UNIVERSITY OF TEXAS ARLINGTON

TxDOT Report 0-7201-R1 Appendix C

HYDROLOGIC APPROACHES TO PLAYA LAKES, AREAS OF SIGNIFICANT KARST GEOLOGY, AND ARID REGIONS: Appendix C

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Appendix C

CONDUCT SURVEY AND INTERVIEWS (TASK 3)

EXECUTIVE SUMMARY

Playa lakes, arid regions, and karst terrains are significant geographic and hydrological features throughout Texas, each posing unique challenges due to their complex and varied hydrology. Currently, there are no standardized guidelines or criteria for the hydrological and hydraulic design of transportation infrastructure in these landscapes, which forces designers to rely heavily on project-specific judgment to determine appropriate hydrological parameters. The primary objective of this task was to conduct surveys and interviews to gather information on the current state of knowledge and practices regarding the hydrology of playa lakes, karst terrains, and arid regions.

The survey engaged a diverse cohort of 76 experts, including representatives from 30 state Departments of Transportation (DOTs), 13 university faculty members, 12 consultants, and 21 other entities encompassing federal, state, city, and local agencies. Ultimately, 24 responses were collected, providing valuable insights into the effectiveness of existing guidelines and modeling approaches related to the hydrology of these critical ecosystems. The survey comprised 37 questions covering various topics, including location, infrastructure design and damages, studies and standards, modeling practices, hydrology and hydraulic models, hydrologic and hydraulic parameters, and recommendations for improvement. Each question was analyzed using pie charts, and specific participant comments were included where relevant.

To gain deeper insights into hydrological practices, the research team conducted follow-up interviews with select participants from the initial survey. This qualitative phase included seven experts from DOTs in Kansas, Minnesota, New Mexico, and Virginia, alongside two researchers, and a consultant. These interviews provided a more nuanced understanding of the challenges and successes encountered in managing hydrological resources in these areas. The interview results are summarized according to the three main areas of questions and are further organized by their relevance to the three focus areas: playa lakes, arid regions, and karst zones.

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CHAPTER C1: INTRODUCTION

This technical memorandum presents the findings from Task 3 of Project 0-7201, titled "*Conduct Survey and Interviews*". The research team carried out surveys and follow-up interviews to assess the current state of knowledge and practices regarding hydrological approaches to playa lakes, karst terrains, and arid regions.

C.1.1. Project Background

Playa lakes, arid regions, and karst terrains are prominent features of the Texas landscape, spread across different parts of the state. The hydrology in these areas is complex and highly variable, influenced by factors such as climate, soil composition, and land use. Consequently, designing infrastructure in these regions poses several challenges. The key challenges related to hydrological studies, along with the design, operation, and maintenance of transportation infrastructure in these environments, are outlined in **Appendix B (Task 2)**.

C.1.2. Objective and Methodology

The primary objective of this task was to assess the current state of knowledge and practices concerning hydrological approaches to playa lakes, arid regions, and karst terrains. This was achieved through a comprehensive survey study targeting a range of professionals involved in hydrological and infrastructure-related fields, followed by in-depth follow-up interviews with selected experts. These interviews provided additional context and deeper insights into the practical challenges, methodologies, and strategies currently being employed. By gathering this data, the task aimed to identify existing gaps, best practices, and areas in need of further research or refinement within these unique and complex environments.

C.1.3. Report Structure

This memorandum is structured as follows: **Chapter C1** provides an overview of the project background, objectives, and the methods used to conduct this task. **Chapters C2** and **C3** present the findings from the surveys and interviews, respectively. Finally, **Chapter C4** summarizes the key insights gained from both the surveys and interviews.

CHAPTER C2: SURVEY ON HYDROLOGIC APPROACHES TO PLAYA LAKES, KARST GEOLOGY, AND ARID REGIONS

C.2.1. Survey Overview

A survey was conducted to assess the current practices in hydrology of playa lakes, arid areas, and karstic zones. The survey questionnaire was divided into six sections: location; infrastructure design and damages; studies, standards, and modeling; hydrology and hydraulic models; hydrologic and hydraulic parameters; and recommendations/suggestions. This task aimed to gather insights from professionals in hydrology and infrastructure design across various geographic regions. The survey was distributed to 76 experts, including representatives from 30 state DOTs, 13 university faculty and researchers, 12 consultants, and 21 other entities (federal, state, cities, and local agencies). A total of 24 responses were collected, comprising participants from the same categories. These responses provided a comprehensive view of the performance and applicability of various hydrology estimation methods, including empirical, semi-empirical, direct, and indirect approaches. The research team used the *QuestionPro* platform for data collection, and the complete questionnaire is provided in **Appendix C Supplemental Materials**.

C.2.2. Survey Questionnaire Development

C.2.2.1. Design Process

The survey on *Hydrologic Approaches to Playa Lakes, Karst Geology, and Arid Regions* was developed through an extensive review of relevant literature and current research in Task 2 (**Appendix B**). The questionnaire was designed to address the critical issues and challenges identified in prior studies, ensuring a comprehensive exploration of hydrologic and hydraulic practices in these environments. The goal was to gather detailed insights into methods, guidelines, and professional experiences, focusing on how these approaches are applied in infrastructure planning, design, and management in playa lakes, karstic areas, and arid regions. The survey aimed to identify current practices and gather expert opinions to help shape future approaches in these challenging settings.

C.2.2.2. Survey Platform

The survey was administered using QuestionPro, a leading online survey platform endorsed by The University of Texas Arlington for academic and administrative research. QuestionPro was chosen for its robust features, including the ability to create and manage web forms, facilitate offline data collection, and perform advanced data analysis. This platform provides a user-friendly interface for survey distribution and data analysis, ensuring a streamlined process for gathering and interpreting survey responses.

C.2.3. Selection of Participants

The selection criteria for survey participants were designed to encompass a broad spectrum of expertise and experience. The targeted participants included professionals from Departments of

Transportation (DOTs), state and federal agencies, cities, university researchers, industry specialists, and professionals in consulting firms. This diverse participant pool was chosen to ensure that the survey captured a wide range of perspectives and practical insights.

C.2.3.1. State Departments of Transportation (DOTs)

The survey initiated by identifying Departments of Transportation (DOTs) operating in states characterized by karst topography, playa lakes, and arid or semi-arid conditions. **Figures C.1a** to **C.1c** illustrate the DOTs located in these respective regions. Of the 32 DOTs identified, 25 are situated in karst areas, 9 in regions with playa lakes, and 15 in arid or semi-arid areas, as summarized in **Table C.1**. Notably, several DOTs have assets in more than one of these environmental conditions. For instance, both Texas and New Mexico include areas with karst formations, playa lakes, and arid regions. Professionals with relevant experience and expertise from each DOT, including state hydraulic/drainage engineers, team leads, and directors, were identified and contacted.

C.2.3.2. Other Participants

A total of 46 individuals were selected to participate in the survey. The list includes 13 from research institutions (universities, research centers), 21 from state and federal agencies and cities, and 12 from consulting firms. **Table C.2** provides a list of the targeted participants drawn from these diverse sources.

C.2.3.3. Status of Survey Submissions by Participants

The survey aimed to collect information from various departments of transportation (DOTs) and other entities regarding their approaches to the hydrology of playas, karst, and arid areas. Out of the 32 DOTs, 30 were contacted, and 15 responded. Three DOTs expressed interest but ultimately did not submit their responses, and six DOTs did not respond at all. Additionally, contact information for the hydraulic or drainage engineers of six DOTs was unavailable. The status of survey submissions from the selected DOTs is visually represented in **Figure C.2**.

In addition to the DOTs, the survey was also sent to 46 selected individuals from other entities. Of these, 9 responses were received. **Table C.2** summarizes the number of responses received from these entities.

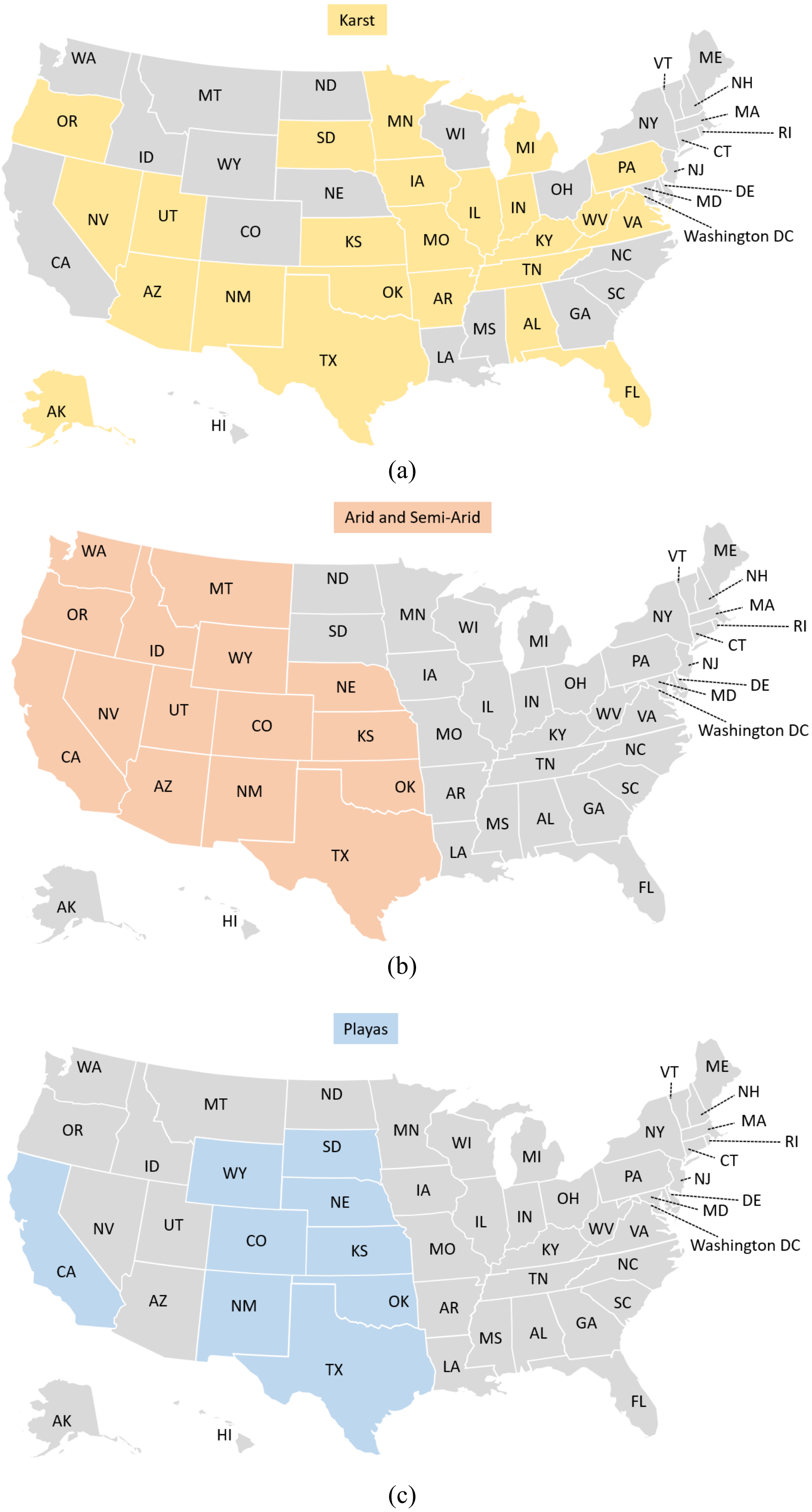


Figure C.1 Distribution of (a) Karst Areas, (b) Arid Regions, and (c) Playa Lakes across the United States

