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# Assessing motorist behavior during flash floods in Tucson, Arizona

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**Abstract**
Weather events often force motorists to drive in unsafe conditions or alter travel plans. Both decisions are imbued with costs that drivers may minimize by developing adaptation behaviors that facilitate safe travel. This study examines motorist behavior in Tucson, where urban flash floods are potentially avoided by strategies such as changing the route or trip timing. A sample of 108 residents completed a stated adaptation questionnaire regarding which behaviors they take to avoid floods prior to departure and upon encountering a flood. A multiple regression analysis tests whether behaviors depend on demographic characteristics, familiarity with flood locations, and previous experience entering floodwaters. This study also considers the types of information that people seek upon encountering a flood. The results highlight the importance of flexibility and familiarity for motorists' decision making. Fewer adaptation behaviors are used for urgent commute trips, but route switching is common for the most frequent trips to work, school, and home. Pre-trip behaviors account for most differences because most respondents use adaptation behaviors upon flood encounter, but age, ethnicity, and previous experience with floods are key factors. Differences in flood avoidance behaviors appear to be linked to travel flexibility, not just propensity to take risks. These results also highlight the significant potential for communicating alternate routes to help motorists reduce flood exposure and other point-location hazards while minimizing travel disruption.

**Keywords** Behavior · Decision · Floods · Hazards · Risk · Vehicles

## Introduction

Weather events often disrupt travel activities and force motorists either to navigate dangerous conditions or to alter travel plans. Though driving in unsafe conditions increases the chances of an accident, decisions to alter travel plans are fraught with opportunity costs and economic costs that often remain unmeasured and unrecognized. Motorists may be

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more willing to avoid dangerous conditions if they have alternatives that do not impinge on other aspects of their travel decision process, such as trip urgency.

Small-scale flash floods provide a good case study for motorist behavior because they constrain mobility, cause a high proportion of weather-related deaths, and are potentially avoidable if they are point locations, particularly if they dissipate quickly. In many cities, urban flash floods are common occurrences with which residents will become familiar over time. Residents who are familiar with common flooding patterns at point locations may develop a broader set of flood-avoidance behaviors. If the hazard is theoretically easier to avoid, it is possible to explore the variety of adaptation behaviors applied as well as the degree to which apparent risk-taking behavior is linked to constrained options, lack of information, and propensity to take risks.

For this study, residents of Tucson, Arizona were asked to participate in a questionnaire that examines behaviors they take when confronted with potential flood hazards prior to departure and upon encountering a flooded roadway for different trip purposes. Logistic regression models were used to assess whether propensity to take flood avoidance behaviors is linked to the trip purpose, demographic characteristics, previous experience entering floodwaters, and familiarity with floods along typical driving routes. Survey participants were also asked to indicate what types of information they use upon encountering a flood to determine what media might be useful for communicating flood danger and safer alternatives.

The results of this study show that Tucson residents are largely familiar with flood hazards and are likely to use flood avoidance behaviors, depending on trip purpose, age, ethnicity, income, and previous experience with floods. The importance of flexibility in decision making is evident among this sample of residents, so efforts to increase the number of options available to people may result in fewer flood-related accidents. The results also highlight the high potential for communication of alternate routes to save lives; over half of the sample has entered floodwaters because they did not know of a viable alternate route, most already use route-switching to avoid floods, and nearly half use a device to seek information upon encountering a flood despite the lack of a source that provides clear and detailed information about how to avoid floods. Such considerations should be explored with respect to other small-scale but disruptive hazards, particularly those that are common and avoidable.

## Motorist behavior during hazardous weather

This study draws upon previous research documenting the impact of weather on transportation networks and travel decisions. Some studies compare transit and road network usage rates on days with fair and poor weather, but most of this body of research is based on travel diary surveys, typically asking whether conditions affected travel decisions such as mode, route, timing, or canceling the trip. Böcker et al. (2013) point out that the context and residents' experiences matter for impact because people acclimatize in different ways to locally specific weather patterns. However, there are trends across several studies pertinent to this analysis.

First is the observation that changes in travel behavior in response to adverse weather conditions depend on the trip purpose. Several surveys have shown that adverse weather conditions are more likely to impact leisure trips than commuting (Böcker et al. 2013; Cools et al. 2010a, b; Liu et al. 2015), especially if the respondent's employer does not

permit flexible work scheduling (Khattak and De Palma 1997). Trips related to family commitments, such as picking up children from daycare or school, also reduce flexibility in mode and timing choice (Khattak and De Palma 1997). In contrast, weather conditions strongly impact the timing choice and mode choice for leisure activities (Kusumastuti et al. 2010).

The second key observation is that the degree to which the trip purpose influences behavioral change varies among demographic groups. For example, elderly travelers are more likely than younger ones to cancel errands and leisure trips in poor weather conditions (Böcker et al. 2017; Cools and Creemers 2013). Aside from canceling leisure trips, however, older drivers are generally less likely to change their travel behavior than younger drivers (Barjenbruch et al. 2016; Cools and Creemers 2013). With respect to gender, Barjenbruch et al. (2016) found that during a winter storm, women were more likely to alter behaviors.

There is also a significant body of work examining motorists' use of information to make travel decisions. Chorus et al. (2006) provide a review of studies regarding the use of advanced traveler information services (ATIS), including theoretical frameworks, who uses ATIS, for what purpose, what types of information are used, and the effect of ATIS on behavior. They identify four key theoretical frameworks for deciding among alternatives: (1) maximization, the exhaustive assessment of all alternatives; (2) satisficing, seeking alternatives until identifying the first acceptable option based on preferred criteria; (3) habit execution, which is not considering alternatives at all; and (4) effort-accuracy tradeoff, striking a balance between effort of consideration and accuracy of decision strategies. The usage and success of these strategies will depend on the quality and availability of decision-support information, previous knowledge, and the attractiveness of alternatives.

Since the present study focuses on weather impacts, the primary interest is in motorists' consumption of weather-related information and how it influences their travel behaviors. There are some inconsistencies across the studies, which likely reflect variation in the types of weather events studied as well as the aforementioned importance of context and familiarity with certain types of weather impacts.

