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## Impacts to Diné activities with the San Juan River after the Gold King Mine Spill

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### Abstract

**Background**—On August 5<sup>th</sup>, 2015, 3 million gallons of acid mine drainage was accidentally discharged from the Gold King Mine near Silverton, Colorado into Cement Creek which is a tributary of the Animas and San Juan Rivers. The government-initiated risk assessment only assessed a recreational scenario (i.e. hiker drinking from the river), failing to recognize the deep connection of the Diné (Navajo) with the San Juan River.

**Methods**—Utilizing a mixed-methods approach we determined the impacts of the 2015 Gold King Mine Spill (GKMS or Spill) on Diné activities. We developed a questionnaire to collect pre- and post-GKMS Diné activity frequency and duration. Navajo Nation Community Health

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Conflict of interest

The authors declare that they have no conflict of interest.

Representatives administered the questionnaire to 63 Diné adults and 27 children living in three Navajo communities along the River.

**Results**—Through analysis of the focus group transcripts we identified 43 unique activities between the Diné and San Juan River. There were significant reductions in the total number, frequency, and duration of livelihood, dietary, recreational, cultural/spiritual and arts and craft activities. On average, Diné activities with the San Juan River following the GKMS decreased by 56.2%.

**Significance**—The significant reduction in activities following the GKMS may lead to long-term trauma, impacting the ability of the Diné to pass down teachings to their children affecting future generations to come. The 43 distinct activities between the Diné and the San Juan River highlight the importance for scientists and disaster responders to consider cultural and spiritual impacts when responding to environmental disasters and conducting risk assessments among Indigenous communities.

### Keywords

Disaster; Indigenous Health; Environment; Activity Patterns; Gold King Mine Spill; Diné (Navajo)

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### Introduction

On August 5<sup>th</sup> 2015, the Diné (Navajo) experienced a man-made technological disaster when the Gold King Mine near Silverton, CO released 3 million gallons of acid mine drainage into Cement Creek a tributary of the Animas and San Juan Rivers [1]. The yellow acid mine drainage traveled 550 miles through the Navajo Nation, located in the Four Corners area of the United States (Arizona, New Mexico, and Utah) (Figure 1). As hundreds of Diné farmers depend on the San Juan River for farming and is used for cultural and spiritual practices, the Navajo Nation declared a state of emergency [2]. The immediate research response was on the environment, specifically river water quality [3,4]. The United States Environmental Protection Agency (U.S. EPA) conducted a recreational risk assessment to assess human health impacts. However, this risk estimate was based solely on a recreational scenario for hikers and concluded that a continuous 64-day exposure to sediments with a daily water intake (2 L/day) from the river would not cause adverse effects over an extended period of time [5]. However, the Diné use the San Juan River for more than just recreational purposes. Additionally, the U.S. EPA's risk assessment did not capture Diné-specific exposure pathways or considered cultural or spiritual activities. Although the need to incorporate culturally-appropriate methods when responding to disasters has been identified for over 20 years, it continues to be excluded in practice [6,7].

Following man-made technological disasters, studies have focused on understanding the sociocultural and mental health impacts on individuals and communities [8-11]. Specifically for subsistence communities, mental and anxiety disorders increase along with a reduction in subsistence activities (i.e., gathering, hunting, fishing) [12-15]. In a survey administered to 594 men and women in 13 Alaskan Native communities one-year after the 1989 Exxon Valdez Oil Spill, 47% reported a decline in time spent hunting and fishing, with 32%

reporting a decline in the number of household members engaging in subsistence activities [16]. Additionally, a higher percentage of Alaskan Natives (48.4%, (91/188)) reported that the Exxon Valdez Oil Spill directly affected hunting, fishing or gathering activities compared to Euro-Americans (28.3% (105/371)) [14]. The studies focusing on Alaskan Native communities reveal that man-made environmental disasters have an impact on subsistence activities that can lead to deeper mental health impacts in Indigenous communities.

More recently, the 2010 Deepwater Horizon Oil Spill (BP oil spill), located in the Gulf of Mexico, also had devastating impacts among the Louisiana Gulf Coast communities. The BP oil spill not only disrupted commercial and subsistence fishing activities but also resulted in unique impacts to the Native Americans of this region [17]. The BP oil spill impacted revered fishing areas and plants used for traditional medicines and basket weaving [18]. A study in 2012 estimated that over the 7 years following the BP oil spill, the total revenue lost in the commercial and recreational fishing sector would be 0.5 to 2.7 billion USD, and 1.4 to 2.4 billion USD, respectively [19]. These estimates included revenue lost from employment in those sectors where livelihoods depended on commercial and recreational fishing. However, in the aftermath of the Deepwater Horizon Oil Spill, subsistence claims were not recognized by the Gulf Coast Claims Facility as a loss of income. This led to hardships and stress by many local fishermen as they were unable to provide their family with a food source. Additionally, much of the impacts to Native American communities in this region could not be truly quantified or compensated for [15,17].

Man-made technological disasters are not the only instances where Native American exposures have been underestimated. Native American specific exposure pathways have also been excluded from risk assessments conducted among superfund sites and communities with high fish consumption dependencies [20-23]. Community-driven research has led to improved exposure estimates among Native American communities and the creation of methods and tools to better quantify these exposures [24-29]. This methodological approach also resulted in the creation of culturally appropriate recommendations and interventions geared towards reducing exposures [30-32]. Incorporating Native American specific exposure pathways in the risk assessment process is possible and should always be incorporated to ensure those most at risk are protected.