Table C.1 List of DOTs selected for survey

No.	Department of Transportation	Karst Areas	Playa Lakes	Arid Regions
1	Alabama (ALDOT)	×		
2	Alaska (DOT&)	×		
3	Arizona (ADOT)	×		×
4	Arkansas (ARDOT)	×		
5	California (Caltrans)		×	×
6	Colorado (CDOT)		×	×
7	Florida (FDOT)	×		
8	Illinois (IDOT)	×		
9	Idaho (ITD)			×
10	Indiana (INDOT)	×		
11	Iowa (Iowa DOT)	×		×
12	Kansas (KDOT)	×	×	×
13	Kentucky (KYTC)	×		
14	Michigan (MDOT)	×		
15	Minnesota (MnDPT)	×		
16	Missouri (MoDOT)	×		
17	Montana (MDT)			×
18	Nebraska (NDOT)		×	×
19	Nevada (NDOT)	×		×
20	New Mexico (NMDOT)	×	×	×
21	Oklahoma (ODOT)	×	×	×
22	Oregon (ODOT)	×		×
23	Pennsylvania (PennDOT)	×		
24	South Dakota (SDDOT)	×	×	
25	Tennessee (TDOT)	×		
26	Texas (TxDOT)	×	×	×
27	Utah (UDOT)	×		×
28	Virginia (VDOT)	×		
29	Washington (WSDOT)			×
30	West Virginia (WVDOT)	×		
31	Wisconsin (WisDOT)	×		
32	Wyoming (WYDOT)		×	×

Table C.2 List of selected entities selected for survey (federal, state, and local agencies, and cities)

Agency	No. of Invited Individuals for Survey	No. of Responses Received	Notes
USACE	5	0	Fort Worth, Tulsa, Albuquerque, California, Washington
FEMA	1	0	Oklahoma
USGS	1	0	Oklahoma-Texas Water Science Center
USBR	5	0	Albuquerque, Colorado, Arizona, California, Texas
Cities	2	1	Fort Worth, Lubbock
Universities	13	4	Texas Tech, UT Austin, New Mexico, Baylor
Other Agencies	7	1	National Cave and Karst Research Institute, High Plains Underground Water Conservation District, Edwards Aquifer Authority, Panhandle Groundwater Conservation District , North Plains Groundwater Conservation District, North Plains Groundwater Conservation District
Consulting Firms	12	3	West Consultants, Gannet Fleming, AECOM, EnTech, HDR, Consor, Dewberry

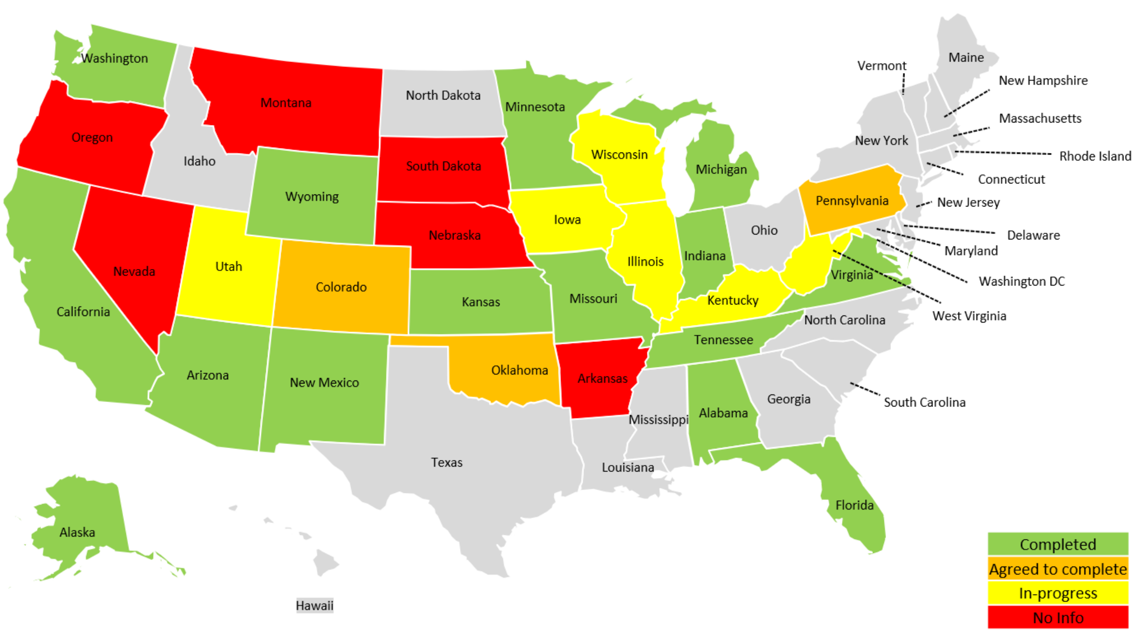


Figure C.2 Status of surveys submissions from the selected DOTs

C.2.4. Survey Results

The survey consisted of 37 questions that addressed a wide range of topics including location, infrastructure design and damages, studies and standards, modeling practices, hydrology and hydraulic models, hydrologic and hydraulic parameters, and recommendations or suggestions. These questions and responses were organized into four distinct sections to comprehensively examine various hydrological contexts.

- **General Questions:** This section includes 12 broad questions covering overarching topics and practices relevant to all types of hydrological studies in playa lakes, arid zones, and karstic regions (**Section C.2.4.1**).
- **Playa Lakes:** The 11 questions here focus specifically on the unique characteristics, methodologies, and challenges associated with the hydrology of playa lakes. It aims to collect detailed information on the identification, modeling, and management of these environments (**Section C.2.4.2**).
- **Karst Regions:** This section includes 13 questions that cover the methods used for identifying and modeling these complex environments, as well as the challenges and considerations specific to karstic landscapes (**Section C.2.4.3**).
- **Arid Regions:** The final section includes 13 question that addresses issues related to arid regions, including methods of identification and classification, as well as design guidelines and standards for hydrological studies of infrastructure in such areas (**Section C.2.4.4**).

It should be noted that Q18 and Q30 to Q34 were repeated for all three regions and are numbered as Q18.1, Q18.2, Q18.3, and Q30.1, Q30.2, Q30.3 through Q34.1, Q34.2, Q34.3. For each question, analysis is provided using pie charts. Specific information and comments from participants are also included where relevant. This structured approach is chosen to capture a comprehensive and organized view of practices and experiences across different hydrological contexts. The full questionnaire is provided in **Appendix C Supplemental Materials**.

C.2.4.1. General Questions

The general section of the survey focused on gathering information about practices and methodologies related to hydrological studies and infrastructure design in playa lake, karst, and arid regions. These series of questions include Q1, Q5 to Q7, Q14 to Q17, Q29, and Q35 to Q37.

Please check below if your institution/company is engaged in work or research in the areas of playa lakes, arid regions, and karstic zones (Q1)

The survey received a total of 33 responses from 24 participants, as they had the option to select more than one region. Among these, 3 participants selected all three regions, 3 selected two, and the rest selected only one region.

The results show varying levels of engagement across these areas, with 42.4% (out of 33 responses) reporting that their institutions focus more on karstic zones more often than arid regions (27.3%) and playa lakes (21.2%) **(Figure C.3)**. Overall, the data suggests that karstic areas are more frequently the subject of study or concern. This can be attributed to the widespread distribution and prevalence of karstic zones in the U.S., as opposed to the more geographically limited arid regions and playa lakes, which are mainly found in the southwestern and western parts of the country (**Appendix B: Figures B.4, B.15,** and **B.33**). Additionally, karst features present unique challenges for DOTs and communities, including hydrological complexities and vulnerabilities to geohazards such as sinkholes, slope instability, and flooding.

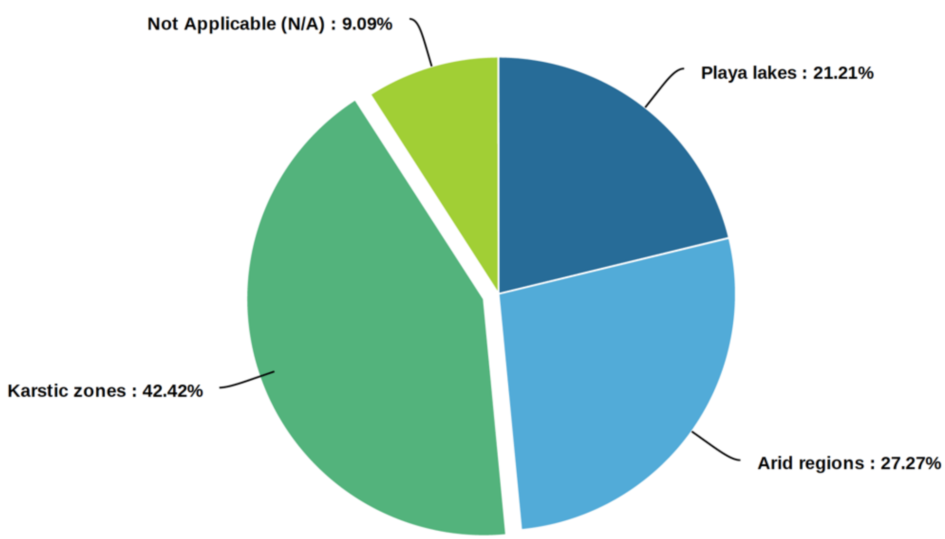


Figure C.3 Responses to engagement in work or research in playa lakes, arid regions, and karst zones (Q1)

Would it be possible to share documentation/manuals/resources that you and/or your company/institution use to identify playa lakes/karstic zones/arid regions? (Q5)

The survey received a total of 33 responses from 24 participants, as they had the option to select more than one region. Among these, 3 participants selected all three regions, 3 selected two, and the rest selected only one region. Twenty percent of respondents expressed a willingness to share documentation or resources related to identifying playa lakes, karst zones, or arid regions, while another 20% indicated they would only provide such materials upon official request. Twelve percent stated they would not share documentation, and 16% were uncertain about their ability to do so. Additionally, 24% noted that the question was not applicable to their work, and 8% selected the "*Others*" option **(Figure C.4)**. Some participants noted that "*We do not have standardized documented methods for identifying playa lakes, karstic zones, or arid regions - each site was investigated independently*".