For example, Cools and Creemers (2013) found that the likelihood of different adaptation behaviors was not affected by the method of obtaining weather information. In contrast, Kilpeläinen and Summala (2007) found that drivers who actively sought weather information reported behavior changes related to strategic decisions, such as route choice and timing, but they also note that their sample only includes those on the road and therefore does not include those who canceled their trip due to weather conditions.

Sometimes people seek confirmation of a hazard from multiple sources before acting (Brilly and Polic 2005; Mileti 1995), including official sources and unofficial sources such as friends and family (Coles and Hirschboeck 2020; Handmer 2001; Mileti 1995; Parker and Handmer 1998; Parker et al. 2009). Barjenbruch et al. (2016) found that the source of information was linked to specific behaviors; those who used government sources were more likely to change their route, those who used personal sources were more likely to change their route or cancel their trip, and those who used media sources were more likely to change timing or proceed as planned. Sources of information may also include on-site communication, such as warning signs or road barriers (Coles and Hirschboeck 2020).

While the previously mentioned studies relied on self-report survey, Ferris and Newburn (2017) examined traffic volumes and number of accidents on flood days with and without the use of a Wireless Emergency Alert disseminated to cell phones. They found that days where alerts were issued had an average 15.9% reduction in accidents and a 3.1% reduction in overall traffic volume compared to days without alerts issued.

It is important to consider that most of the studies measuring behavioral response to weather consider widespread events such as high winds or winter storms, affecting all roads in a region and rendering route switching less useful as an adaptation strategy (De Palma and Rochat 1999; Khattak and De Palma 1997). This study focuses on urban flash floods, which tend to be point locations that are more likely to be avoidable with alternate routes, depending on the road network density and return period design of flood mitigation infrastructure such as bridges and culverts. As fixed points, flood locations can be learned by local residents through experience (Ruin et al. 2007), signage, or through documentation that is made accessible to the public.

It is also important to study motorist behavior during floods because exposure is particularly linked to daily mobility, as evident by the high proportions of flood deaths associated with vehicles. Across several studies, over half of flood-related deaths are the result of vehicles entering floodwaters (Ashley and Ashley 2008; Diakakis and Deligiannakis 2013, 2015; FitzGerald et al. 2010; Jonkman and Vrijling 2008; Jonkman and Kelman 2005; Ruin 2010; Terti et al. 2016; Peden et al. 2017). Many studies attempt to determine the risk factors associated with flood mortalities, including environmental conditions, demographic characteristics, and behavior (Ashley and Ashley 2008; Becker et al. 2015; Coates 1999; Diakakis and Deligiannakis 2013, 2015; FitzGerald et al. 2010; Gruntfest 1977; Jonkman and Vrijling 2008; Jonkman and Kelman 2005; Kellar and Schmidlin 2012; Maples and Tiefenbacher 2009; Sharif et al. 2012; Špitalar et al. 2014; Staes et al. 1994; Terti et al. 2016; Pearson and Hamilton 2014; Peden et al. 2016, 2017; Pereira et al. 2017; Salvati et al. 2018; Vinet et al. 2016). In addition to mortality studies are those that examine risk perception and self-reported behavior (Coles and Hirschboeck 2020; Franklin et al. 2014; Hamilton et al. 2016a, b, 2018; Creutin et al. 2009, 2013; Lutoff et al. 2016; Ruin et al. 2008, 2014; Drobot et al. 2007) or observe behaviors at flood locations (Gissing et al. 2016). For reviews of studies examining intentional entry into floodwaters, see Ahmed et al. (2018) and Becker et al. (2015).

Environmental factors for flood exposure and mortality include geographic location, time of day, and type of flood. Location-dependent factors include those which determine flood regimes, such as topography, hydrology, and climatology, and those which determine rates of flood exposure, such as population size and road network density (Paul et al. 2018; Kellar and Schmidlin 2012; Sharif et al. 2012, 2015). While urban centers have more deaths overall, rural areas have greater mortality rates when normalized for population (Diakakis and Deligiannakis 2013, 2015; Kellar and Schmidlin 2012; Maples and Tiefenbacher 2009; Shabou et al. 2017; Sharif et al. 2012, 2015; Špitalar et al. 2014), likely because rural areas likely have less flood mitigation infrastructure and fewer options for alternate routes. Higher density of flood-prone roadways, such as low-water crossings, road cuts, and low bridges, also raises motorist exposure to floods (Debionne et al. 2016; Sharif et al. 2012).

Flood mortality is also linked to some degree of surprise. Flash floods are short-fuse events that rise and recede within minutes or hours of rainfall or dam failure (National Weather Service 2018), leaving little time for warning or response (Parker et al. 2009). Flash floods are the deadliest type of flood in the United States, and while they are more frequent than river floods or tropical events, they are usually much smaller-scale events (Kellar and Schmidlin 2012; Sharif et al. 2012, 2015). Limited visibility is also a factor, as high proportions of flood casualties occur during twilight or nighttime hours (Diakakis and Deligiannakis 2013; Jonkman and Kelman 2005; Maples and Tiefenbacher 2009; Sharif et al. 2012; Špitalar et al. 2014; Terti et al. 2016). Additionally, low-water crossings often occur in hilly areas where topography limits drivers' visibility and therefore reaction

time. Warning signs mitigate these losses by building awareness of flood locations, and the presence of signs and barricades at low-water crossings are strong deterrents for driving through flooded roadways (Coles and Hirschboeck 2020). Drivers have more awareness of flood risks on familiar roads (Ruin et al. 2007), and while many flood deaths occur on roads near the victim's home (Maples and Tiefenbacher 2009), it is likely more attributable to probability of exposure than to greater propensity to take risks on familiar roads.

