wogalter et al. 1995; Leonard 1999). The risk perceived from color mapping is important to understand to help facilitate more effective risk communication in disasters.

It has been suggested that there is no concrete singular way to use color to visualize data (Lipkus and Hollands 1999). Millet et al. (2020) similarly suggested risk information may need to be personalized and take geographical factors into account. The risk and severity that forecasters attempt to communicate with color may not match what specific populations perceive (Bitterman et al. 2023). Silic et al. (2017) also highlights the relevance of culture in risk perception and associations with color. Risk communication in flooding is most effective when cultural and local context is taken into consideration (Burningham et al. 2007; Martens et al. 2009). Tailored communication that is people-centered is usually more effective than top-down communication (Haer et al. 2016). Social networks have also been shown to help facilitate attitudes for preparedness in flood risk (Lo 2013; Bubeck et al. 2012).

With the existing literature of how color usage is important to risk perception, capturing how WFOs use color to communicate risk is of great interest for efforts seeking to improve forecasting. While flood risk communication and color usage in risk communication have been studied, there is little insight in how color usage is used broadly across the United States to help facilitate flood risk perception. As such, the central question guiding the analysis for this study is as follows: how do WFOs use color to visually communicate risk to the public for flooding in graphics?

## 3. METHODS

In order to capture a satisfactory sample of forecast graphics put out by WFOs across the United States, major flooding events were identified from the NOAA National Centers for Environmental Information (NCEI) annual report for Billion Dollar Disasters (Smith 2021; 2022; 2023). The years 2020 up to 2022 were selected to collect more recent data.

Below is a description of these processes for transparency in our approach, followed by recaps of the documented events. Forecast graphics that use color to communicate risk were collected from Facebook. All local WFOs post on two social media platforms, X (formerly Twitter) and Facebook; however, since X no longer offers a free academic API (Academic Programming Interface), collecting posts using Facebook’s filtered search function was the best way to identify and collect the relevant posts. Additionally, users who interact with the WFOs on Facebook appear to be different from those who interact with the WFOs on X (Krocak et al. 2024). Posts were found and identified as relevant based on a process previously used by the Institute for Public Policy Research and Analysis for collecting WFO posts in advance of severe weather events (Bitterman et al. 2024). WFOs were included in the search if they experienced the hazard, including both being in the direct path of the weather event, as well as if they issued watches, warnings, or advisories for that event. Included offices were determined based on the archives available from the Iowa Environmental Mesonet (Iowa State University n.d.).

The dates for the inventoried events started five days prior to the event and ceased on the last day of the weather event. The decision to inventory products five days out from events was due to most rain forecasts being issued around the same time frame. Cataloging of products was completed between May 24, 2024 and July 8, 2024. Graphics were included that presented forecast information, instead of hindcasts or observations. Radar graphics were also excluded. The catalog does not include maps that just are explanatory to describe an area and vary in colors (e.g., map of WFOs in the United States), nor does the catalog include text products. In other words, the maps had to use colors meaningfully to communicate a forecast in order to be included in the study. There were a total of 371 products collected in the date range. The inventory covers four different billion-dollar flooding events. The first event chronologically occurred from January 10 to January 12, 2020. The second event occurred from January 24 to January 29, 2021. The third event occurred from May 17 to May 18, 2021. The final event covered took place from July 26 to July 28, 2022. To document each product, a row was filled out in a spreadsheet with relevant information as each WFO Facebook page was systematically examined. Each graphic received its own row in the inventory spreadsheet and its characteristics were identified through each column. Descriptions of each item that was coded for in the inventory are in Table 1.

**Table 1.** Descriptions of the information that was cataloged for this inventory.

| Column in Inventory | Description |
|---|---|
| **product** | Name of graphic on webpage. |
| **office** | Which WFO office the graphic was produced from. |
| **region** | Which NWS region the WFO is in. |
| **use** | The overall purpose of the graphic, which was either pulled from a product description or written by the research team if no description was provided. |
| **hazard** | Which weather phenomenon the graphic was describing, e.g., flooding, precipitation, wind, etc. |
| **interactive** | Binary capture for if the product was **interactive** (e.g., had zoom capabilities or overlay toggles) or **static**. |
| **type of color scale** | If the colors on the graphic were **discrete** (e.g., finite colors for each step in legend) or **continuous** (e.g., smoothed, blended colors throughout legend). |
| **number of colors and categories** | Documented number of colors used in graphics; e.g., the SPC Convective Outlook has 5 colors. If there were continuous color schemes, this number was counted from the number of tick marks on the legend. |
| **color range bin** | This is a label for the type of color scheme the graphics were using. **Rainbow** refers to colors in a scale that cover multiple hues and saturations, following the visible spectral scheme. **Monochromatic** describes colors in a scheme that are the same hue, though different shades (e.g., light blue to dark blue). **Analogous** refers to color schemes where the hues are next to each other on a color wheel (e.g, yellow, orange, red). Lastly, **complementary** color schemes refer to hues that are opposite to each other on the color wheel (e.g. red, green). |
| **Color names** | The names of the colors in the graphic, following the standard |