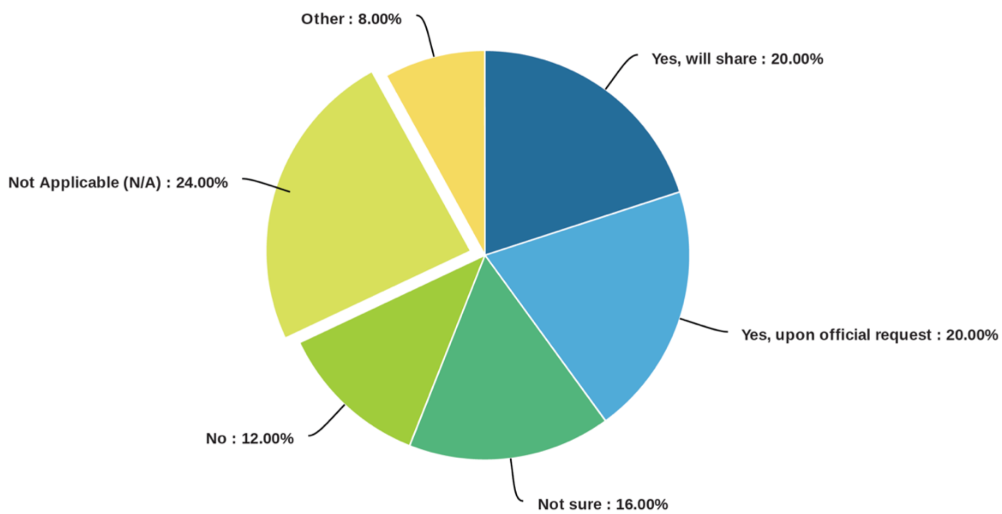


Figure C.4 Responses to sharing documentation used by participants to identify playa lakes, karstic zones, and arid regions (Q5)

Does your institution/company have infrastructure assets in playa lakes, arid regions, and karstic zones? Select all apply (Q6)

If yes, what type of infrastructure?
☐ Roadway
☐ Railways
☐ Bridges
☐ Aviation and airport
☐ Soft infrastructures (banks, schools, colleges, hospitals, etc.)
☐ Other(s): Specify

Most of the respondents reported having infrastructure assets in karstic zones (32.4%), followed by arid regions (29.7%) and playa lakes (21.6%) (**Figure C.5**). A smaller group stated that having infrastructure in these regions was not applicable to them (8.1%), while others acknowledged either a lack of knowledge (5.4%), or were entirely unaware of any relevant contacts or resources (2.7%). One respondent noted that while they have clients with infrastructure in playa and arid regions, the details are confidential.

The data highlights the prevalence of infrastructure assets in karstic zones and arid regions, with fewer in playa lakes, and also reveals knowledge gaps in some respondents.

To enhance understanding, respondents were asked to specify examples of infrastructure assets in different environments, along with their functions. Some examples provided include:

- *Playa Lakes*: Buildings, roadways, culverts, bridges, erosion control features, etc.
- *Arid Areas*: Buildings, roadways, bridges, culverts, erosion control features, water lines, sanitary lines, stormwater lines, streets, trees, drainage infrastructure, and other miscellaneous infrastructure maintained by cities.
- *Karst Zones*: Roadways, bridges, culverts, erosion control features, SWM, fiber optics for electronic signs, overhead signs, signs, ditches, closed storm sewer systems, and guardrails.

Additional information is needed to analyze the geographic distribution of respondents' institutions, which could yield insights into regional infrastructure development patterns, identify collaboration opportunities, and inform the development of guidelines for hydrological studies in these areas.

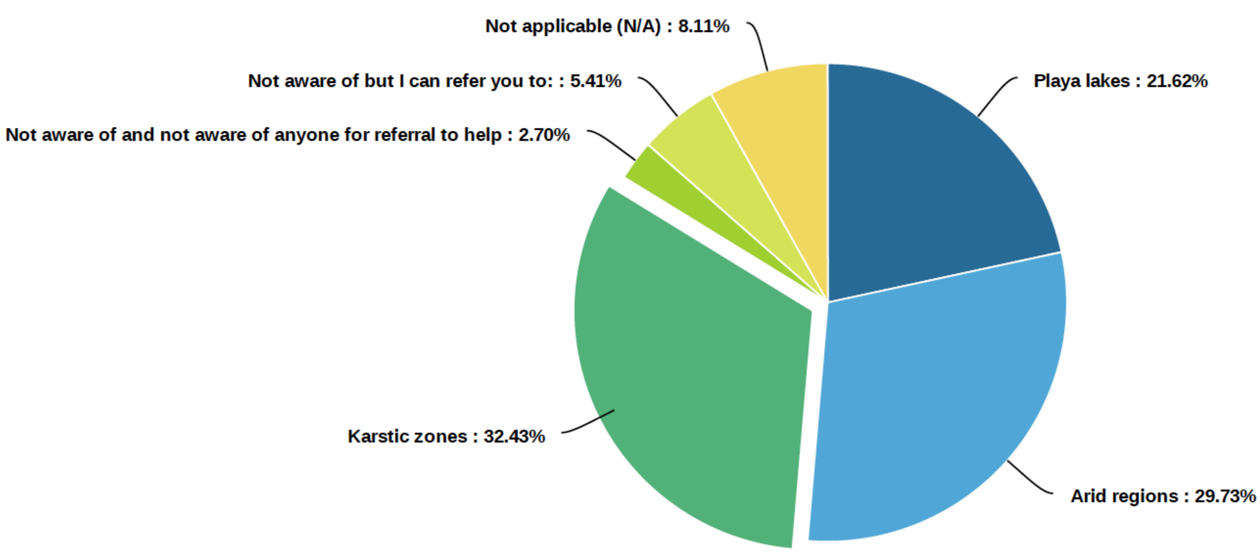


Figure C.5 Responses to having infrastructure assets in playa lakes, arid regions, and karst zones (Q6)

Do you have any specific hydrology & hydraulic study reports or design considerations for the design of infrastructures in playa lakes, arid regions, and/or karstic zones? If yes, would it be possible to share any reports or design considerations? (Q7)

A significant portion of respondents (52%) reported having hydrology and hydraulic study reports related to infrastructure design in playa lakes, arid regions, or karstic zones. Of those with such reports, the majority (70%) indicated a willingness to share them, either directly or upon formal request. However, 4% of respondents mentioned that their reports could not be shared due to confidentiality restrictions, and 8% noted that the question was not applicable to their practices. Additionally, 36% of respondents indicated they do not have such reports, possibly due to limited study or the specific nature of their infrastructure projects (**Figure C.6**)

In cases where respondents prefer official channels, submitting formal requests through institutions or organizations may be necessary. Additionally, exploring online repositories and databases of scientific publications and technical reports can provide access to publicly available information.

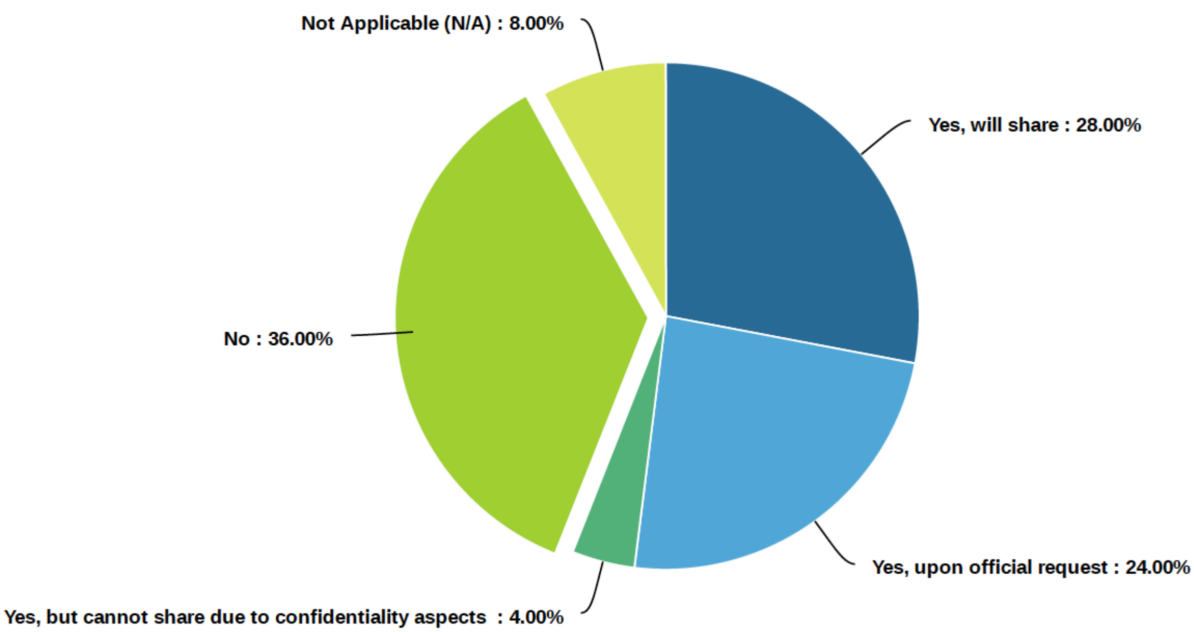


Figure C.6 Responses to having specific hydrology & hydraulic study reports or design considerations for the design of infrastructures in playa lakes, arid regions, and karst zones (Q7)

Do you have personal experience in hydrology and hydraulic studies/modeling of playa lakes, arid regions, and karstic zones? (Q14)

A majority of respondents (71.4%) reported personal experience in hydrology and hydraulic studies, or modeling related to playa lakes, arid regions, and karstic zones (**Figure C.7**). Among these, 70% reported experience in only one region, 15% in two regions, and 15% in all three regions. This high level of expertise suggests that the project team effectively engaged the right participants to address the complex hydrological and hydraulic challenges in these environments. Additionally, the widespread occurrence of these geographic areas across the nation, along with their unique challenges, offers opportunities for collaboration and knowledge sharing.

Several participants reported experience across multiple areas, with 44% having experience in arid regions, 34% in karst zones, and 22% in playa lakes. Sample responses highlighting their expertise in these environments included the following:

- *"I have done the most with playa lakes that occur in our semi-arid region. I have also done ecohydrological studies in karstic zones."*
- *"I have experience with drainage structures in karst areas."*
- *"I have designed projects that drain into karst features."*
- *"I have performed hydrologic and hydraulic analysis for transportation drainage structures (bridges and culverts) for 30 years for Kansas. Design in all of these areas is difficult and relies not only on hydraulic/hydrologic modeling, but greatly on experience, inspections, discussions with local landowners, and other information. I have experience in karstic regions."*
- *"Roswell Artesian Basin; San Solomon springs system; Capitan Reef; southern Sacramento Mountains."*

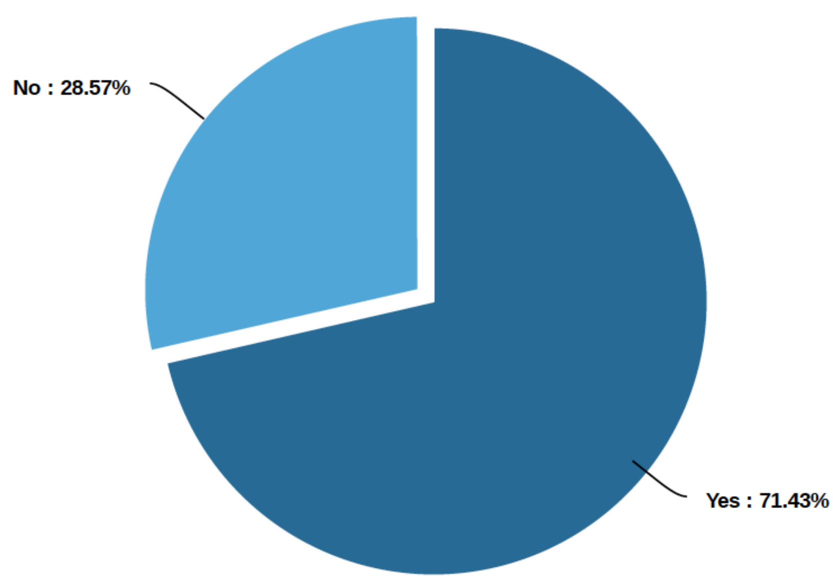


Figure C.7 Responses to have personal experience in hydrology and hydraulic studies/modeling of playa lakes, arid regions, and karst zones (Q14)

In a follow-up question (Q14.1), the participants were asked "*If your answer to the previous question was "No", could you please refer any expert in this area*?