Demographic factors, especially gender and age, have been associated with flood-related behaviors and mortalities. Males make up 60–80% of victims across studies, which is variously attributed to risk-taking behavior as well as increased rates of exposure due to participation in certain occupations and leisure activities and higher vehicle occupancy rates among males than females (Ashley and Ashley 2008; Badoux et al. 2016; Coates 1999; Diakakis and Deligiannakis 2013; FitzGerald et al. 2010; Jonkman and Vrijling 2008; Jonkman and Kelman 2005; Kellar and Schmidlin 2012; Maples and Tiefenbacher 2009; Paul et al. 2018; Salvati et al. 2018; Sharif et al. 2012; Sisak 2015; Terti et al. 2016; Diakakis and Deligiannakis 2015; Franklin et al. 2014; Pearson and Hamilton 2014; Hamilton et al. 2018; Peden et al. 2016, 2017; Pereira et al. 2017). Cai et al. (2016) found higher risk perception among females during rainy weather conditions, but Hatfield and Fernandes (2009) show that higher risk perception does not always translate into safer behavior. Drobot et al. (2007) and Coles and Hirschboeck (2020) found that men and women reported having driven into floodwaters at equal rates, but there are other gender differences in flood-related behaviors and attitudes. For example, the lack of an alternate route is a much stronger incentive to enter floodwaters for women than for men (Coles and Hirschboeck 2020).

Studies examining age suggest that youths and the elderly have disproportionate mortality rates given their proportion of the population, often attributed to difficulty wading or swimming in swift water (Ashley and Ashley 2008; Badoux et al. 2016; Coates 1999; Diakakis and Deligiannakis 2013; FitzGerald et al. 2010; Paul et al. 2018; Salvati et al. 2018; Vinet et al. 2016; Yale et al. 2003). Young adults also have disproportionate mortality rates that are often attributed to less driving experience and higher propensity to take risks (Drobot et al. 2007; Maples and Tiefenbacher 2009; Salvati et al. 2018), but as with gender, activity travel behaviors related to age (commuting, errands, etc.) will influence how much time individuals spend on the road (Kim et al. 1998) and thus their exposure to floods and other hazards.

## Urban flash floods in Tucson, Arizona

Tucson is located in a semi-arid region that receives intense convective thunderstorms during the North American Monsoon, mainly July through August. Flood events are common, but they are only recorded if someone reports damage or injury (NOAA 2019). Weather stations across the Tucson area report an average of 8–10 days of rain per month during the monsoon season, indicating flood potential every 3 days.

The intense rainfall produces flash floods that rise faster and deeper in urban areas where impervious surfaces prevent infiltration. Motorists are particularly vulnerable to flood dangers because the infrastructure that handles stormwater is integrated into the road networks. Since bridges and culverts may trap debris and thus exacerbate floods, streets often pass directly through normally-dry creek beds (called washes) as "dip" crossings. Additionally, many streets have been constructed as conveyance channels through which stormwater

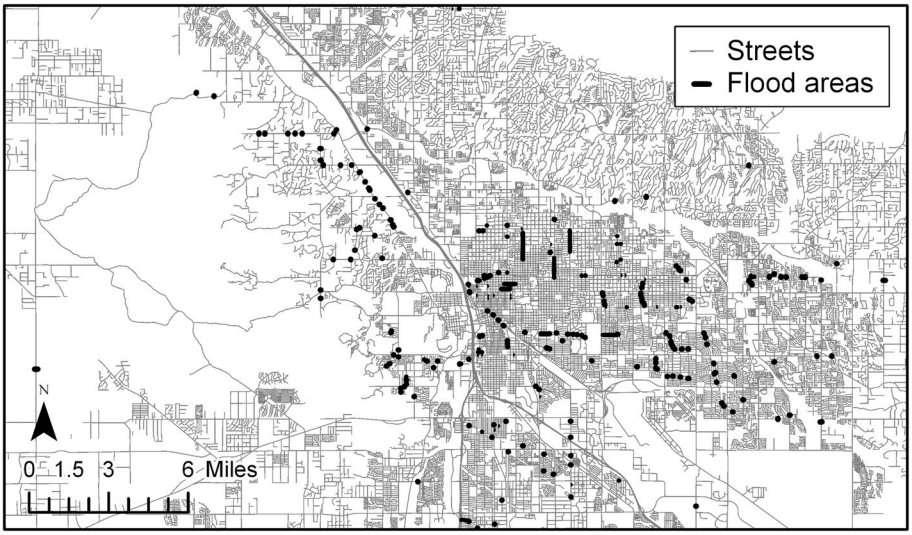


**Fig. 1** Map of typical flood areas that are marked by one or more warning sign, obtained from the City of Tucson and Pima County data portals (City of Tucson 2018; Pima Association of Governments 2018)

flows down the centerline for several blocks at a time. As a result, the metropolitan area's 980,000 residents encounter hundreds of flood areas across the road network each time it rains (see Fig. 1) and some streets become completely inaccessible (Coles 2020). Typical flood events are therefore disruptive even if they are not considered "extreme" events and do not produce recorded damage or injury.

The National Weather Service and the city and county governments have established several education campaigns designed to deter motorists from driving into flooded roadways (National Weather Service, n.d.; Tucson Department of Transportation, n.d.; PRFCD 2019). These campaigns include information distributed through websites, videos, mailers, social media, and local television and print media. Additionally, the city and county governments provide signage at most of the flood areas in their respective jurisdictions, including permanent signs, seasonal A-frame signs, and full barricades. The media frequently mention Arizona Revised Statute 28-910 (2006), referred to as "the Stupid Motorist Law," which requires individuals to pay for the costs of swift-water rescue if they drive around a barricade.

This study builds upon the results of a previous study in Tucson (Coles and Hirschboeck 2020). In that study, people who admit to having driven into floodwaters also report that they have encountered flooded roads and decided not to drive through, indicating that they make the decision on a case-by-case basis after evaluating environmental conditions and options. While individuals may have different levels of risk tolerance, their decisions are also mediated by factors other than risk perception and propensity to take risks. Coles and Hirschboeck (2020) found that the key deterrents for entering floodwaters include danger, the presence of a barricade or sign, the risk of damage to the vehicle, and the presence of passengers. The key incentives for entering floodwaters include the prior successful crossing of another vehicle, having family on the other side, and not knowing another possible route. The size of the vehicle also matters, as people who drive larger vehicles such as trucks and sport utility vehicles are more likely to have driven into flooded roadways. This

study takes the case-by-case nature of flood-related decisions as its foundation, and focuses on the options that people are willing and able to take to avoid floods.