| | |
|---|---|
| | rainbow set and neutrals (red, orange, yellow, green, blue, purple, pink, brown, black, gray). |
| **Color hex codes** | The hex code of the color on the legend of the graphic, e.g., #43C438, which was pulled using the ColorZilla hex code picker tool (iosart 2024). |
| **key/legend** | Binary **yes** or **no** if the graphic used a key or legend. |
| **label** | If the graphic had additional labels (text or numbers) on the image (e.g., enhanced, slight). |
| **key scale type** | Describing the type of information the graphic product is displaying. **Numeric** refers to the physical extent of a hazard (e.g., inches of rain). **Probability** describes the likelihood of a hazard (e.g., 50% chance). **Impact-based** describes the categorical impact of a hazard (e.g., watch or warning categories). |
| **colorblind friendly** | Binary marker (**yes** or **no**) if graphic's color scheme was colorblind-friendly, determined using Toptal Colorblind Web Page Filter (Colorblind Web Page Filter n.d.). |
| **citations** | Link to the product, product description, and other related websites that provided the information to fill out the previous columns. |
| **link to product examples** | Link to saved image in protected drive (e. g., jpeg/png file) of graphics that was saved from the webpage. |
| **number of likes/shares** | Number of likes, comments, and shares of the post containing the graphic. |
| **post text** | Text of the post on Facebook containing the graphic. |

Statistics showing the frequency of each characteristic of the products of the inventory were calculated using R (R Core Team 2024). Frequencies of hazard type, region, color range bin, and key scale type were calculated and plotted. The maximum, mean, median, and standard deviation of the number of categories were calculated. The frequency of color hex codes were also calculated and plotted on a bar plot.

## 4. RESULTS

In regard to the hazard type of the graphics, the most frequent hazard was flooding (76.5%), followed by severe storms (16.7%), and tornadoes and droughts (1.6%) (Fig. 1). Geographically, most of the graphics came from offices located in the NWS's southern region (44.5%), followed closely by the central region (42.9%), and finally, western region (12.7%) (Fig. 2). There were no graphics pulled from the eastern region.

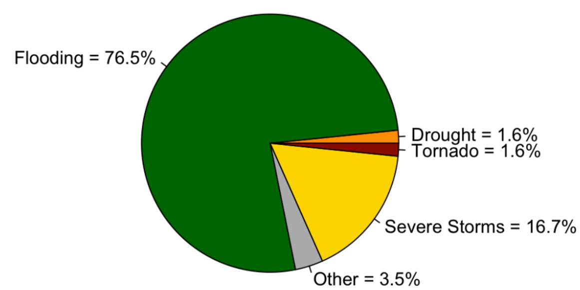


**Fig. 1.** Pie chart of hazard usage

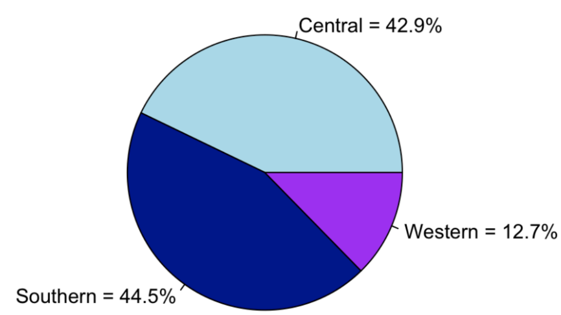


**Fig. 2.** Pie chart of graphic regions in catalog

As for whether the color scheme was continuous or discrete, 95.1% of the graphics were discrete while 4.9% were continuous; all of the graphics were static. Both the median and mean for the number of color categories was 5, with a standard deviation of 3.38. The maximum number of categories was 19, while the minimum was 1. For the color range bin, the most frequent was monochromatic (39.2%), followed by analogous (31.0%), rainbow (24.6%), complementary (2.6%) and other (0.8%) (Fig. 3).

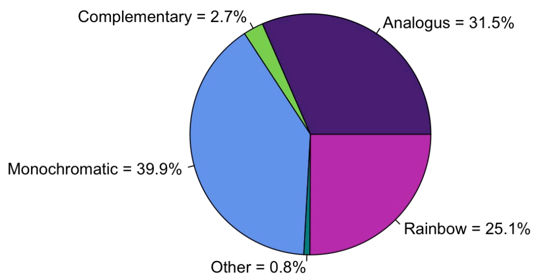


**Fig. 3.** Pie chart of color range bin usage

Most (77.9%) of the graphics contained some type of legend for the color usage, while 22.1% did not have a legend. For the type of color key scale, the most common was impact-based (48.8%), followed by numeric (33.2%), then probability (17.8%) (Fig. 4).