Among respondents who lacked personal experience in hydrology and hydraulics of playa lakes, arid regions, and karst zones, only 15% (3 participants) were able to refer an expert in the field. The majority (85%) either did not have relevant connections or found the question not applicable (**Figure C.8**), which may be attributed to the specialized nature of the field, geographic limitations, or the lack of direct relevance to their specific work. The limited availability of expert referrals highlights potential knowledge gaps and resource constraints for those without personal experience in the field.

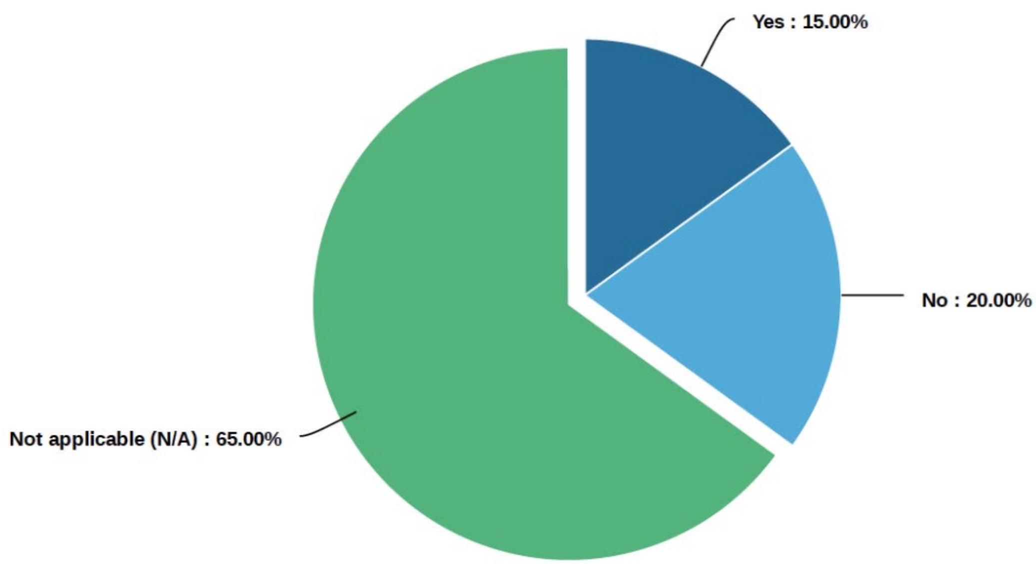


Figure C.8 Responses to the request for referrals of experts with experience in hydrology and hydraulic studies/modeling of playa lakes, arid regions, and karstic zones (Q14.1)

Do you or your institution/company use federal/state guidelines or standards for hydrology/hydraulic study and modeling in playa lakes, arid regions, and karstic zones?(Q15)

A significant portion of respondents (65.6%) reported following federal or state guidelines for hydrology and hydraulic studies across different regions. The usage rates vary slightly by area, with 25% of respondents applying guidelines in arid regions, 21.9% in karst zones, and 18.8% in playa lakes (**Figure C.9**). This variation may reflect differences in the availability of federal and state guidelines, as well as the unique challenges and regulatory requirements specific to each region. The literature review conducted in **Appendix B** (Task 2) highlighted the lack of hydrology and hydraulic guidelines for playa lakes at both the state and federal levels.

Additionally, 34.4% of respondents indicated that federal or state guidelines were "*Not Applicable*" to their practices (**Figure C.9**). This may be due to the specialized nature of their projects, the scale of operations, or the availability of more tailored guidance.

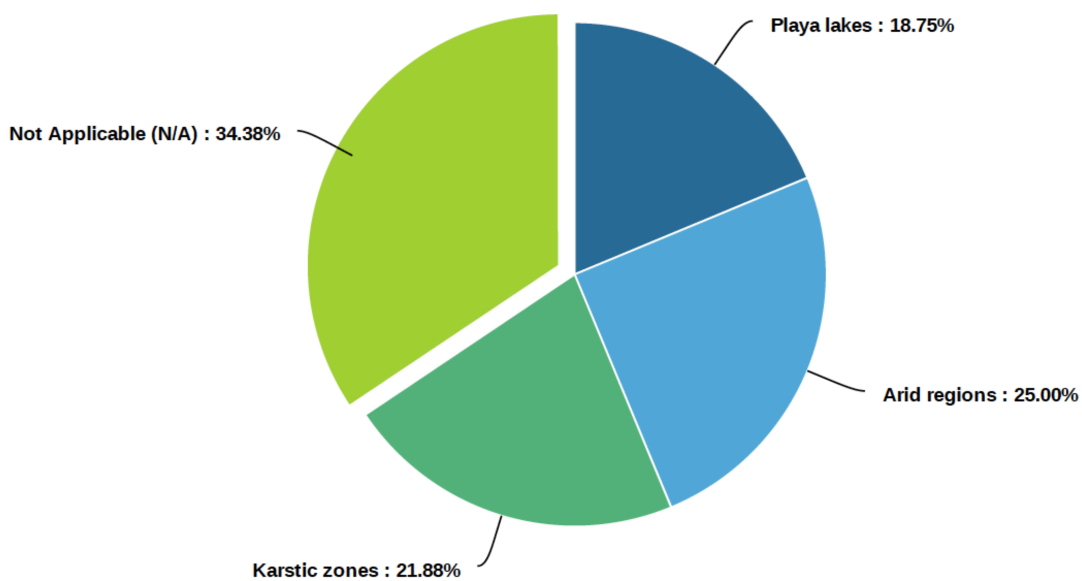


Figure C.9 Responses to using federal/state guidelines or standards for hydrology/hydraulic study and modeling in playa lakes, arid regions, and karst zones (Q15)

The participants provided the following information on the federal and state guidelines or standards they use for hydrology and hydraulic studies and modeling in playa lakes, arid regions, and karst zones:

<u>Playa Lakes</u>

- *"I said "yes" to playa lakes to gain access to this comment section. To my knowledge, there are no federal or state guidelines on playa lake modeling."*
- *"TSSWCB guidance for brush management for water supply enhancement. Not intended for infrastructure design.*
- *"We typically utilize federal, state, and county guidelines for analysis and infrastructure design recommendations. Federal guidelines have included HEC-18; state guidelines include Arizona state specific departments including the Arizona Department of Transportation, the Arizona Department of Environmental Quality. County regulations are specific to the site location but have included Maricopa, Pinal, and Pima counties."*
- *"ADOT manuals and guidelines, ADWR State Standards, and FHWA guidance."*
- *"FHW"*
- *"We use FHWA recommendations, along with USACE guidelines and others. FHWA publications like HEC-18, HEC-20, HEC-23 and others."*

Arid Regions

- *"State (guidelines)"*
- *"Recent publication of FHWA HEC-19 "Highway Hydrology: Evolving Methods, Tools, and Data" contains information on both arid and karstic hydrology. While I did not author either of those sections, I was a member of the team that wrote HEC-19 and was the first reviewer for both sections. I wrote the section on Paleohydrology, which has use in arid areas."*
- *"We typically utilize federal, state, and county guidelines for analysis and infrastructure design recommendations. Federal guidelines have included HEC-18; state guidelines include Arizona state specific departments including the Arizona Department of Transportation, the Arizona Department of Environmental Quality. County regulations are specific to the site location but have included Maricopa, Pinal, and Pima counties."*
- *"FEMA guidelines for floodplains; additional information on scour should employ a geomorphologist and/or pier erosion specialist. The City (of Fort Worth) uses the iSWM technical manual for the H&H and water quality (e.g., gabion baskets) practices."*
- *"TSSWCB guidance for brush management for water supply enhancement. Not intended for infrastructure design."*
- *"ADOT manuals (hydrologic & hydraulic drainage manuals) and guidelines (roadway design guidelines), ADOT C-Standard drawing details, ADWR State Standards (Floodplains), and FHWA guidance (i.e., HY-8, FHWA Hydraulic Toolbox, Climate Change, etc.)."*
- *"FHWA"*
- *"We use FHWA recommendations, along with USACE guidelines and others. FHWA publications like HEC-18, HEC-20, HEC-23, and others."*

Karst Zones

- *"Recent publication of FHWA HEC-19 "Highway Hydrology: Evolving Methods, Tools, and Data" contains information on both arid and karstic hydrology. While I did not author either of those sections, I was a member of the team that wrote HEC-19 and was the first reviewer for both sections. I wrote the section on Paleohydrology, which has use in arid areas."*
- *"TSSWCB guidance for brush management for water supply enhancement. Not intended for infrastructure design."*
- *"FHWA"*
- *"At INDOT we maintain the existing runoff rates to the karst features."*
- *"We use FHWA recommendations, along with USACE guidelines and others. FHWA publications like HEC-18, HEC-20, HEC-23, and others."*
- *"VDOT and VDEQ Standards and regulations"*

Do these (federal/state) guidelines or standards provide adequate information for designing infrastructures in playa lakes, arid regions, and karstic zones? (Q16)

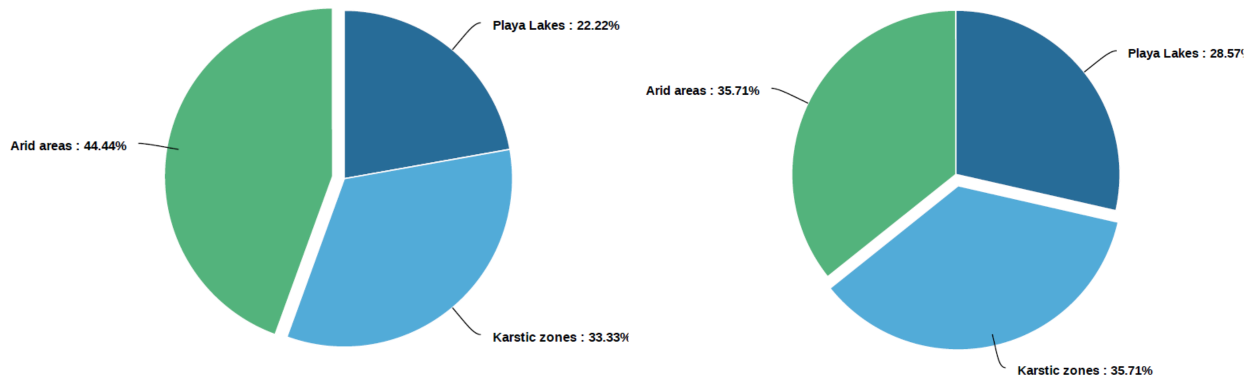
Although 65.6% of responses indicated the use of federal or state guidelines for hydrology and hydraulic studies across different regions (**Q15** and **Figure C.9**), 58.3% reported that the current guidelines or standards are inadequate for designing infrastructure in playa lakes, arid regions, and karst zones (**Table C.3**). It should be noted that some participants selected more than one region; therefore, the number of responses were greater than the number of respondents. Among this group, the strongest call for revisions focused on playa lakes.