## Methods

### Data collection: in-person survey

During July 2017, in-person surveys were administered to a convenience sample of 108 Tucson residents recruited from multiple visits to thirteen public locations with pedestrian traffic, including three streets, six public libraries, two farmers' markets, and the University of Arizona campus. To acquire a sample as demographically diverse as possible, the library locations were distributed throughout the city, targeting branches in neighborhoods with different demographic characteristics. The survey included a questionnaire as well as a route-mapping exercise, in which participants provided turn-by-turn directions along their typical routes. This analysis focuses on the questionnaire results regarding flood avoidance behaviors prior to and during a trip. The route-mapping analysis is reported elsewhere (Coles 2020).

The questionnaire was based primarily on the stated adaptation approach, in which participants indicate if and how they would change their behavior under certain conditions (Cools et al. 2010a; D'Arcier et al. 1998; Parvaneh et al. 2014; van Bladel et al. 2008). Specifically, participants were asked to indicate which behaviors they would take (1) prior to leaving if it is raining and flooding is possible, and (2) if a flood is encountered while driving. Behaviors they might take prior to leaving include: change mode of transportation, change timing of the trip (leave earlier or later), change route, change destination, or proceed with no change. Behaviors they might take upon encountering a flood include change route, change destination, pause the trip, and proceed with no change. The options were provided in a matrix (behavior by destination), and participants were able to select multiple responses for each destination.

Ability to take adaptive behaviors likely depends on knowledge about flood locations and safer alternatives, which they may attain through personal experience or seeking further information. Participants were asked about their previous experience with flooded streets, including whether their typical driving routes pass through flood areas and whether they have previously entered floodwaters for lack of an alternate route. They were also asked which information sources they would seek during a flood encounter, when access to information is more limited. Participants were able to select any number of the following: call someone I know, call the police or fire department, ask someone at the flood site, make a visual assessment of environmental conditions, use a device to search the Internet, other, and do not seek further information. The questionnaire included a blank for "other" and a blank to explain which specific Internet sources are accessed.

Finally, participants provided basic demographic data, including gender,[1] age, ethnicity (by census category), educational attainment, and typical modes of transportation, including car, SUV, truck, motorcycle or scooter, bicycle, bus, walking, rides from others, and other. Multiple responses were permitted for ethnicity and mode of transportation. Table 1

[1] The questionnaire form left gender open-ended by using a blank instead of pre-determined categories, but all participants who provided a response entered either male or female.

**Table 1** Proportion of the survey sample that selected each category, and comparison to population proportions from the US Census Bureau (2017) where applicable

| Demographic | % Of sample (US Census) | Demographic | % of sample (US Census) |
|---|---|---|---|
| *Gender* | | *Highest education completed* | |
| Male | 44.55 (49.6) | Some high school | 0.93 |
| Female | 55.45 (50.4) | High school or GED | 13.89 |
| *Age* | | Some college | 16.67 |
| 18–29 | 19.81 | Associate or technical trade degree | 6.48 |
| 30–39 | 18.87 | 4-year or baccalaureate degree | 22.22 (25.8) |
| 40–49 | 11.32 | Graduate degree or further | 39.81 |
| 50–59 | 24.53 | *Ethnic identity* | |
| 60 + | 25.47 | African American | 10.2 (5.0) |
| Mean | 46.5 | American Indian or Alaskan Native | 1.9 (2.9) |
| Range | 19–77 | Asian, Asian American, Pacific Islander | 8.3 (3.2) |
| *Modes of transportation* | | Caucasian, White | 63.0 (73.5) |
| Car | 82.41 | Hispanic or Latino/a | 20.4 (42.6) |
| SUV | 9.26 | Other | 6.5 |
| Truck | 11.11 | *Annual household income* | |
| Motorcycle or scooter | 2.78 | Less than $14,999 | 14.42 |
| Bicycle | 24.07 | $15,000–24,999 | 10.58 |
| Walk | 17.60 | $25,000–49,000 | 25.96 |
| Bus | 5.56 | $50,000–74,999 | 20.19 |
| Rides | 2.78 | $75,000–99,999 | 10.58 |
| Other | 0.93 | $100,000 + | 18.27 |

contains the demographic characteristics of the study sample. Compared to the US Census Bureau (2000) statistics, certain groups are overrepresented. The sample is 55.45% female, compared to 50.4% of Tucson residents. In terms of ethnicity, the African American and Asian identities are overrepresented while American Indian, White or Caucasian, and Hispanic or Latino/a identities are underrepresented compared to the Tucson population. Finally, the sample includes a much higher proportion of college-educated individuals at 62.03%, compared to the city's 25.8%.

To account for these differences, the logistic regression models used in this analysis apply survey weights derived from area population characteristics in the 2013–2017 American Community Survey Public Use Microdata Sample (ACS PUMS), obtained with the tidycensus R package (Walker 2020). Weights are derived from microdata records identified in the eight Public Use Microdata Areas (PUMAs) that cover the city of Tucson and environs, representing the geographic area from which survey respondents were drawn. Information on age, racial/ethnic identification, and gender are drawn from the PUMS dataset for the Tucson area, and matched to the survey sample in this study. Tabulated weights from the PUMS dataset for the Tucson area are then used to weight cases in the logistic regression models, which are further described in the next section.

### Analysis

The first part of the analysis compares the proportions of individuals who use each type of behavior for each destination before and during a trip. This analysis tests the hypothesis that adaptive decision making will be more limited for urgent trip purposes, such as commuting to work and school, than for errands and leisure. To avoid confounding the results for individuals who do not have a work or school commute, these analyses include only individuals who provided a route or stated adaptation behavior for the respective destination. There are 42 school commuters (38.9%) and 93 work commuters (86.1%) in the sample. The survey did not ask specifically about the possibility of flexible work schedules, but it is an important consideration for future studies because it reduces the urgency of the commute and opens further travel options. Since urgency for trips home or to appointments will vary from time to time, these destinations have not been included in the analysis comparing urgent versus non-urgent trips.