While the environmental impacts of the GKMS have been investigated [3,4,33], the Diné-specific impacts as a result of the GKMS are unknown and/or misunderstood by federal risk assessors. The initial risk assessment following the GKMS conducted by the U.S. EPA only considered a recreational scenario and concluded that there would be no adverse effects from exposure to the sediments and consumption of the surface water by domestic livestock and wildlife. The U.S. EPA's risk assessment did not take into account the cultural, residential or dietary pathways of the Diné. To the Diné the San Juan River is considered a sacred river [34]. There are prayers and ceremonies that honor this special relationship. For centuries the Diné have relied on the San Juan River for agricultural, recreational, spiritual and cultural purposes. Their crop seeds, which are passed down from generation to generation, are directly dependent on the San Juan River for survival [35]. The San Juan River's well-being is connected to the Diné's state of Hózhó. Hózhó expressed in terms of Diné thoughts and expression are quite impossible to translate into English. Hózhó expresses the idea of

striving to keep balance, and bounds beauty, order, and harmony [36]. The Navajo Concept of Balance and Beauty includes consideration of the nature of the universe, the world, man, the nature of time and space, creation, growth, motion, order, control, and the life cycle. The Diné's state of Hózhó was disrupted on August 5<sup>th</sup>, 2015, when the Gold King Mine Spill disaster occurred causing their sacred river to turn a bright orange and bringing trauma to the Diné community. The Diné relationship with the San Juan River has existed since time immemorial. This “spatio-temporal” relationship may be more important to consider in regards to water governance than the boundaries set by jurisdiction [37].

To understand the potential impacts to livelihood, dietary, recreational, cultural, and art activities from the GKMS on the Diné people, this study employed culturally-appropriate methods. The Navajo Nation led the research agenda and the research questions were community-driven. A team of Diné centered researchers and community leaders was created and involved a partnership with the Navajo Nation Department of Health Community Health Representatives, Diné College, T’o Bei Nihí Dził (with water, we are strong; a grassroots community group), Shiprock Chapter, and Navajo Nation EPA. In addition to Diné scientists on our team, we were also guided by Diné cultural experts and Diné experts from Diné faith-based organizations. The objectives of this study were to 1) quantify the impacts of the 2015 GKMS on Diné-specific activities, and 2) understand differences in number, frequency, and duration of activities by participant demographics.

## Material and Methods

### Study location

This study was conducted on the Navajo Nation in the local government subdivisions called Navajo Nation Chapters including Shiprock, NM; Upper Fruitland, NM; and Aneth, UT (Figure 1). The Navajo Nation is the second largest federally recognized tribe in the United States with the largest tribal land base of 27,000 square miles located in the Four Corners of the Southwest (CO, NM, AZ, and UT). The three chapters are within 100 miles of each other along the San Juan River and are unique in their demographics, politics, membership, cultural and traditional activities and response to GKMS. Upper Fruitland and Shiprock Chapters are connected to the Navajo Indian Irrigation Project (NIIP) and members have farm units connected to the irrigation and drainage system of NIIP. Upper Fruitland Chapter opened their irrigation canals after the Navajo Nation EPA declared the San Juan River to meet agricultural standards of use which was three weeks after the GKMS [38]. Shiprock Chapter decided to keep their irrigation canals closed for one more year until questions regarding contaminant transport and uptake and health impacts were answered. This resulted in farmers completely losing their crops for that season [34,37,39]. The Aneth Chapter located downstream in Utah, is the most rural Chapter and is not connected to NIIP nor does the Chapter have centralized farm units with centralized irrigation systems. However, they rely on a water treatment systems operated by Navajo Tribal Utility Authority (NTUA) that pumps groundwater along the San Juan River which was initially hypothesized to have a cone of influence that created a falling river, potentially drawing contaminants into the water treatment plant [40].

## Approval of study

This research is approved and overseen by the Navajo Nation Human Research Review Board (NNHRRB) and the University of Arizona Office for Human Research Protections. As part of the NNHRRB protocol, supporting government and community resolutions were obtained from Northern Navajo Agency Council, Shiprock Chapter, the San Juan River Farm Board, Navajo Nation Grazing Committee District #12 and Navajo Nation Grazing Committee #13. Supporting letters were received from the President and Vice-President of the Navajo Nation Russell Begaye and Jonathan Nez; Directors of the Navajo Nation EPA Natural Resources, and Health; Program director of Navajo Community Health Representatives Program; Diné College Division of Science and Physical Education; Community Outreach and Patient Empowerment; Little Colorado River Watershed Association; and Black Mesa Water Coalition.

## Community-engagement

The study described in this article is part of a larger Diné-led project, the Gold King Mine Spill (GKMS) Diné Exposure Project, conducted by a multi-collaborative and interdisciplinary team composed of four academic partners, including the University of Arizona, Northern Arizona University, Fort Lewis College, and Diné College, as well as the Navajo Nation Community Health Representative (NN CHR) Program, Tó Bei Nihi Dziil ((TBND) a grassroots Diné organization concerned about water security), and Diné Elders. At every stage of the research process, including the grant proposal stage, design, recruitment, and dissemination process we have met and ensured the voice of our Diné community partners was prioritized. As an example, Diné partners have not only reviewed and approved this manuscript but are also included as co-authors. All data and associated products (e.g., presentations, manuscripts, dissemination materials) belong to the Navajo Nation. The GKMS Diné Exposure Project obtained permission from the NNHRRB for every conference presentation, outreach activity, and manuscript produced (including this manuscript). As part of the data sharing agreement with the NNHRRB any and all data shall be given to the Diné at the conclusion of the study.

## Focus groups

During Spring 2016, residents from each of the Navajo Nation Chapters were recruited for participation in focus groups via radio ads broadcasted in the Navajo language on KTNN (a major radio station on the Navajo Nation); flyers posted in the Chapter houses; word of mouth; and social media. Semi-structured focus group discussions were held at the Navajo Nation Chapters in Shiprock, NM; Upper Fruitland, NM; and Aneth, UT (Figure 1). The purpose of these focus groups was to obtain qualitative data to document the impacts of the GKMS on the Diné and to inform a structured questionnaire to identify and quantify interactions with the San Juan River to be administered to households in the three Diné Chapters. A total of 12 focus groups were held from May 13<sup>th</sup> - June 17<sup>th</sup>, 2016. Participants were asked how often and in what ways they use the San Juan River water and sediment before and after the GKMS (Supplementary Information 1: Focus group questions). Each focus group discussion and study procedure description took approximately 180 minutes. Trained Diné facilitators read the consent form orally in English or Navajo

to the participants. Participants who agreed to be in the study provided written informed consent and were reimbursed \$25. Focus groups were audio recorded and one Diné and one non-Diné notetaker recorded written notes. As some focus groups were all in Navajo, a Diné speaking facilitator and notetaker were always present. Focus group facilitators and notetakers compiled a list of the activities mentioned by participants during the focus groups. Through four meetings, a consensus panel of Diné and non-Diné facilitators, notetakers, community partners, and university researchers agreed upon 43 unique ways in which the Diné interact with the River.