Table C.3 Summary of responses regarding whether federal/state guidelines and standards provide adequate information for designing infrastructure in playa lakes, arid regions, and karstic zones (Q16)

Statement	Playa Lakes	Karstic zones	Arid areas	N/A	Overall
Yes. Standards/guidelines provide adequate design as is.	2 10.53%	3 15.79%	4 21.05%	10 52.63%	19 100%
No. Standards/guidelines need modification or revision	4 16.67%	5 20.83%	5 20.83%	10 41.67%	24 100%

Min Max

Among those who responded "*Yes, standards/guidelines provide adequate design as is.*", more participants expressed satisfaction with the guidelines for infrastructure design in arid regions (44.4%) and karstic zones (33.3%), compared to playa lakes, where only 22.2% perceived the guidelines as adequate (**Figure C.10a**). Conversely, among those who responded "*No, standards/guidelines need modification or revision.*", a larger percentage indicated the need for revisions in the guidelines for infrastructure design in arid regions (35.7%) and karst zones (35.7%), while a smaller proportion (28.6%) felt revisions were necessary for playa lakes (**Figure C.10b**). These results suggest a need for improvements or modifications to existing guidelines, with particular focus on playa lakes, which appear to present the most pressing challenges not fully addressed by current standards.



(a) (b)

Figure C.10 Responses to the question on whether participants agree that federal and state guidelines and standards provide adequate information for designing infrastructure in playa lakes, arid regions, and karstic zones. The figures highlight participants who responded: (a) "*Yes, the standards/guidelines provide adequate design as is.*" and (b) "*No, the standards/guidelines need modification or revision.*" (Q16)

In a follow-up question, participants who answered "*No*" to any areas in Q16 were asked to identify which aspects of available standards or guidelines for playa lakes, karst areas, and arid regions require improvement, revision, or modification. Specifically, they were asked whether major or minor changes are needed in the following categories:

- Hydrology and runoff calculations
- Hydrology modeling
- Hydraulic modeling
- Data collection methods
- Geology and detection techniques

Figures C.11a to **C.11c** presents the response to this question for the playa lake, karst areas, and arid regions, respectively.

For playa lakes, most respondents believe significant improvements, revisions, or modifications are necessary for the current standards or guidelines across all five categories. "Hydraulic Models" and "Data Collection Methods" received the lowest (45.5%) and highest (54.5%) rankings for necessary changes, respectively. In contrast, only 8.3% to 18.2% feel that minor adjustments are required. Additionally, a notable portion of respondents expressed uncertainty about the need for changes: 36.4% were uncertain regarding “Data Collection Methods” (the lowest), while 41.7% were uncertain about “Hydrology and Runoff Calculations” (the highest) (**Figure C.11a**). For karst areas, a similar percentage of participants chose need for "major modifications" or "not sure" (30-50% vs. 36.4-50%). Conversely, 10% to 30% feel only minor adjustments are required (**Figure C.11b**). In arid regions, the majority believe substantial improvements are necessary across all categories (33.3% to 54.5%). Only 8.3% to 18.2% feel minor adjustments are needed, while 36.4% to 41.7% are uncertain about whether changes are needed (**Figure C.11c**).

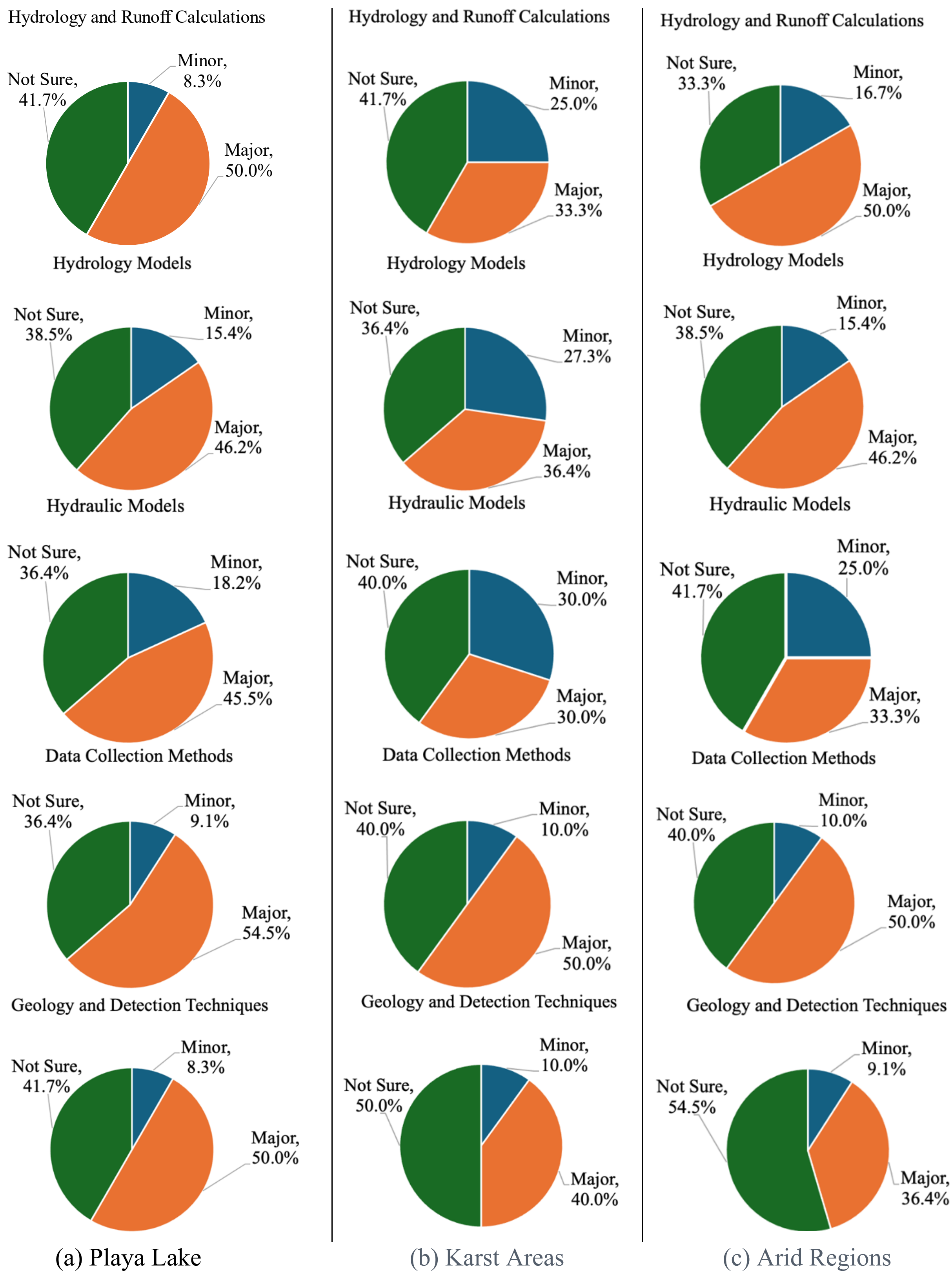


Figure C.11 Responses to the question on whether current guidelines/standards require improvement/revision/modifications for (a) Playa lakes, (b) Karst areas, and (c) Arid region (Q16)

Please select any of the following areas (playa lakes, arid regions, and karstic zones) that your institution/company conduct any hydrology studies or modeling in those areas?(Q17)

Among the participants, 79.1% reported conducting hydrology studies or modeling in only one region, while 18.3% worked in two regions and 12.5% in all three. Of these responses, approximately 27.6% indicated conducting hydrology studies specifically in karst zones, reflecting a focused interest in the complex hydrological and geological interactions typical of these areas. A larger portion, 37.9%, reported concentrating their work on arid regions, highlighting significant efforts to address challenges such as extreme weather conditions in dry, desert-like environments. Studies related to playa lakes are less common, with 20.7% of studies engaged in this area. Additionally, 13.8% of responses indicated that their work does not include a specific focus on these regions (**Figure C.12**).

Approximately 27.6% of respondents are involved in hydrology studies or modeling specifically within karst zones, reflecting a focused interest in the complex hydrological and geological interactions typical of these regions. A larger portion, 37.9%, reported concentrating their work on arid regions, highlighting a significant emphasis on addressing challenges such as extreme weather conditions in dry, desert-like environments. Studies related to playa lakes are less common, with 20.7% of respondents engaged in this area. Additionally, 13.8% of respondents indicated that their work does not include any specific focus on these regions (**Figure C.12**)

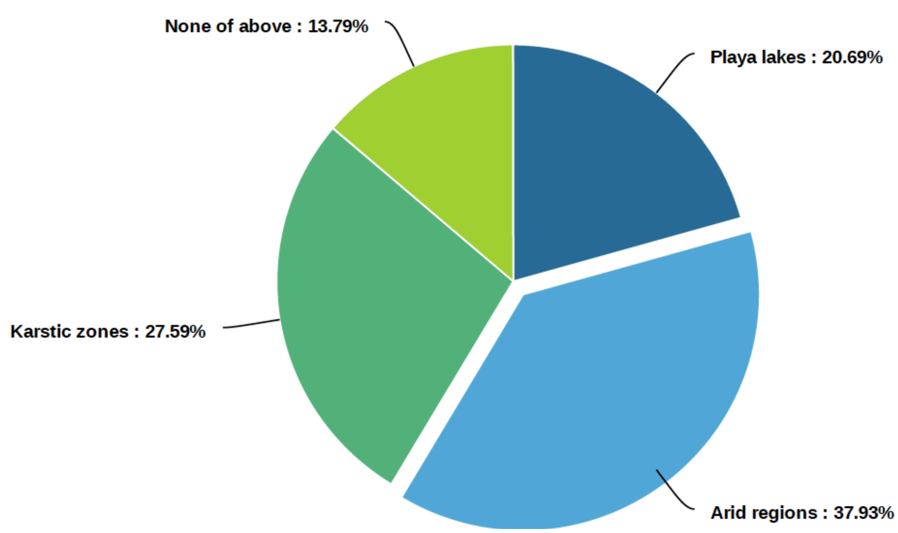


Figure C.12 Responses to whether participants (or their institution) conduct any hydrology studies or modeling in playa lakes, arid regions, and karstic zones? (Q17)

How do you validate your hydrological models of any areas with playa lakes, karst region, and/or arid areas?(Q29)

The question on methods of validation of hydrological models in playa lakes, karstic regions, and arid areas reveals a variety of approaches and practices employed by participants. The most common method, reported by 31.3% of respondents, was the comparison of hydrographs with field observations or gauge data. This highlights the critical role of empirical data in evaluating model accuracy and ensuring reliable predictions in these complex environments.

In addition to hydrograph comparisons, other validation techniques include the validation of individual model components (12.5%), the use of agency and data repository resources (6.3%), and spatial validation of water surface elevation during flood events (12.5%). Notably, 37.5% of respondents either used "*Other*" methods for validation or indicated that the question was not applicable to their work (**Figure C.13**). This suggests the existence of alternative validation techniques not explicitly covered in the survey and indicates that validation practices may vary considerably based on the specific needs and context of the study or project design.