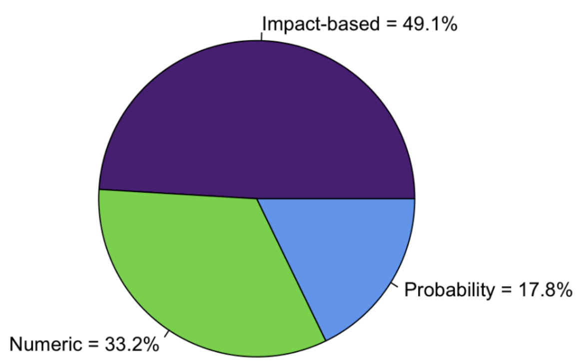


**Fig. 4.** Pie chart of key scale type

In regard to graphics being colorblind friendly, 48.0% were considered colorblind friendly while 52.0% were not. Graphics were posted on average one day out from the start of the flooding event, or the day before the flooding event started. There were 230 unique and 1,837 total hex codes cataloged in this dataset. The three most frequent hex codes were #006D2C (dark green), followed by #FFCC4F (orange-yellow), then #FFFA8A (light yellow) (Fig. 5). In total the most common hex code color was green (488), followed by yellow (217), then red (171).

**Table 2.** Total number of hex codes in each color category

| Color | Count |
|---|---|
| **Green** | 488 |
| **Yellow** | 217 |
| **Red** | 171 |
| **Orange** | 154 |
| **Pink** | 84 |
| **Purple** | 23 |
| **Brown** | 15 |
| **Blue** | 11 |
| **Grey** | 4 |

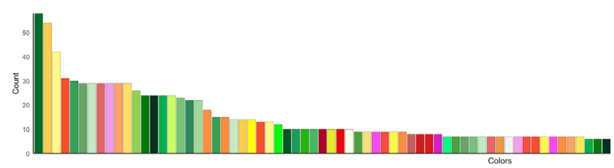

**Fig. 5.** Bar chart of color frequency

## 5. DISCUSSION

Around 25% of graphics related to billion-dollar flooding events from WFOs between 2020 and 2022 used a rainbow scheme, which has been noted to be visually overwhelming and misleading (Crameri et al. 2020). The other 75% used simpler and more intuitive ranges such as analogous or monochromatic. Most of the rainbow graphics may be due to the use of other product templates, such as convective or excessive rainfall outlooks. Around half the graphics used color to communicate impact; conveying severity and impact could be important as the public may struggle to understand purely quantitative data (Wanless and Riley 2023). The average number of categories of color were five, which is an ideal number as seven or more can be visually overwhelming (Carr et al. 2016). The majority of graphics (80%) contained some type of key or legend, which is essential to explain how color is communicating risk in a graphic. Less than half of the graphics (48.0%) were colorblind friendly, which may partly be owed to the use of rainbow color ranges. In terms of the hazard type, most (76.6%) of the graphics were directly related to flooding or excessive rainfall. Compared to other hazard types, severe storm graphics also played a noteworthy role during flooding events, as severe convection can contribute to flooding and excessive precipitation. There were six color hex codes that were used exactly the same amount, with each one representing a different category on the convective outlook key. This is likely due to the frequent usage of convective outlooks in graphics during flooding events.

In regard to the colors themselves, green was the most common color that appeared in graphics for flooding events. Orange and red were also common colors, which makes sense given the common use of an analogous color range. There was rare use of pink or magenta. The most absent color was blue, with no shade of blue appearing in the graphics. This was counter to what was expected, as studies have shown that the color blue is associated with flooding by the public (Cheong et al. 2020).

While there was decent saturation with the total inventory size, there were still more billion dollar events to be covered in 2022 or later. None of the events covered in the time period for this study occurred in the NWS eastern region, so no sample graphics were collected from there. This is a considerable limitation as this study may not pick up any major differences in the eastern region. Furthermore, this study carried out a relatively elementary analysis of graphic characteristics, versus a more in-depth examination that may consist of correlations or relationships.

## 6. FUTURE WORK AND CONCLUSION

While the colors common in flood graphics were found, there was no identification of the reasoning behind the colors used. Future work could qualitatively explore reasoning for why some colors are widely used while others are mostly absent. Furthermore, the analysis carried out in this study could be further expanded to identify relationships between different characteristics of the graphics. An example of this includes identifying which colors are most common in each key scale type. It should be noted again that no graphics were pulled from the NWS eastern region. Future work could identify flooding events that occurred in each region, so that a more rigorous regional analysis could be carried out. This type of work does not necessarily need to be limited to flooding. Future studies could also carry out similar methodology for different hazards, such as severe storms or fire weather.

Overall, there was strong overlap on general colors being used, such as green or yellow being common. However, the actual usage of the colors had considerable differences across the data. The color range bin and key scale type, for example, did not have one dominant type. This implies that NWS offices may have a variety of ways to use color, or that it may vary between the offices. While there are documented uses of unintuitive or confusing color usages, this variety may be for the better, as there is no singular way to use color to communicate a hazard. Color should be used meaningfully with geographical and cultural contexts in mind, so what works for one WFO may be counterproductive to another WFO or region.

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