To further evaluate the potential relationships between travel decision making and survey respondent characteristics, we fit a series of survey-weighted logistic regression models with key survey responses as outcome variables. Survey-weighted models were prepared using the R survey package (Lumley 2010). The models were fit for a series of outcome variables designed to measure multivariate relationships between respondent characteristics and decision-making in potential and confirmed flood events. Outcome variables modeled include whether or not respondents stated that they would proceed as usual for any destination, whether or not they selected both proceed and one or more adaptation behaviors, and whether or not respondents who work would change their route. Model predictors include demographic characteristics such as age, gender, income, and race/ethnicity; access to a large vehicle; flood zones crossed per mile on their typical routes; awareness of whether or not their routes cross flood zones; and prior experience in a flood.

Content analysis was also performed on the notes provided by participants in open-ended answers or during the mapping discussion to triangulate quantitative analysis and gain further insight into their experiences with floods and factors that influence their decision making.

## Results

### Adaptation behaviors before and during travel

Nearly all participants indicated that they would use some kind of flood avoidance behavior prior to leaving if flooding is possible (88.0%) or upon encountering a flood while driving (91.7%) for at least one destination (Figs. 2, 3). Only two respondents selected proceed as the only behavior option across all destinations prior to departure. For flood encounter, fewer than five individuals selected proceed only for any given destination and none selected proceed as the only behavior.

Different types of behaviors are more prevalent for certain trip purposes. The most common pre-trip adaptation behaviors are changing the departure time and changing the route, with approximately half of participants using these behaviors across destinations (Fig. 2). Canceling the trip is the most common behavior for errands and leisure travel.

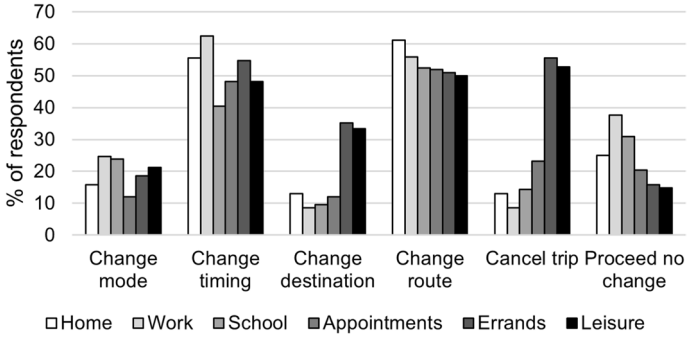


**Fig. 2** Proportion of respondents who use each adaptation behavior for a given trip purpose if they have not yet departed but conditions indicate that roads may be flooded (i.e., it is raining)

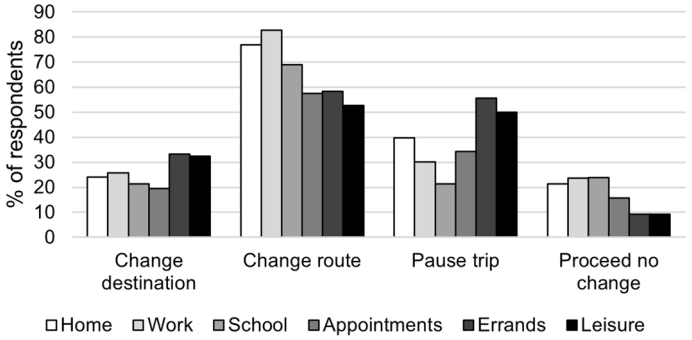


**Fig. 3** Proportion of respondents who use each adaptation behavior for a given trip purpose if they encounter a flood while driving

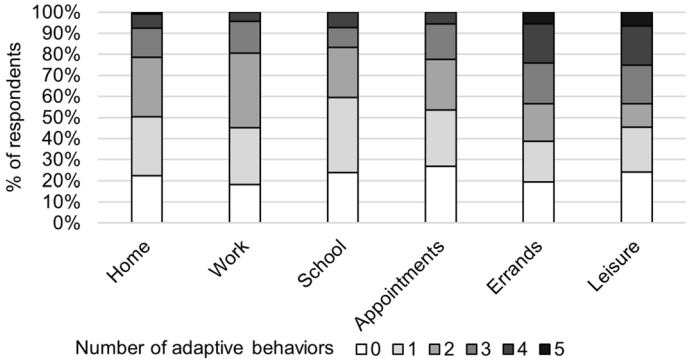


**Fig. 4** Proportion of respondents who use 0, 1, 2, 3, 4, or 5 out of 5 possible adaptation behaviors for each trip purpose prior to departure if roads may be flooded

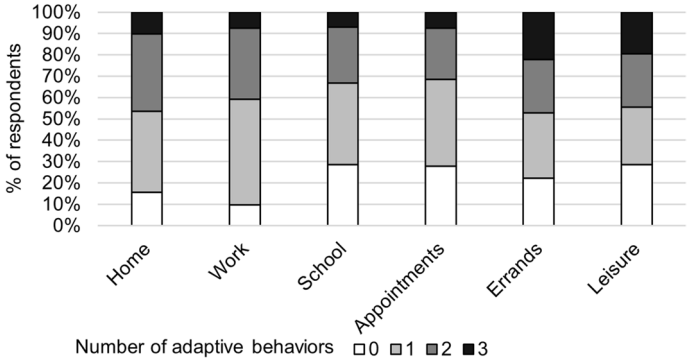


**Fig. 5** Proportion of respondents who use 0, 1, 2, or 3 out of 3 possible adaptation behaviors for each trip purpose upon flood encounter

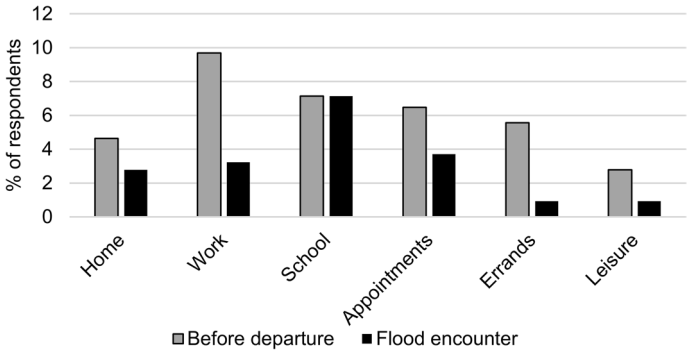


**Fig. 6** Proportion of respondents who selected proceed with no change as the only behavior they use prior to departure and upon flood encounter

After encountering a flood, changing the route is the most common behavior for all destinations. Pausing the trip is also common for errands and leisure trips (Fig. 3).