### Household Questionnaire

The resulting questionnaire was subdivided into the following sections: livelihood, recreational, spiritual and ceremonial, and arts and crafts activities. For each activity, household participants were asked if they engaged in the activity before the GKMS, and the frequency and duration of the activity before the GKMS. Participants were then asked the level of engagement for each activity after the GKMS compared to before the GKMS (Figure 2), and the frequency and duration for each activity after the GKMS (Figure 2). The questionnaire had the following categories to document the frequency of each activity: never, special occasion, 1-3 times a week, 4-6 times a week, and daily. The duration choices were: less than 30 minutes, 30 minutes, 60 minutes, and greater than 60 minutes (Figure 2).

Participants residing in Upper Fruitland, Shiprock or Aneth Chapters within one-mile of the San Juan River were recruited by the Navajo Nation Community Health Representatives (NNCHRs). The University of Arizona research team trained twenty-two NNCHRs in human subjects research, and questionnaire administration in an eight-hour workshop. NNCHRS administrated the questionnaire to adult participants residing within the Upper Fruitland, Shiprock and Aneth Chapters from August 8<sup>th</sup>-12<sup>th</sup>, 2016. Figure 3 depicts the participant flow diagram. We recruited 59 households seeking one adult and one child participant. If a child was not present, then the spouse was given the opportunity to participate. The questionnaire administration and study procedures took approximately 90 to 120 minutes. Parents and/or guardians were asked to answer questions pertaining to their children. The consent form was in English and was read orally in English or Navajo to the participants by the NNCHRs. Participants who agreed to be in the study provided written informed consent and were reimbursed \$25 for study participation.

### Grouping of activities

The 43 activities included in the questionnaire were further subdivided into various categories. The categories were chosen based on consultation with Diné community partners. The categories were livelihood, dietary, recreational, cultural and spiritual, and arts and crafts (Supplementary Tables S1-S5). The livelihood category was defined as activities needed for means of economical and life support. The dietary category was reserved for activities where a person was directly eating or drinking items. The recreational category was for activities where a person was engaging with the San Juan River for enjoyment. These recreational activities were unique and were not included in the initial U.S. EPA risk assessment. The cultural and spiritual category was for activities that are specific to Diné

culture or Diné beliefs and religion. Activities included in the arts and crafts category are for activities where a craft or art item would be produced.

### Data analysis

Statistical analyses were completed using R 3.1 (R, Vienna, Austria). The frequency of each activity was converted into events per week. For each participant, each activity frequency was assigned a value (e.g., daily = 7 events per week. If a category had a range (e.g. 1-3 times per week) then the values were inputted evenly across the number of responses. For the “special” occasion category, we assumed this event would occur less than once a month. The duration of each activity was converted into minutes per day. We assumed each activity did not occur more than once a day. For the category “less than 30 minutes,” a value of 15 minutes was used. For the category “greater than 60 minutes,” we used a value of 90 minutes. Converting categorical values has been previously completed for dietary activities, and was adapted here for recreational, livelihood, cultural, and arts and craft activities [41]. To calculate the total percent change by category from *before* to *after* the GKMS, the number of activities for each participant was summed, the *after* number of activities was subtracted from the *before*, divided by the denominator (number of activities *before* the GKMS) then multiplied by 100. The Wilcoxon signed-rank test was used to determine differences in the total number, frequency, and duration of activities before and after the GKMS. Additionally, a Kruskal-Wallis test was used to determine if there were differences in the number, frequency, and duration of activities by age of participants (adults vs children), chapter (Shiprock, Aneth, Upper Fruitland), education (less than high school, high school, any college, 2-year college degree +), income (less than 20,000, 20,001 to 40,000, 40,000 +), or voting in political elections (tribal, federal, state). Voting in political elections was of interest because it may be associated with behavior changes following environmental threats [42].

## Results

### Participant characteristics

A total of 124 community members participated in the focus groups: 112 identified as Diné and 12 did not disclose their cultural identity. Participants included 18 young adults (18 to 24 years), 28 adults (25 to 54 years), and 50 elders (55 years or older). From the focus groups, we identified 43 unique ways in which the Diné interact with the San Juan River.

NNCHRs administered the questionnaire to 63 Diné adults (18-84 years). Parents completed the questionnaire for 27 Diné children (1-14 years). The average age of adults was 51 years and 7 years for children. Participants included 42 (67%) adult females and 15 (56%) child females. All the adult and child participants were Diné. A total of 20 adults and 11 children resided in Upper Fruitland Chapter; 18 adults and 12 children resided in Shiprock Chapter; and 25 adults and four children resided in the Aneth Chapter (Table 1).

### Adult activity patterns

The adults reported their top three pre-GKMS activities as: “Ate local crops irrigated with water from the San Juan River” (68.3%); “Played in the San Juan River (e.g., swimming,

diving)” (42.9%); and “Played in or contacted mud, soil or sediment along the San Juan River” (39.7%) (Supplementary Tables S1-S5). The 63 adults reported engaging in a total of 418 activities, with each individual participating in an average of 6.6 (range: 0- 29) activities before the GKMS (Table 2). After the GKMS, the 63 individuals reported engaging in a combined total of 187 activities, with each individual participating in an average of 2.9 (range: 0-23) activities (Table 2). The average decrease in dietary activities was 48.1%. The average decrease in recreational, livelihood, cultural and spiritual, and arts and craft activities were 39.7%, 28.5%, 29.8 % and 2.4%, respectively (Table 2). There was a significant difference in the overall change in number of activities before and after the GKMS (Wilcoxon signed rank test, p-value < 0.0001) (Table 2). The change in number of activities before and after the GKMS was also significantly different for all categories except for arts and crafts (Table 2).

There was a significant difference in the overall change in frequency (events per week) of activities before and after the GKMS (Wilcoxon signed-rank test, p-value <0.0001). The average frequency of activities (events per week) before the GKMS was 13 (range: 0-100) (Table 3). After the GKMS, the average frequency of activities (events per week) was 4.4 (range: 0-62.3) (Table 3). The change in frequency of activities before and after the GKMS was also significantly different for each category except for arts and crafts (Table 3).