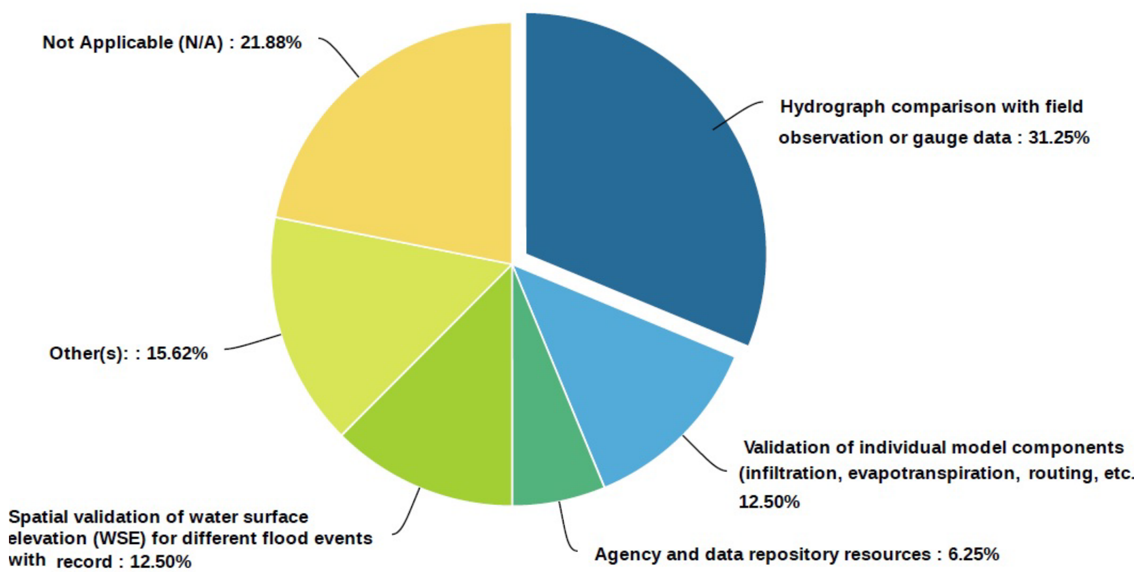


Figure C.13 Responses to the question regarding how participants validate their hydrological models in areas featuring playa lakes, karst regions, and/or arid environments (Q29)

Participants provided the following information on "*Other*" methods and "*Agency and data repository resources*" they use to validate their hydrological models in areas featuring playa lakes, karst regions, and/or arid environments:

Other Methods

- *"Regional regression equation developed from observed"*
- *"In 35 years of practice, I have never seen a case where data were available to validate a model directly. Validation has to be done using basic tools of fluvial geomorphology; bankfull dimensions, bedload sediment, etc. Visual comparison of model results versus what exists on the ground, and assessment of reasonability."*
- *"Validation is also performed against USGS/TxDOT regression equations."*
- *"NMDOT is beginning to consider impacts of Playa lakes, Karst (SE New Mexico) and arid areas (SW New Mexico). a number of NMDOT consultants have made recent studies of these areas using HEC-HMS, and the Virginia paper listed above."*
- *"Regression Equations."*

Agency and Data Repository Resources

- *"Aerial photography, local reporting, bridge inspections, O&M maintenance interviews."*
- *"We always validate hydrology as best we can from observations or historical accounts, reports."*

What recommendations do you have for improving hydrological models in playa lakes/arid areas/karstic zones? (Q35)

For improving hydrological models in various regions, 26.9% of responses provided recommendations specific to arid regions, 19.2% focused on playa lakes, and 19.2% addressed karst zones, while 34.6% indicated that the question was not applicable to their practice (**Figure C.14**).

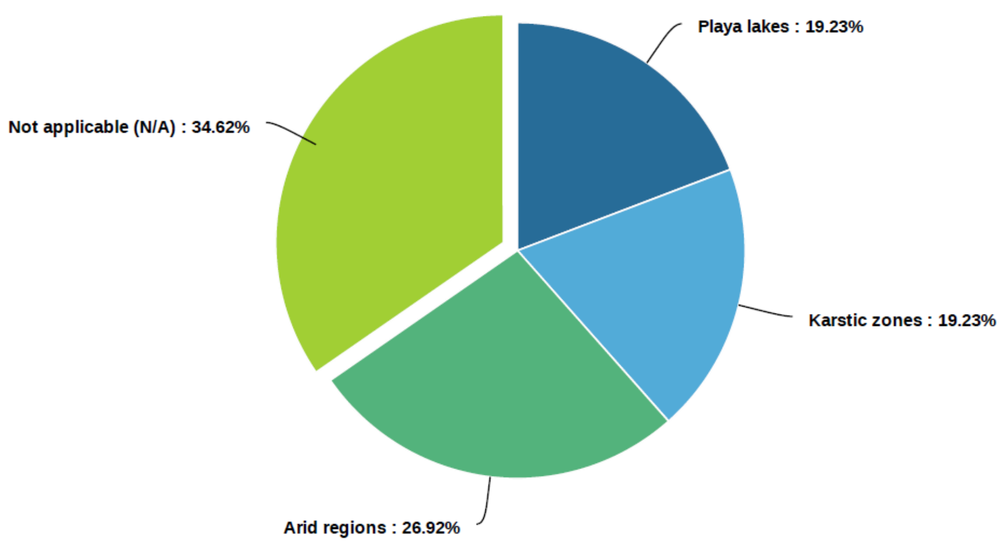


Figure C.14 Responses to the question whether participants have recommendations for improving hydrological models in playa lakes, arid areas, or karstic zones (Q35)

The recommendations provided by the participants for each environment are summarized below:

<u>*Playa Lakes*</u>

- *Adequate field measures to verify model inputs and the drainage area parameters correlate underlying soil type.*
- *Defining interior drainage pattern properly.*
- *Understanding that minor changes in topography from natural or anthropogenic modification can result in vastly different internal drainage pathways in this low topography environment*
- *First, we need to articulate what PROBLEMS the hydrology of playa lakes present. Without some idea of what they are, we have no idea what we should be looking for. As stated, the breadth of the study is far too large, and difficult to relate to highway design and construction.*
- *Hydrologic modeling must consider the varied soil conditions, since estimated flow must consider both the nearly impervious soils that typify the surrounding, rocky region, and the sometimes highly permeable soils within the lakebed itself. Larger storms than the typical design storm and back-to-back storms must be considered because there is no outfall and hence ponding is often the primary concern.*

<u>*Arid Regions*</u>

- *Adequate understanding of soil water movements in unsaturated zone/conditions by soil type.*
- *Taking into account the erosion and sedimentation along with rainfall-runoff modeling.*
- *Dynamic models, and models including sediment loading. The sediment intrusion contributes to a different density and viscosity of fluid, for which most of the scour/erosion model has not considered*
- *Arid area hydrology is a little more defined, but there are unseen problems. Destructive and disruptive flooding in arid areas is episodic, and related to "pluvial years." Normal, parametric statistics are misleading and do not capture important aspects of arid lands- order statistics are more informative. The dominant condition in arid lands is drought; the problem condition is episodes of large rainfall depths and very large discharges. An attendant problem is enormous bedload sediment transport during the pluvial years. In the end, that sediment transport is a major problem for highways.*
- *Most arid regions are nearly flat, and typical 1-dimensional hydrographical models may not provide accurate predictions. 2-dimensional modeling should be used whenever possible. In addition, accurate topography is critical yet often difficult to obtain. Site specific LiDAR should be used, when possible, although for large watersheds this is not realistic, in which case the inherent uncertainty of the model must be acknowledged with risk analysis used to provide design inputs. if applicable.*
- *We use 2-D models such as HEC-RAS 2D and ICM (from Autodesk/Innovyze).*

<u>*Karst Zones*</u>

- *Using Clark Unit Hydrograph method after properly defining the watershed storage term.*
- *Similarly, the problem stated is too broad. Need definition of problems.*

- *I'm not happy with our rudimentary methodology of using drainage area only, but other methods typically require a resource investment that isn't justified by an increase in accuracy in karst areas.*
- *Develop a technique for determining depth and extent of Karst areas that may impact roads and highways*

What resources do you use to stay up to date with the latest research in playa lakes/arid areas/karstic zones? (Q36)

Regarding staying updated with the latest research, 13% of respondents engage with resources specifically related to playa lakes, and another 13% focus on karstic zones. Meanwhile, 26.1% utilize resources pertinent to arid regions. A notable 47.8% of respondents indicated that this question is not applicable to their work, suggesting that the relevance of these resources may vary depending on the specific focus of their professional activities (**Figure C.15**).

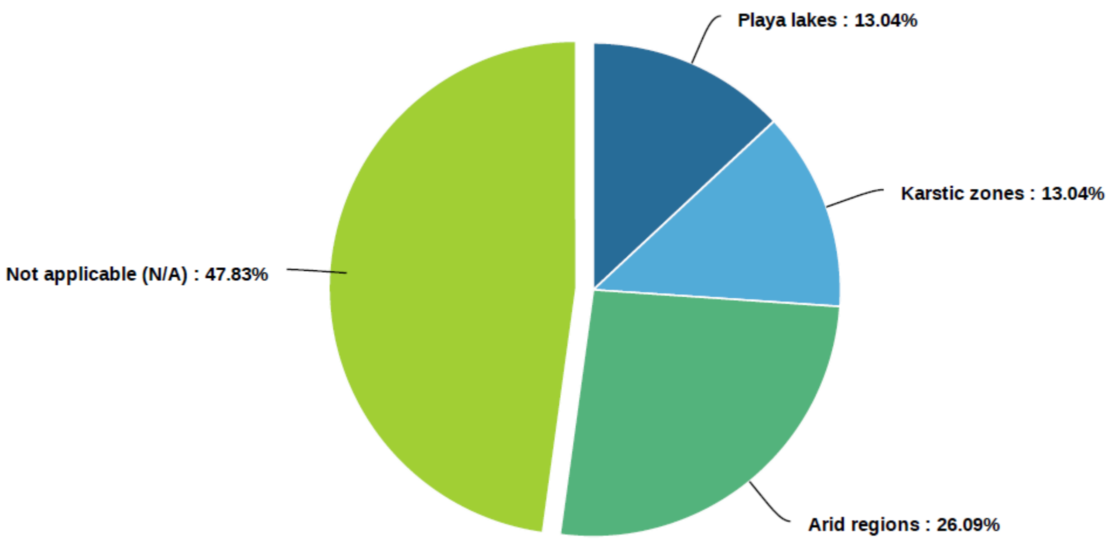


Figure C.15 Responses to the question regarding the resources participants use to stay updated with the latest research in playa lakes, arid areas, or karstic zones (Q36)

The participants provided the following information regarding the resources the use to stay updated with the latest research in playa lakes, arid areas, or karstic zones.

<u>*Playa Lakes*</u>

- *"Geological journals"*
- *"Since these issues have been my life's study for decades, I tend to keep up through the literature"*
- *"Research papers as available through Google Scholar and other sources. However, project budget and time constraints do not always allow research to be conducted."*

<u>*Arid Regions*</u>

- *"FHWA, NOAA and USGS publications, mostly"*

- *"Since these issues have been my life's study for decades, I tend to keep up through the literature"*
- *"As above, research papers as available through Google Scholar and other sources. However, project budget and time constraints do not always allow research to be conducted."*
- *"Texas Floodplain Management Association"*
- *"ASCE Publications"*

Karst Zones

- *"Since these issues have been my life's study for decades, I tend to keep up through the literature"*
- *"Virginia DCR and Virginia DEQ"*

Would you be willing to participate in an interview to discuss your personal experience regarding hydrology and hydraulic study/modeling in Playa lakes/arid areas/karstic zones? (Q37)

Out of 24 participants, 17 individuals (including 10 DOTs and 7 from other groups) expressed their willingness to participate in an interview to discuss their experiences with hydrology and hydraulic modeling in one or more of these environments: playa lakes, arid areas, and karst zones. Conversely, 7 participants indicated they were not interested in participating. Among those willing to participate, 27.6% are interested in discussing playa lakes, 34.5% in arid regions, and 37.9% in karst zones (**Figure C.16**).