Trip urgency appears to influence how many adaptive behaviors people are likely to use. Prior to departure, participants report fewer adaptation behaviors for commuting to school or work than for less urgent trips such as errands or leisure (Fig. 4). Participants on average use more than two adaptive behaviors for errands and leisure, but fewer than two behaviors for home, work, school, and appointments. For flood encounters, the difference in the number of adaptive behaviors used for urgent and non-urgent trips is smaller. More respondents provided two or three behaviors for errands and leisure than for other trip purposes. However, the proportion of the sample using at least one behavior is highest for home (84.3%) and work (90.3%), due largely to the prevalence of route switching for these destinations (Fig. 5). Route switching is the most common adaptation behavior for flood encounter, and is reported for home, work, and school more often than appointments, errands, and leisure. Proceed without change is more likely to be selected for home, work, school, and appointments than for errands and leisure (Fig. 6).

Approximately 35.2% of participants selected change mode of transportation for one or more of the destinations. Of these, individuals, 60.5% had listed among their typical

**Table 2** Results of multiple regression analysis

| Predictor | Model 1: Proceeds as usual prior to departure | | Model 2: Proceeds as usual upon flood encounter | | Model 3: Exhibits flexible decision-making prior to departure | | Model 4: Exhibits flexible decision-making upon flood encounter | | Model 5: Changes route to work prior to departure | | Model 6: Changes route to work upon flood encounter | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coef. | SE | Coef. | SE | Coef. | SE | Coef. | SE | Coef. | SE | Coef. | SE |
| Age | − 0.11*** | 0.03 | − 0.05* | 0.25 | − 0.10*** | 0.02 | − 0.06* | 0.03 | 0.01 | 0.02 | − 0.08* | 0.04 |
| Gender (reference: male) | 0.66 | 0.63 | − 0.18 | 0.68 | 0.61 | 0.60 | 0.04 | 0.70 | 0.25 | 0.68 | − 1.55 | 0.90 |
| Income $25,000–74,999 | 0.82 | 1.02 | 1.6 | 0.82 | 0.62 | 1.05 | 1.61 | 0.86 | − 0.48 | 0.948 | − 2.65* | 1.00 |
| Income $75,000 + | 1.2 | 1.14 | 0.18 | 0.94 | 0.77 | 1.13 | 0.29 | 0.98 | − 1.62 | 1.13 | − 3.60** | 1.05 |
| Flood areas encountered per mile of routes provided | 0.69 | 2.00 | 0.06 | 1.48 | 1.18 | 2.09 | 0.22 | 1.49 | 0.49 | 1.97 | − 0.56 | 2.39 |
| White racial/ethnic identification | 0.79 | 0.76 | 2.2* | 0.97 | 0.36 | 0.79 | 2.74** | 0.95 | 2.58* | 1.15 | 3.31* | 1.40 |
| Access to a large vehicle | 1.00 | 0.78 | − 0.54 | 0.89 | 0.42 | 0.70 | − 0.95 | 0.89 | 2.04* | 0.89 | 1.63 | 1.11 |
| Awareness of flood areas on typical routes | − 0.98 | 0.71 | − 0.32 | 0.76 | − 0.55 | 0.68 | − 0.67 | 0.77 | 2.23* | 1.03 | 0.51 | 0.90 |
| Prior experience entering floodwaters | − 0.59 | 0.63 | − 2.1** | 0.73 | − 0.13 | 0.61 | − 2.37** | 0.77 | 0.69 | 0.81 | 0.10 | 0.95 |
| Intercept | 3.65 | 1.37 | 0.31 | 1.45 | 3.09 | 1.35 | 0.36 | 1.50 | − 3.81 | 1.83 | 5.94 | 2.00 |

Statistical significance denoted by *$p$=0.05; **$p$=0.01; ***$p$=0.001

methods of transportation at least one in which they would be exposed during storms, including bicycle, walk, and motorcycle or scooter.

## Demographics

The results of each regression model are reported in Table 2. The first two models evaluate the conditional probability that survey respondents select proceed as usual for at least one destination. Model 1 shows that prior to departure, before flooding is confirmed, age has a strong inverse relationship to the likelihood of proceeding as usual. The model suggests that, independent of all other predictors, older respondents are less likely to say that they would not change their travel plans. Upon flood encounter (Model 2), age is similarly predictive of decision-making as older respondents are less likely to proceed with travel plans as usual in this scenario. Respondents who identify as white are more likely to say that they would proceed as usual in a flood event than respondents who do not identify as white.

As noted above, few individuals selected proceed as usual as the only option. Models 3 and 4 examine the propensity of individuals to select proceed as well as one or more adaptation behaviors, thus demonstrating flexible decision-making. Prior to departure (Model 3) and upon encountering a flood (Model 4), age is negatively associated with flexibility. In other words, younger participants are more likely to have flexible behaviors than older participants. Similarly, upon encountering a flood, individuals who identify as white are more likely to exhibit flexible behaviors.

The descriptive analysis demonstrates the urgency of commutes and the pervasive use of alternate routes, so we also analyze, for the subset of survey respondents who are currently in the workforce, whether or not respondents say that they would change their travel routes to work in rain and flood events. These results are summarized in Models 5 and 6. Model 5 results suggest that respondents declaring that they would change their routes to work prior to departure are more likely to identify as white than nonwhite, and they are also more likely to say that they have access to a large vehicle such as a truck or SUV. For flood encounters (Model 6), younger respondents and white respondents are more likely to say that they would change their routes to work. Notably, income has an inverse relationship to this decision, as higher incomes are associated with a lower probability of changing one's route to work relative to the lowest-income reference group. A similar analysis was run for changing the timing of the trip to work, but no statistically significant differences were observed across the model results.