Duration of activities (minutes per day) followed a similar pattern. There was a significant difference in the overall change in duration of activities before and after the GKMS (Wilcoxon signed-rank test, p-value <0.0001). The average duration of activities (minutes per day) performed before the GKMS was 61.3 (range: 0-710) minutes per day (Table 4). After the GKMS, the average duration of activities (minutes per day) performed was 15.4 (range: 0-15.4) (Table 4). The change in duration of activities before and after the GKMS was significantly different for the following categories: livelihood, recreational and cultural and spiritual activities (Table 4).

### Child activity patterns

The top three activities that child participants engaged in before the GKMS were “Ate local crops irrigated with water from the San Juan River” (44.4%); “Played in or contacted mud, soil or sediment along the San Juan River” (29.6%); and “Played in the San Juan River (e.g., swimming, diving)” (25.9%) (Supplementary Tables S6-S10). The change in number of activities before and after the GKMS was significantly different (p-value < 0.0001) (Table 5). The 27 children engaged in a total of 84 activities, with an average of 3 (range: 0-15) activities before the GKMS (Table 5). After the GKMS, the 27 children engaged in a total of 28 activities, with each child engaging in an average of one (range: 0-8) activity (Table 5). The change in the number of activities before and after the GKMS was also significantly different for each of the following categories: dietary, livelihood, and recreational (Table 5).

There was also a significant difference in the change in frequency (events per week) and duration (minutes per day) of activities of children before and after the GKMS (Wilcoxon signed-rank test, p-value=0.003 and p-value=0.009, respectively). The average frequency of activities (events per week) performed was 3.6 (range: 0-13.1) events per week before the GKMS (Table 6). After the GKMS, the average frequency of activities (events per week)



performed by children was 1.2 (range: 0-8.1) events per week. The average duration of activities for children was 10.8 minutes per day before the GKMS, and 1.2 minutes per day after the GKMS (Table 7).

A Kruskal-Wallis test was used to determine if there were differences in the number, frequency, and duration of activities by age of participants (adults vs children), chapter (Shiprock, Aneth, Upper Fruitland), education (less than high school, high school, any college, 2-year college degree +), income (less than 20,000, 20,001 to 40,000, 40,000 +), or voting in political elections (tribal, federal, state). There was a statistically significant difference in the change in number (overall and cultural), and frequency (overall, cultural, and dietary) of activities by age, with adults having a greater reduction compared to children (Supplementary Tables S11-S13).

## Discussion

Environmental disasters damage local landscapes, and communities may experience a sense of loss of culture. Loss of culture is difficult to quantify, as definitions for culture are dynamic and undergo changes with time [43]. Culture is often associated with a place, and thus culture loss within Indigenous communities can include loss of local knowledge, subsistence production, and connections to the land [43-46]. In the wake of environmental disasters that damage the local landscape, such as oil spills [16,47], exposure to nuclear radiation [48], deforestation [49], and the toxic impacts of mining [43], the sense of loss is a theme that emerges from affected Indigenous communities. The GKMS severely impacted the Diné's reliance on the San Juan River. In this study, we found significant reductions in the total number, frequency (events per week), and duration (minutes per day) of livelihood, dietary, recreational, cultural/spiritual and arts and craft activities. The top three activities adult and child participants engaged in before the GKMS were "Ate local crops irrigated with water from the San Juan River;" "Played in or contacted mud, soil or sediment along the San Juan River;" and "Played in the San Juan River (e.g., swimming, diving)" (Supplementary Tables S1-S10). This speaks to the Diné dependence on farming and their direct influence on children's activities. The largest impact for Diné adults was on the dietary activities, with an average 48.1% decrease in these activities. There was an average 28.5% decrease in livelihood activities among the adults and an average 29.8% decrease in cultural and spiritual activities. For children, the largest impact was also on the dietary activities, with an average 30.6% decrease in these activities. There was an average 24.7% decrease in recreational activities and an average 24.7% decrease in livelihood activities. Only age of participants (adults vs children) was significant in the change in the number (overall and cultural), and frequency (overall, cultural, and dietary) of activities, with adults having a greater decrease in activities compared to children.

The Diné have traditionally operated based on the seasons. The GKMS occurred in August (*Biniant'aats'ozí*), the beginning of the fall season, when the harvest season *Aakei*, begins [50]. As *Aakei* ends in October (*Ghaaji*) it is celebrated through the Northern Navajo Nation Fair and marked with the *Yeji bi Chei* ceremonies and the beginning of winter [50]. The GKMS occurred at a critical growing time that would have severely impacted the ability to harvest crops. The seasonal connection with the agricultural and cultural activities may

explain the dramatic decrease in the number of people reporting no longer consuming crops irrigated with water from the San Juan River (decrease from 43 to 21 people). The GKMS impacted not only agricultural activities but also cultural activities that were taking place to celebrate the end of the harvest season. In this study, 13 participants reported that before GKMS, they grew corn with the San Juan River water to pray, but after the GKMS only one person reported doing this activity. Before the GKMS, 11 participants reported that they gathered plants along the San Juan River to make medicine, but after the GKMS this decreased to zero.

Similar to the Indigenous communities affected by the Exxon Valdez and Deepwater Horizon spills [7,15,51], the GKMS was perceived by residents of the Navajo Nation as a direct threat to their way of life. The Diné have a deep connection with the San Juan River as a source of livelihood and culture. In focus groups, Diné residents affected by the GKMS expressed concerns over consuming local produce in fear that the food items would be contaminated, but this goes beyond the Euro-American concepts of threats to health and the economy. The GKMS is also perceived to be a danger to the continued survival of Diné culture [8,9,52]. As expressed by one community member,

“We have little ones and there is a lot of teaching in farming. To wake up early and work. We don't have that and can't pass (teach) it on right now. That's what they need. It's a setback”.

Passing on these traditions is an important component of Diné culture. The significant reduction in all activity categories following the GKMS indicates that Diné teachings may not be passed down to their children, which may affect future generations to come. Whether or not environmental contamination from the GKMS persists in the River, the GKMS has clearly impacted the Diné.