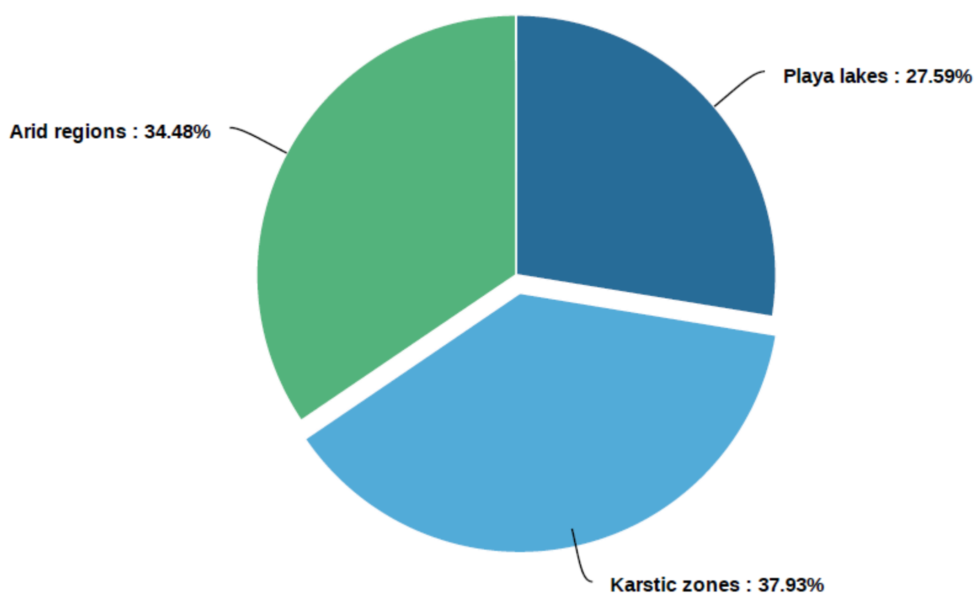


Figure C.16 Responses to the question regarding willingness to participate in a follow-up interview to discuss personal experiences related to hydrology and hydraulic studies/modeling in playa lakes, arid areas, or karstic zones (Q37)

C.2.4.2. Questions Specific to Hydrologic Approaches to Playa Lakes

This section of the survey aimed to gather data on the practices and methodologies used in hydrological studies and infrastructure design specific to regions with *playa lakes*. The relevant questions include Q2, Q8, Q9, Q18.1, Q21, Q22, and Q30.1 to Q34.1.

What are the methods that you or your institution/company use to identify the playa lake location?(Q2)

Participants employed diverse methods to identify playa lake locations, as detailed in **Table C.4**. Topographic maps and field surveys/ground truthing proved the most frequently utilized techniques. However, 14 participants indicated this question was inapplicable to their work, and two participant used methods not listed in **Table C.4**. Given that participants could select multiple options, the question yielded a total of 47 responses. Subsequent analyses are based on response frequency relative to the total.

Traditional methods, including topographic maps (14.9%), field surveys/ground truthing (14.9%), and soil and ground depression surveys (6.4%), comprised the largest portion (36.2%) of responses. Advanced techniques such as LIDAR (8.5%), drones/UAVs (6.4%), remote sensing (4.3%), and geophysical methods (4.3%) accounted for a smaller proportion (23.5%) of responses. Historical hydrological analysis contributed 6.4%, and other unspecified techniques 4.3% (**Figure C.17**).

A variety of methods are used by the participants to identify playa lake locations. The largest group of participants (36.2%) reported using traditional methods, such as topographic maps (14.9%), field surveys/ground truthing soil (14.9%), and soil and ground depression surveys (6.4%). Fewer participants (23.5%) employed advanced techniques like LIDAR (8.5%), drones and UAVs (6.4%), remote sensing (4.3%), and geophysical methods (4.3%). Historical hydrological analysis was used by 6.4%, and other techniques by 4.3% of respondents. Notably, 29.8% did not use any specific method for identifying playa lake locations (**Figure C.17**). The results highlight a potential variability in practices or a lack of standardized approaches in some cases.

The participants who selected the "*Others*" option provided the following additional information and comments:

- *New roadway alignments are very rare; features such as playa lakes are reflected on old plans; often by fill sections or differences in pavement.*
- *We use GIS layers provided by others that delineate playa areas. We also rely on USGS StreamStats to check our estimates of non-contributing drainage area. Q1 only allows me to select one of the options. For Kansas, we deal with playa, semi-arid/arid regions, and some karst areas.*

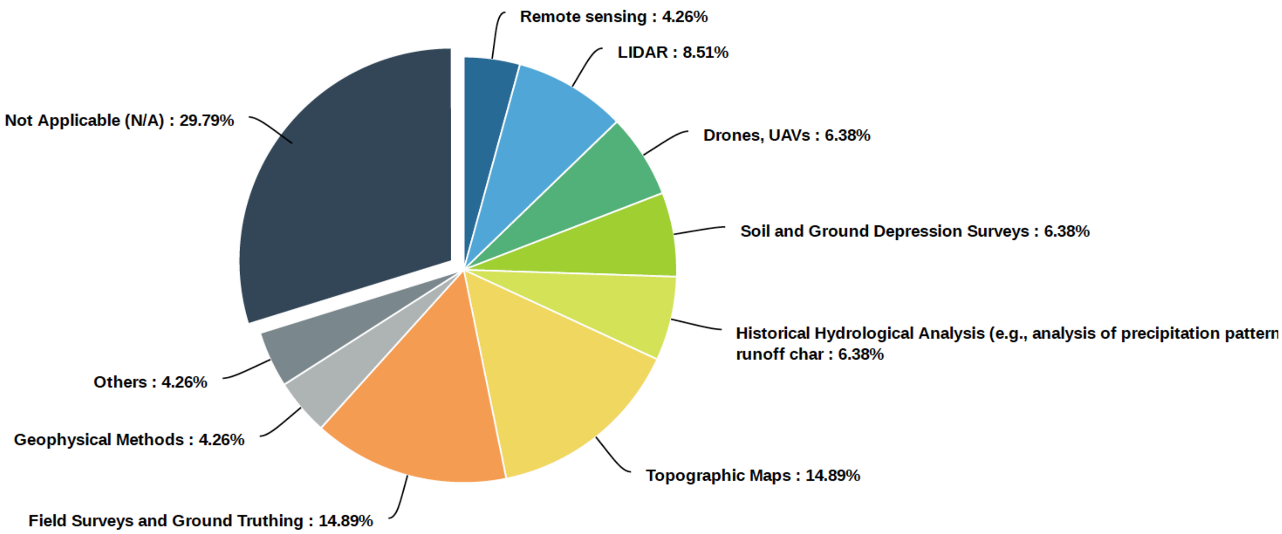


Figure C.17 Responses to the question about the methods used by participants or their institution/company to identify playa lake locations (Q2)

Table C.4 Summary of responses to the question about the methods used by participants or their institution/company to identify playa lake locations (Q2)

Method	Participants																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Remote sensing	x		x																						2
LIDAR			x							x					x						x				4
Drones, UAVs	x									x								x							4
Soil and Ground Depression Surveys				x						x														x	3
Historical Hydrological Analysis							x			x								x							3
Topographic Maps				x		x	x			x								x			x			x	7
Field Surveys and Ground Truthing	x			x		x	x			x								x						x	7
Geophysical Methods	x																							x	2
Others						x															x				2
Not Applicable (N/A)		x			x			x	x		x	x	x	x		x	x		x	x		x	x		14

Have you or your institution/company encountered or are aware of cases where infrastructures were damaged (partially or completely) due to the lack of proper design guidelines or standards for playa lakes?(Q8)

In response to the question, 8% of participants reported experiencing such damage and were willing to provide further details. Meanwhile, 24% were unsure if such incidents had occurred, and 32% confirmed they had not encountered any related issues. Additionally, 36% of respondents found the question not applicable to their experience (**Figure C.18**). These responses suggest that while a small portion of participants have dealt with infrastructure damage linked to inadequate design guidelines, a significant number remain uncertain or have not faced such challenges.

Figure C.18 Responses to the question on whether participants or their institution/company have encountered or are aware of infrastructure damage due to the lack of proper design guidelines or standards for playa lakes (Q8)

If your answer to the previous question was "yes", what was the reason(s)?(Q9)

The results indicate that the primary reasons for infrastructure damage in playa lakes, due to inadequate design guidelines, were uncertainties in hydrology and hydraulic modeling (25%) and a lack of data (25%). However, a significant portion of respondents (50%) cited unspecified reasons, suggesting potential gaps in communication regarding the causes of such damage. **Figure C.19** provides a breakdown of the factors contributing to infrastructure damage in playa lake regions. Key issues related to data include uncertain geological investigations (16.7%) and challenges with data collection, particularly limited and low-quality data (8.3%). Additional factors include uncertain hydrology/hydraulic methodologies (8.3%), models incapable of considering playa lake physical properties (8.3%), and failure to account for the spatial and temporal variability of effective parameters in modeling playa lakes (8.3%).

Participants also provided additional reasons, including:

- *"Geotechnical considerations: playa lakes present soil strength conditions that are very challenging. In addition, fill material needed for embankment in playa lake areas are typically fine-grained, and subject to great capillary rise, compounding other material strength problems."*
- *"Dust from playas causing several serious vehicular accidents. Study was done by NMDOT Environment Group on dust mitigation."*
- *"Infrastructure may have been subject to higher than expected storm water runoff."*

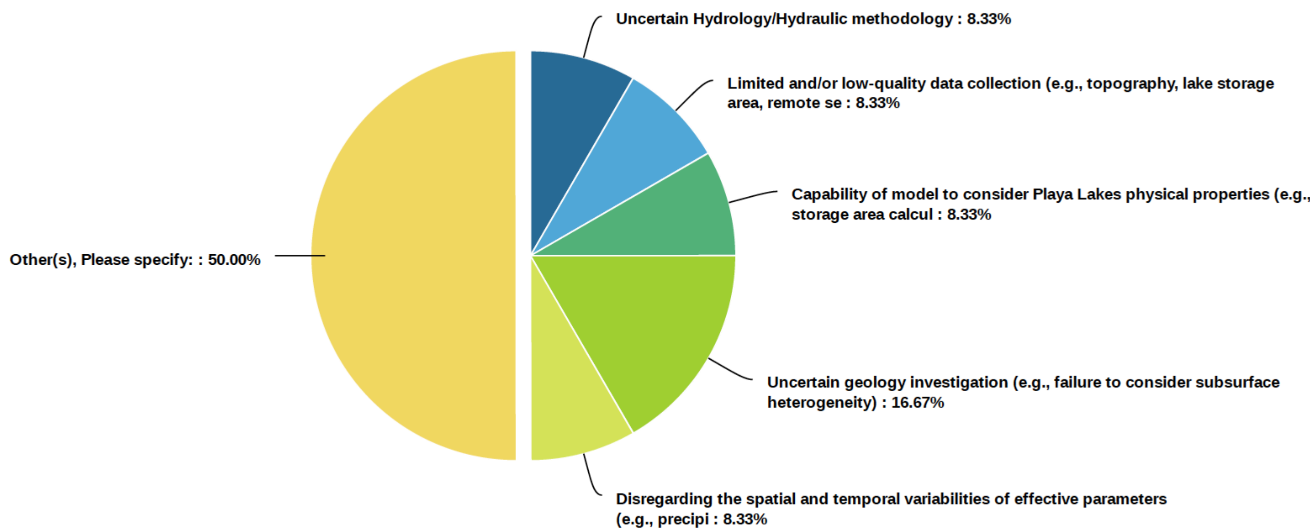


Figure C.19 Responses to questions regarding the reasons for infrastructure damage in playa lake areas (Q9)

Please select if your institution/company use any of the following methods to identify the evolution of Playa Lakes?(Q18.1)

Participants were asked to identify the evolution of playa lakes, karst areas, and arid regions through questions 18.1 to 18.3. In this section, the responses to Q18.1 are presented, and responses to Q18.2 and 18.3 are presents in the following sections covering karst areas, arid regions.