## Previous experience and awareness of flood areas

When asked whether their typical driving routes pass through flood areas, 67.6% of respondents selected yes, 21.3% selected no, and 9.3% selected "I don't know." Respondents also indicated awareness of flood areas during the route mapping activity; eighteen identified one or more routes as having flood areas, six individuals described an origin or destination as one that becomes isolated during floods, and eight provided the alternate routes that they will take if it is raining. Notably, Model 5 results show that individuals who are aware that their typical routes flood are more likely to change their route to work prior to departure.

Participants were asked whether they had ever driven into flooded roadways for any of the following reasons: (1) they knew an alternate route does not exist, (2) they were not aware of an alternate route, or (3) they were aware of an alternate route but it was too far

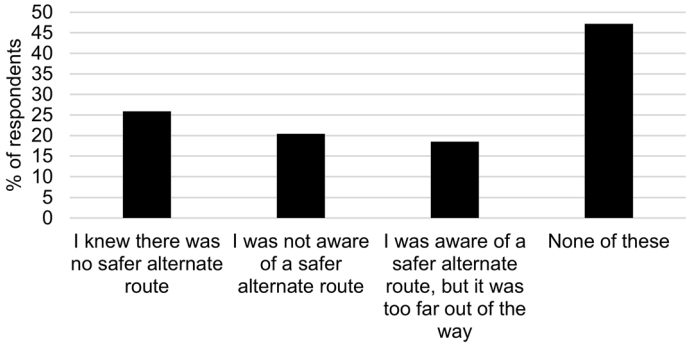


**Fig. 7** Proportion of respondents who have entered floodwaters because they did not have or were not aware of an alternate route, and those who entered floodwaters because the alternate route was too far out of the way

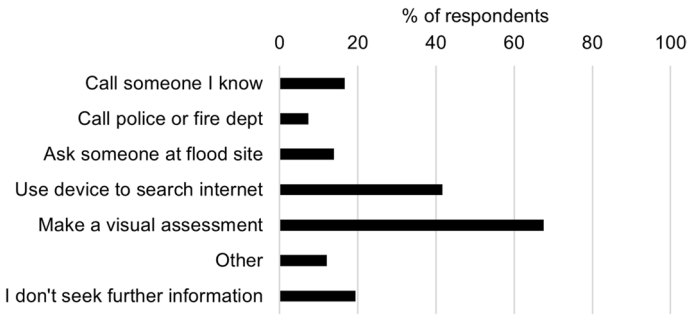


**Fig. 8** Proportion of respondents who seek further information from each source after encountering a flooded road

out of the way. Over half (52.8%) selected one or more of these answers, indicating that they entered flooded roadways because they did not have or were not aware of a viable alternate route (Fig. 7). Model 2 shows that respondents who have entered floodwaters for lack of an alternate route are significantly less likely to proceed as usual with travel plans upon flood encounter. This same subset is less likely to exhibit flexible decision-making upon flood encounter (Model 4).

The questionnaire also asked how far participants would be willing to drive to avoid floods, measured in miles and minutes. Participants report a willingness to drive an average of 4.51 miles and 10.94 min to avoid floods. Two individuals (1.85%) left the answer blank for miles and 27 (25%) left it blank for minutes. No one provided an answer that was less than one mile.

## Information sources

Figure 8 shows the percent of respondents who report using each information source. The most common response selected was “make a visual assessment of environmental conditions” (67.7%), which includes the presence of signs and barricades, listed by several participants in the blank next to “other.” The other common response for the “other” blank

was radio, provided by four participants. The second highest information source selected was use a device to search the Internet (41.5%). Participants were asked to provide specific sources, of which several listed mapping or navigation apps (13 individuals), weather apps or websites (10 individuals), the Arizona Department of Transportation website (2 individuals), Twitter (2 individuals), and news sources (2 individuals).

Approximately 19.4% of participants indicated that they do not seek further information upon encountering a flood. Nine individuals (8.3%) selected this option and no other information source, indicating that they never seek further information. Each of these individuals had listed several adaptation behaviors that they would take to avoid floods before leaving and after encountering floods and seven of these individuals are aware of flood areas on their typical routes.

## Discussion

Participants are more likely to alter their travel plans upon flood encounter than prior to departure, suggesting a tendency to seek confirmation first. However, many choose to take flood-avoidance behaviors prior to departure and therefore prior to confirmation that their routes have flooded. This tendency suggests that they are aware of the flood regime in Tucson and have adapted to it by developing multiple strategies for flood avoidance (Böcker et al. 2013).

The analysis raises questions about the degree to which behavior is linked to risk-taking propensity and the ability to be flexible with decision making. The results of the trip purpose analysis suggest that flexibility is an important consideration for behavioral response to floods. People take more adaptive behaviors and are less likely to proceed with no change for less urgent errands and leisure trips than for commutes. These results align with previous studies that have shown adverse weather to have greater impact on less urgent trips (Böcker et al. 2013; Cools et al. 2010a, b; Liu et al. 2015; Khattak and De Palma 1997; Kusumastuti et al. 2010). Since changing the timing and the route are already common behaviors for commutes, employers could further help reduce flood losses by offering flexible scheduling or telecommute options to keep drivers off the roads during floods. They could also be lenient with employees arriving late or departing early to avoid floods.

The demographic analysis shows there is no statistically significant difference in reported behavior based on gender, similar to previous studies (Coles and Hirschboeck 2020; Drobot et al. 2007). However, other demographic groups do report different behaviors. The tendency for younger individuals to select proceed with no change at higher rates than older individuals would seem to support the assumption that young people are more willing to take risks while driving (Drobot et al. 2007; Maples and Tiefenbacher 2009; Salvati et al. 2018) and previous studies that found older drivers more likely to cancel errands and leisure trips in poor weather (Böcker et al. 2017; Cools and Creemers 2013). However, younger drivers are also more likely to select both proceed and adaptive behaviors before and during a trip, suggesting that proceed is considered as one option among many and that younger drivers may be more flexible with travel plans (Barjenbruch et al. 2016; Cools and Creemers 2013). A similar pattern is observed for participants who identify as white. These results support previous findings that for many individuals, the decision to enter floodwaters is made on a case-by-case basis after weighing situational factors, including trip urgency and environmental conditions (Coles and Hirschboeck 2020).