The GKMS affected the Diné in ways that perhaps can never be truly quantified. To the Diné, water is life and since time immemorial To (water) has been part of the Diné Lifeway [53-55]. To the Diné, Tó (water) is one of the Four Sacred Elements along with Kq' (fire/light), Nlchí (air), and Tadiiín (pollen/earth) that require protection. The disturbance of the San Juan River was a direct attack on the Diné Lifeway. It is through these elements that Sá'ah Naaghái Bik'eh Hózhóón is achieved. Sá'ah Naaghái Bik'eh Hózhóón is translated as Diné walking or being in a state of beauty with the natural world [53,56]. It is not a theory; this is the way of life for the Diné. If one of these elements is out of sync, the entire person walking in beauty is affected. It is through the harmonious way of life and these elements, crucially water, that the Diné walk in beauty. These Four Sacred Elements are mentioned and embedded in Diné Bi Beehaz'áanii or The Fundamental Laws of the Diné [53-55,57]. They are inseparable, they co-exist, they complement each other, and one cannot exist without the other, in there is the delicate balance. To disrupt this it is to disrupt harmony, Hózhq'q'j' (Beauty Way). Once the harmony is disrupted it has to be restored through a series of ceremonies and contact with Mother Earth. This entails prayers, songs and rituals through complex spiritual ceremonies by Traditional Practitioners (Medicine Men or Chanters) to restore and maintain balance and harmony in the lives of the people. To the Diné, the Four Sacred Elements of life must be respected, honored and protected for they sustain life.

The 43 distinct activities between the Diné and the San Juan River highlight the importance for scientists and disaster responders to assess cultural impacts in the risk assessment process, particularly when responding to environmental disasters. Conventional risk assessments are limited by their quantitative focus on measuring human health effects and do not capture socio-cultural impacts, a practice that leads to underestimation of exposure. One of the earliest instances where the need for culturally-appropriate research methods was identified was in the aftermath of the Exxon Valdez Spill [6]. Nearly 21 years later, a panel of experts identified similar needs at the “Assessing the Effects of the Gulf of Mexico (Deepwater Horizon) Oil Spill on Human Health 2010 Workshop” [47]. Experts in the field of exposure and emergency response highlighted the importance of using a holistic approach and providing cultural competence and transparency as part of the research process. Theoretical frameworks for conducting risk assessment with Indigenous communities have been published [58]. These frameworks for evaluating risks in Indigenous communities recognize that socio-cultural, spiritual, ecological and community factors are inextricably linked [59-61]. The framework developed by Harris & Harper (2000) includes common exposure pathways such as consumption activities (e.g., dietary ingestion), but also eco-cultural activities (e.g., medicinal, religious or cultural practices unique to each community) that are specific to Native American communities. Furthermore, the U.S. EPA commissioned The LifeLine Group to develop The LifeLine Community Based Assessment Software™ (CBAS) to evaluate community-specific potential exposures and risks [28]. A holistic risk assessment approach among those affected by the GKMS could have captured the potential harms to culture posed by the contamination of the San Juan River. The tools and resources exist to incorporate culturally-specific exposure pathways into the risk assessment process, and it is time for these to be incorporated when responding to disasters.

The present study has several limitations. The participant questionnaire responses may be subject to recall bias, resulting in potentially overestimating or underestimating participant activity patterns. However, their responses speak to the significant impact that the GKMS has had on their lives. Their perceptions of how the GKMS impacted their activities may be more important than objective measurements because they capture the personal perceived effects of the GKMS. While participants were not asked why they decided to stop engaging in activities, these dramatic changes in activities may be rooted in emotion. A previous study investigating behavioral and attitude changes after the Deepwater Horizon Oil Spill, found that the strongest predictor of change was if residents were affected emotionally by the oil spill [42]. Data on the frequency and duration of activity engagement at the individual level is necessary to estimate exposure, and can be obtained by video recording or daily logs [62,63]. However, these methods are time consuming and may also alter behavior, which could impede the speed in which the community impacts are assessed during an emergency response situation such as the GKMS. As we were interested in the frequency and duration of activities over a full year, a daily activity log for a week during each season would have captured the cultural activities that can occur in different seasons. This daily activity log would also help us determine if we underestimated the frequency and duration of activities by assuming that each activity only occurred once a day. However, this would have potentially caused an overburden to the participants during this traumatic event and thus a survey was deemed the most appropriate method to obtain activity data. One of the

impacts that was not assessed in our study was the economic impact to the community. Five years after the Deepwater Horizon Oil Spill, a survey was administered to 351 non-Native residents of Alabama and Florida [42]. Participants were asked if to what extent, if at all, the oil spill negatively personally affected them economically, emotionally, socially, and/or physically. The highest impact reported was economic impact followed by emotional, social, and physical impacts. Future studies should also assess the economic impacts in addition to environmental, mental health, and cultural impacts to Indigenous communities. Furthermore, future studies should not only quantify activity changes but also investigate what factors are associated with these changes, such as occupation, being a caregiver to a child, connection with the environment, or knowledge of environmental contamination. Understanding factors associated with these changes would provide us with an opportunity to create programs that can offer assistance to those affected.

The GKMS is not the first mine spill to affect the Navajo Nation. In 1979, a dam failed which resulted in 94 million gallons of acid mill waste spilling into the Puerco River, a spill that continues to affect the residents of Church Rock, NM [26,64]. At the time, no studies focused on how activities of the residents were affected. Our results demonstrate that the behaviors of the Diné living along the San Juan River changed as a result of the GKMS. The significant reduction in the number, frequency and duration of activities that the Diné have reported following the GKMS could lead to long-term historical trauma [8,9,52]. The trauma they experience along with inability to pass their teachings onto their children could negatively affect the ability to pass on their cultural teachings for generations to come. Culturally sensitive community outreach is necessary for the recovery and healing among the Diné, along with utilization of interpreters. In Indigenous communities, monetary compensation with government apologies goes a long way to restoring mistrust, anger and resentment of government officials. The ability to respond in a culturally-appropriate manner is crucial when working with the communities affected. Governmental agencies, community members, scientists, and media outlets need to develop a cohesive culturally relevant dissemination strategy and work together to assess and mitigate the impacts of environmental disasters.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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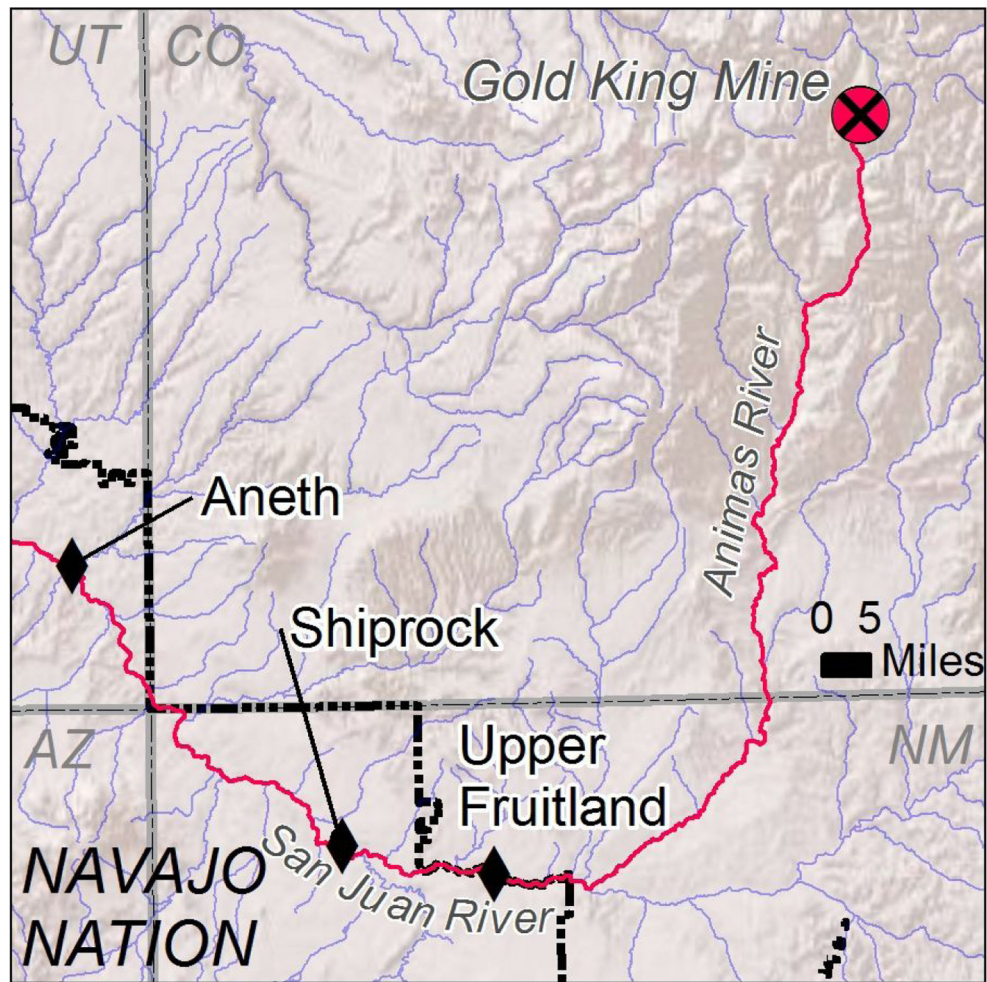
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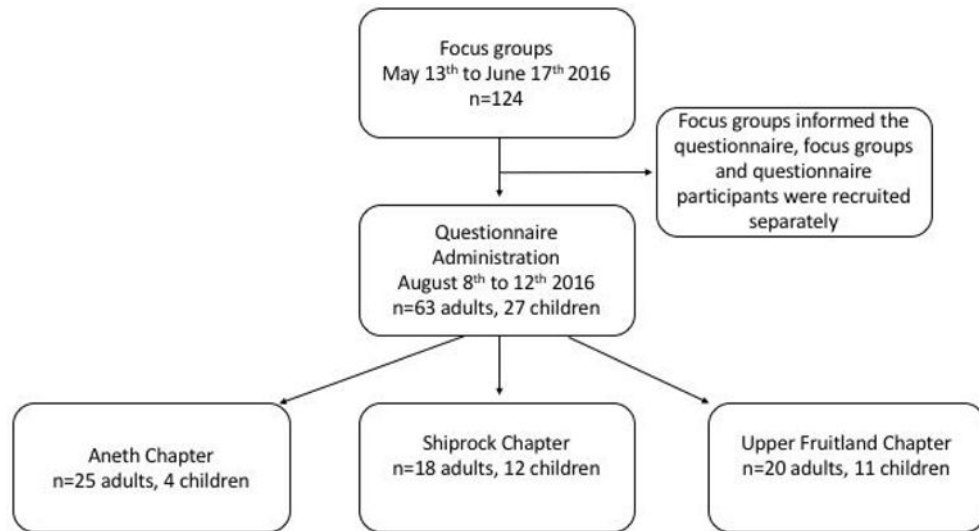
**Figure 1.** Study Location is on the Navajo Nation in the Four Corners Region of the Southwest and includes the Navajo Nation Chapters along the San Juan River in Upper Fruitland, NM; Shiprock, NM; and Aneth, UT.

	ENGAGED IN ACTIVITY BEFORE SPILL			SEASON				Frequency of Activity			Duration of Activity					
	YES	NO	DID NOT KNOW	SPRING	SUMMER	FALL	WINTER	1 x Day	4-6 x a week	1-3 x a week	Special occasion	Never	>60 MINUTES	60 MINUTES	30 MINUTES	LESS THAN 30 MINUTES
Played in the San Juan River (e.g., swimming, diving)																

	LEVEL OF ENGAGEMENT IN ACTIVITY AFTER SPILL COMPARED TO BEFORE			SEASON				Frequency of Activity			Duration of Activity					
	LESS	SAME	MORE	SPRING	SUMMER	FALL	WINTER	1 x Day	4-6 x a week	1-3 x a week	Special occasion	Never	>60 MINUTES	60 MINUTES	30 MINUTES	LESS THAN 30 MINUTES
Played in the San Juan River (e.g., swimming, diving)																

Figure 2. Example of questionnaire section to obtain pre-GKMS and post-GKMS activity pattern data



**Figure 3.** Participant flow diagram for developing the activity questionnaire and administering activity questionnaire to three Navajo Nation chapters.