One surprising result is that individuals with access to a large vehicle are more likely to change their route to work prior to departure, even though there is widespread belief that larger vehicles are more capable of passing safely through floodwaters than smaller vehicles (Coles and Hirschboeck 2020). However, this result is likely due to the small number of individuals (fourteen) who drive large vehicles and have a work commute.

Awareness of flood areas and alternative routes is a critical factor for precautionary behaviors. Two thirds of this study sample are aware that floods occur on their typical routes, and those with a work commute are more likely to change their route even before confirming the flood. Furthermore, over half of the sample have previously entered flooded roadways because they did not have or were not aware of a viable alternate route, and these individuals were more likely to alter travel plans even before departure. Previous studies have found that flood-avoidance behavior is linked to previous traumatic flood experience (Drobot et al. 2007; Hamilton et al. 2016a). It is also possible that people who seek alternatives will nonetheless enter floodwaters when other options are unavailable or untenable, as evidenced by the number of individuals who selected proceed as one option along with several flood-avoidance behaviors.

Support for helping Tucson residents develop familiarity with flood areas and safer alternate routes has enormous potential to save lives and property, particularly if alternate routes could be communicated easily to individuals who may not be familiar with the area. Most survey participants indicated they would be willing to drive at least one mile to avoid floods, and most destinations could be reached safely with a detour of less than one mile (Coles 2020). One option would be to provide an app or website that indicates flood areas and potential alternate routes. A large portion of the sample already uses a device to search the Internet for information upon encountering a flood, even though there is no specific Internet or app-based source that provides a clear and reliable explanation of which roads are flooded and which are relatively safe. The Alert Map operated by the Pima County Regional Flood Control District may be an ideal source for such communication, since it already includes data from rain and stream gauges, radar, and National Weather Service warning polygons (Pima County Regional Flood Control District 2017). Reports from Waze, mPing, and other user-generated data could supplement this information, though extensive outreach would be necessary to encourage widespread use of the apps for this purpose. At present, they do not provide a reliable decision tool for motorists because they rely on user reports and do not provide positive instructions for how to avoid floods, which leads to safer driving behaviors (Hamilton et al. 2018). Four individuals mentioned that they seek further information on the radio, which generally offers little or no specific information unless an accident has already been reported. It would be an easily accessible source of information for motorists, however, and could be used to direct motorists to more detailed information sources.

Since environmental cues remain an important component of decision making related to flooded streets, continued use and improvement of signs, barricades, depth gauges, flashing light indicators, and other signals of danger will aid motorists, especially those who are unfamiliar with the area. Some washes are much deeper than they appear, and some are hidden behind hills or blind corners, so additional visual aids may be necessary.

While 19.4% of the sample indicated that they do not seek additional information when they encounter a flood, only nine individuals report that they never seek further information. Since seven of those individuals are aware that their typical routes intersect flood areas and all of them listed several adaptation behaviors that they take to avoid floods, it is likely that they have already developed coping strategies to avoid floods and therefore do not usually need further information. This assumption is supported by the high

rates of route switching among more frequently-traveled destinations such as home, work, and school, as well as a previous study that found that people who are familiar with their driving environment rely less on real-time information systems to find alternate routes that avoid congestion (Casas and Kwan 2007).

## Conclusions

The results of this study show that many residents of Tucson have developed multiple adaptation strategies to avoid floods, and that they often adjust their travel plans prior to departure thus before the flood threat has been confirmed. The types of adaptation strategies used depend on the trip purpose, demographic characteristics, and familiarity with flood areas, and previous experience entering floodwaters. These results also raise questions about whether people who take adaptive behaviors do so because they are more risk averse or because they have more options, since there is significant evidence that flexibility is an important factor in travel decisions.

Urgent trips such as commutes to work appear less flexible than trips for errands and leisure, particularly for decisions made prior to departure. However, familiarity seems to mediate the relative inflexibility of commutes because route switching is one of the most common behaviors for the most common trips home, to work, and to school; indeed, those who are aware of flood areas on their typical routes are more likely to change their route to work. Future iterations of this study should consider the frequency of travel for all routes, so that these relationships can be captured for errands and leisure travel as well. Furthermore, individuals who have entered floodwaters for lack of an alternate route are less likely to proceed with no change, indicating that past traumatic experience may be contributing to risk-averse behavior.

Some demographic groups appear more likely to proceed with no change, including younger drivers and individuals who identify as white. However, these groups are also more likely to select both proceed and one or more adaptation behaviors as potential options, and are in fact more likely to change their route to work upon encountering a flood. The complexities inherent to such situation-dependent decisions are difficult to capture in a survey, particularly the thresholds for choosing one behavior over another which may be in fact dynamic or altered in a state of duress. However, the results suggest that many Tucson residents enter floodwaters after other options have been exhausted.

These results have several implications for flood risk management and education campaigns. There are already several education campaigns designed to increase risk perception, but if motorists have constrained options then more should be done to ensure people have multiple feasible options for keeping themselves safe. Encouraging flexible scheduling and adding mitigation infrastructure to areas that do not have alternate routes would be one way to provide additional flexibility.

Providing more information about the locations of flood areas and safer alternate routes would be particularly useful. Communicating the availability of alternate routes would likely reduce flood exposure for several reasons: (1) changing the route is already the most common adaptation behavior; (2) people are willing to drive at least one mile to avoid floods, which is further than what is needed for most detours; (3) more than half have previously driven into floodwaters because they did not have or were not aware of a viable alternate route; and (4) many are already seeking information, especially with navigation apps, even though these sources of information do not provide details about flood area

locations and potential alternatives that avoid them. If this information could be provided in real time, it would be invaluable for those traveling unfamiliar routes.

The results of this study also provide important considerations beyond floods to other conditions that disrupt travel by creating unsafe conditions. If motorists have opportunities to minimize the costs of travel disruption, they are likely to take protective action. Ensuring the availability of viable alternatives and communicating relatively safe and dangerous routes for different types of hazards will continue to improve road safety and encourage safe driving behaviors.

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## Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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