**Table 1.**

Characteristics of study participants. All characteristics reported as counts (percentages) except for age (years), which is reported as mean  $\pm$  sd

<b>Characteristic</b>	<b>Adults (n=63)</b>	<b>Children (n=27)</b>
<b>Age (mean <math>\pm</math> sd)</b>	51 $\pm$ 19	7 $\pm$ 3.6
Years	18-84	1-14
<b>Gender</b>	<b>n (%)</b>	<b>n (%)</b>
Female	42 (67)	15 (56)
Male	21 (33)	12 (44)
<b>Tribe</b>		
Diné	63 (100)	27 (100)
<b>Chapter</b>		
Upper Fruitland	20 (32)	11 (41)
Shiprock	18 (28)	12 (44)
Aneth	25 (40)	4 (15)
<b>Education</b>		-
Less than high school	11 (17)	-
High school or GED	20 (32)	-
Any college	22 (35)	-
2-year college degree +	9 (14)	-
Did not want to answer	1 (2)	-
<b>Household Income</b>		-
Less than 20,000	22 (35)	-
20,001 to 40,000	22 (35)	-
40,001 +	11 (17)	-
Do not know	2 (3)	-
Did not want to answer	6 (10)	-
<b>Participate in Political Elections</b>		-
Yes Tribal	54 (86)	-
Yes Federal	34 (54)	-
Yes State	43 (68)	-
No	9 (14)	-

-, not applicable as question was not asked for children.

**Table 2.**

Summary of activity patterns before and after GKMS for adults (n=63)

	Min	25%	50%	75%	Max	Mean	SD	p-value <sup>I</sup>
<b>Number of Activities (activities per person)</b>								
<b>All</b>								<0.0001
Before	0	1	5	9	29	6.6	7.1	
After	0	0	1	3	23	2.9	5.5	
Percent Change	0	0	62.1	100	100	56.6	42.3	
<b>Dietary</b>								
<b>Dietary</b>								<0.0001
Before	0	1	2	3.5	9	2.6	2.4	
After	0	0	0	2	8	1.3	2.1	
Percent Change	0	0	50	100	100	48.1	49.2	
<b>Recreational</b>								
<b>Recreational</b>								<0.0001
Before	0	0	0	2	3	1	1.2	
After	0	0	0	0	3	0.2	0.6	
Percent Change	0	0	0	100	100	39.7	49.3	
<b>Livelihood</b>								
<b>Livelihood</b>								<0.0001
Before	0	0	0	2	8	1.5	2.2	
After	0	0	0	0.5	8	0.6	1.5	
Percent Change	0	0	0	58.3	100	28.5	42.2	
<b>Cultural and Spiritual</b>								
<b>Cultural and Spiritual</b>								<0.0001
Before	0	0	0	2	9	1.3	2.1	
After	0	0	0	0	6	0.5	1.2	
Percent Change	0	0	0	70.8	100	29.8	43.2	
<b>Arts and Crafts</b>								
<b>Arts and Crafts</b>								0.21
Before	0	0	0	0	4	0.2	0.7	
After	0	0	0	0	5	0.2	0.8	
Percent Change	0	0	0	0	100	2.4	29.0	

<sup>I</sup>Wilcoxon signed-rank test

Percent change was calculated by the following: the number of activities for each participant were summed, the *after* number of activities for each participant was subtracted from the *before*, then divided by the denominator (number of activities *before* the GKMS) and multiplied by 100.

**Table 3.**

Summary of frequency of activities before and after GKMS for adults (n=63)

	Min	25%	50%	75%	Max	Mean	SD	p-value <sup>I</sup>
<b>Frequency of Activities (events per week)</b>								
<b>All</b>								<0.0001
Before	0	0.06	5	18.7	100	13.0	19.2	
After	0	0	0.03	4.6	62.3	4.4	10.8	
Percent Change	0	1.2	77.8	100	100	59.2	50.5	
<b>Dietary</b>								
<b>Dietary</b>								<0.0001
Before	0	0.03	2	8.1	36	5.5	8.0	
After	0	0	0	0.15	20	1.9	4.2	
Percent Change	0	0	58.2	100	100	47.8	55.5	
<b>Livelihood</b>								
<b>Livelihood</b>								<0.0001
Before	0	0	0	4	28	3.0	5.4	
After	0	0	0	0.02	19	1.2	3.4	
Percent Change	0	0	0	99.8	100	33.6	45.5	
<b>Recreational</b>								
<b>Recreational</b>								<0.0001
Before	0	0	0	3	15	2	3.9	
After	0	0	0	0	15	0.4	2.1	
Percent Change	0	0	0	100	100	41	49.4	
<b>Cultural and Spiritual</b>								
<b>Cultural and Spiritual</b>								<0.0001
Before	0	0	0	1.1	21	2.1	4.6	
After	0	0	0	0	11	0.8	2.3	
Percent Change	0	0	0	73.3	100	30.8	43.7	
<b>Arts and Crafts</b>								
<b>Arts and Crafts</b>								0.28
Before	0	0	0	0	12	0.4	1.8	
After	0	0	0	0	12	0.2	1.5	
Percent Change	0	0	0	0	100	7.3	25.5	

<sup>I</sup>Wilcoxon signed-rank test

Percent change was calculated by the following: the frequency of activities for each participant were summed, the *after* frequency of activities for each participant was subtracted by the *before* and then divided by the denominator (frequency of activities *before* the GKMS) and multiplied by 100.

**Table 4.**

Summary of duration of activities before and after GKMS for adults (n=63)

	Min	25%	50%	75%	Max	Mean	SD	p-value <sup>I</sup>
<b>Duration of Activities (minutes per day)</b>								
<b>All</b>								<0.0001
Before	0	0	0.4	77	710	61.3	125.6	
After	0	0	0	0.14	293	15.4	53.9	
Percent Change	0	0	39.7	100	100	46.5	46.5	
<b>Livelihood</b>								
Before	0	0	0	17.7	326	24.3	54.5	
After	0	0	0	0	185	6.2	26.8	
Percent Change	0	0	0	100	100	37.4	46.6	
<b>Recreational</b>								
Before	0	0	0	4.6	150	14.9	32.6	
After	0	0	0	0	64.3	1.1	8.1	
Percent Change	0	0	0	100	100	38	48.9	
<b>Cultural and Spiritual</b>								
Before	0	0	0	4.6	257	17.8	49	
After	0	0	0	0	108	5.2	19.5	
Percent Change	0	0	0	73.3	100	30.8	43.7	
<b>Arts and Crafts</b>								
Before	0	0	0	0	154	4.3	21.8	
After	0	0	0	0	154	2.9	19.7	
Percent Change	0	0	0	0	100	5.7	22.6	0.28

<sup>I</sup>Wilcoxon signed-rank test

Percent change was calculated by the following: the duration of activities for each participant were summed, the *after* duration of activities for each participant was subtracted by the *before* and then divided by the denominator (duration of activities *before* the GKMS) and multiplied by 100.

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**Table 5.**

Summary of activity patterns before and after GKMS for children (n=27)

	Min	25%	50%	75%	Max	Mean	SD	p-value <sup>I</sup>
<b>Number of Activities (activities per person)</b>								
<b>All</b>								<0.0001
Before	0	0	2	5	15	3.1	3.8	
After	0	0	0	1.5	8	1.0	1.9	
Percent Change	0	0	0	84.2	100	36.2	44.0	
<b>Dietary</b>								0.006
Before	0	0	1	2.5	9	1.5	2.0	
After	0	0	0	1	3	0.5	0.8	
Percent Change	0	0	0	83.3	100	30.6	44.3	
<b>Livelihood</b>								0.02
Before	0	0	0	1	5	0.6	1.1	
After	0	0	0	0	1	0.1	0.3	
Percent Change	0	0	0	33.3	100	24.7	43.1	
<b>Recreational</b>								0.02
Before	0	0	0	2	3	0.9	1.1	
After	0	0	0	0	3	0.3	0.7	
Percent Change	0	0	0	33.3	100	24.7	43.0	
<b>Cultural and Spiritual</b>								0.20
Before	0	0	0	0	2	0.2	0.5	
After	0	0	0	0	1	0.1	0.3	
Percent Change	0	0	0	0	100	11.1	32.0	
<b>Arts and Crafts</b>								NA
Before	0	0	0	0	0	0	0	
After	0	0	0	0	0	0	0	
Percent Change	0	0	0	0	0	0	0	

<sup>I</sup>Wilcoxon signed-rank test

Percent change was calculated by the following: the number of activities for each participant were summed, the *after* number of activities for each participant was subtracted from the *before*, then divided by the denominator (number of activities *before* the GKMS) and multiplied by 100.



**Table 6.**

Summary of frequency of activities before and after GKMS for children (n=27)

	Min	25%	50%	75%	Max	Mean	SD	p-value <sup>I</sup>
<b>Frequency of Activities (events per week)</b>								
<b>All</b>								0.003
Before	0	0	0.13	6	13.1	3.6	4.5	
After	0	0	0	0.10	8.1	1.2	2.5	
Percent Change	0	0	0	99.5	100	32.6	49.7	
<b>Dietary</b>								0.04
Before	0	1	0.03	4.0	12	2.1	3.0	
After	0	0	0	0.03	7	1.0	2.1	
Percent Change	0	0	0	97.7	100	22.4	71.1	
<b>Livelihood</b>								0.02
Before	0	1	0.03	0.03	5	0.5	1.2	
After	0	0	0	0	2	0.1	0.4	
Percent Change	0	0	0	33.3	100	24.7	43.0	
<b>Recreational</b>								0.02
Before	0	0	0	0.1	6	0.8	1.7	
After	0	0	0	0	4	0.2	0.9	
Percent Change	0	0	0	16.4	100	22.2	40.3	
<b>Cultural and Spiritual</b>								0.37
Before	0	0	0	0	5	0.19	0.9	
After	0	0	0	0	0.03	0.002	0.009	
Percent Change	0	0	0	0	100	7.4	26.7	
<b>Arts and Crafts</b>								NA
Before	0	0	0	0	0	0	0	
After	0	0	0	0	0	0	0	
Percent Change	0	0	0	0	0	0	0	

<sup>I</sup>Wilcoxon signed-rank test

Percent change was calculated by the following: the frequency of activities for each participant were summed, the *after* frequency of activities for each participant was subtracted by the *before* and then divided by the denominator (frequency of activities *before* the GKMS) and multiplied by 100.

**Table 7.**

Summary of duration of activities before and after GKMS for children (n=27)

	Min	25%	50%	75%	Max	Mean	SD	p-value <sup>I</sup>
<b>Duration of Activities (minutes per day)</b>								
<b>All</b>								0.009
Before	0	0	0	1.3	62	10.8	21.3	
After	0	0	0	0	17	1.2	4.1	
Percent Change	0	0	0	95.2	100	32.0	46.4	
<b>Livelihood</b>								
<b>Livelihood</b>								0.02
Before	0	0	0	0.5	26	3.6	8.0	
After	0	0	0	0	8.6	0.5	1.8	
Percent Change	0	0	0	37.5	100	24.6	42.6	
<b>Recreational</b>								
<b>Recreational</b>								0.02
Before	0	0	0	0.8	51	6.8	14	
After	0	0	0	0	8.6	0.7	2.3	
Percent Change	0	0	0	37.4	100	24.6	42.7	
<b>Cultural and Spiritual</b>								
<b>Cultural and Spiritual</b>								0.37
Before	0	0	0	0	10.7	0.40	2.1	
After	0	0	0	0	0.1	0.005	0.02	
Percent Change	0	0	0	0	100	7.4	26.7	
<b>Arts and Crafts</b>								
<b>Arts and Crafts</b>								NA
Before	0	0	0	0	0	0	0	
After	0	0	0	0	0	0	0	
Percent Change	0	0	0	0	0	0	0	

<sup>I</sup>Wilcoxon signed-rank test

Percent change was calculated by the following: the duration of activities for each participant were summed, the *after* duration of activities for each participant was subtracted by the *before* and then divided by the denominator (duration of activities *before* the GKMS) and multiplied by 100.

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