Participants were asked to select the methods used by their institution or company to identify the evolution of playa lakes. The percentage for each method is as follows:

- Remote Sensing/LIDAR/Drones, UAVs (10.7%)
- Hydrological monitoring (e.g., water surface elevation, gauge monitoring at inflow and outflow boundaries) (14.3%)

- Bathymetric surveys (3.6%)
- Ground Penetrating Radar (GPR) (3.6%)

Additionally, 21.4% selected the "*Others*" category, which includes various unspecified methods, while 46.4% indicated that none of these methods are applicable to their work. **Figure C.20** depicts the various approaches employed to track and assess the evolution of playa lakes, as reported by respondents.

Under the "*Others*" category, participants provided the following additional methods or comments:

– *"Borehole coring to assess sedimentology"*

– *"Remote sensing has probably not been used to great advantage in these pursuits. Probably the greatest deficiency in arid land hydrology is the sparsity of data on rainfall, runoff, and on concurrent rainfall/runoff. The simple infrequency of rainfall and vast spatial areas involved make data collection expensive, and still result in little data."*

– *"Soil sampling"*

– *"Historical aerial photography, field inspection. We haven't used bathymetry in either Playa Lakes nor Arid Regions since the watercourses in both have been dry when we have investigated."*

– *"We use GIS layers that identify playa boundaries and extents, terrain data, topo maps, and USGS StreamStats (that identifies non-contributing drainage area totals)."*

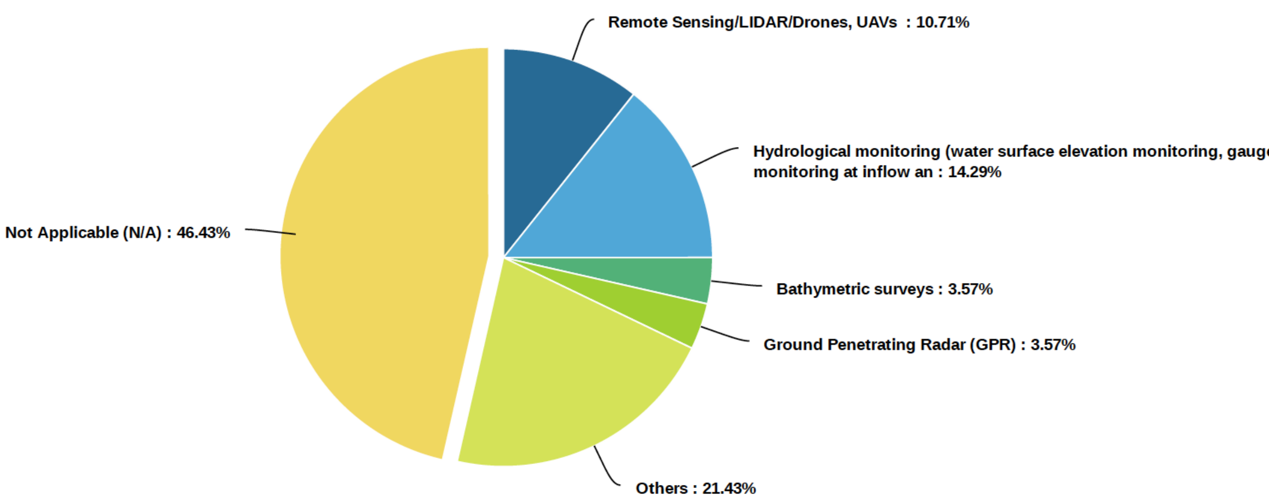


Figure C.20 Responses to questions regarding the methods used by participants or their institutions/companies to identify the evolution of playa lakes (Q18.1)

Note: The responses related to karst areas and arid regions are provided in other sections under Q18.2 and Q18.3, respectively.

Please select any of the following models that you use/have used to simulate the hydrology of playa lakes. (Q21)

The participants were asked if they have utilized any of the following models to simulate the hydrology of playa lakes:

- SWAT (Soil and Water Assessment Tool)
- VIC (Variable Infiltration Capacity)
- MODFLOW (Modular Ground-Water Flow Model)
- MIKE SHE (MIKE Soil-Atmosphere-Water)
- HEC-HMS
- PRMS (Precipitation-Runoff Modeling System)
- RHESSys (Regional Hydro-Ecologic Simulation System)
- PRC (Pond and Reservoir Routing Model)

Given that participants could select multiple options, the question yielded a total of 25 responses. Subsequent analyses are based on response frequency relative to the total.

Figure C.21 presents an overview of the various hydrological models employed by participants or their affiliated institutions and companies in simulating playa lake hydrology. Based on the results, HEC-HMS emerged as the most commonly used model, representing 24% of responses, while SWAT accounted for 4% of responses. None of the participants reported using VIC, MODFLOW, MIKE SHE, PRMS, RHESSys, or PRC. Additionally, 28% of responses referenced other unspecified models, and 44% indicated that these models are not applicable to their work.

Under the "*Others*" option, participants provided several detailed responses, including the following:

- *"I have not used the models on playa lakes, SWAT, MODFLOW MIKESHE, and HEC-HMS has capability to model. A few add on may be needed."*
- *"ICPR"*
- *"When I was doing design for playa lakes, we had no access to methods from within TxDOT; I obtained SCS TR-20 (original FORTRAN version) and self-taught on it."*
- *"Our own in-house modeling of potential ET and infiltration"*
- *"StreamStats, 2D modeling that includes distributed rainfall (FLO-2D, HEC-RAS 2D)"*
- *"ADOT Rational Tool, FCDMC Rational Method guidelines, City of Tucson PC-Hydro. NRCS Curve Number Method for Wildfires, review of 2D Model output."*

Figure C.21 Responses to questions on models used by participants or their institutions/companies to simulate the hydrology of playa lakes (Q21)

If any of the above is selected, would it be possible to share a copy of the model setup and project reports?(Q22)

This was a follow-up to Q21. **Figure C.22** summarizes the responses regarding information sharing. As shown, only 7.7% of respondents are willing to share both model setups and project reports, with an additional 7.7% willing to provide only project reports upon official request. In contrast, 46.1% of respondents are unsure about sharing these materials, and 38.5% indicated they would not share any materials. These results suggest that the willingness to share model setups and project reports is limited. The reluctance may stem from concerns over confidentiality or proprietary information, highlighting the need for clear guidelines and agreements to facilitate the sharing of valuable hydrological data and methodologies. This is supported by one participant's comment: "*Client confidentiality restricts us from releasing specific information*".

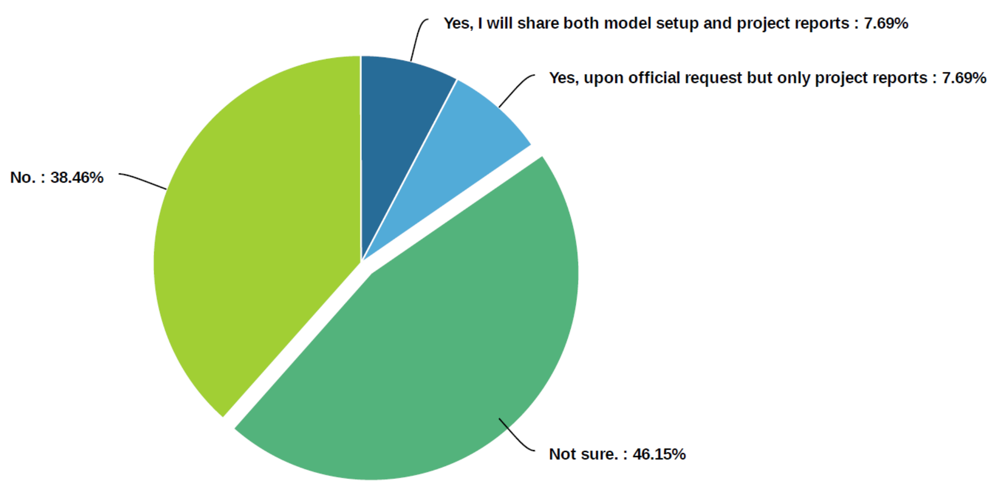


Figure C.22 Responses to the question regarding sharing a copy of the model setup and project reports for playa lakes (Q22)

What is the methodology that you or your institution/company use to calculate the runoff in playa lakes/arid areas/karstic zones? (Q30.1)

Participants employed various methodologies and models to calculate runoff in *playa lakes*. As shown in **Figure C.23**, the most frequently cited approaches included the SCS Curve Number (13.3%), SCS Unit Hydrograph/NRSC Dimensionless Unit Hydrograph (13.3%), HEC-HMS (13.3%), and the Rational Method (11.1%). A smaller subset of respondents reported using, Statistical Analysis of Stream Gauge Data (6.7%), and the TR-55 method (6.7%). Less common methods included the Clark Unit Hydrograph (4.4%) and Omega EM Regression Equations (2.2%). Notably, methods like the Santa Barbara Hydrograph Method and the Time-Area Method were reported as not being used for runoff calculations in playa lakes. Additionally, 11.1% of participants indicated that runoff calculation was not applicable to their work, while 8.9% reported using alternative methods.

In a follow-up question the participants were asked "*If you selected other methodologies, please specify those methodologies below*:"

The following methods and comments were provided by participants:

- *"Green-Ampt method for modeling infiltration and kinematic wave model for rainfall to runoff transformation".*
- *"This question is very ambiguous. HEC-HMS is not a method, it is a modeling software package that incorporates a number of methods. The SCS Curve number method is a part of a method- loss accounting. TR-55 is outdated; the Windows version does not even include the original computations. The SCS Unit Hydrograph and the NRCS Dimensionless Unit Hydrograph are one and the same. The Rational Method is only used on watersheds <200 acres. It is extremely rare in Texas to have gauge data that are pertinent to a design watershed; however transposition of gauge data can be a useful tool. I was instrumental in the development of the Omega-Em regression equations; they are the best regression equations available for Texas, but have limitations. In FHWA HDS-2, the Index Flood Method has been revised and presented. In many cases, the methods available are useful as validation, if not primary methods."*
- *"Streamstats, 2-Dimensional rain-on-grid modeling (HEC-RAS 2D, FLO-2D)"*

These results suggest that while widely accepted methods like the SCS Unit Hydrograph/NRSC Dimensionless Unit Hydrograph, SCS Curve Number, and models such as HEC-HMS are preferred for their general applicability, less conventional techniques, including 2D Rain-on-Grid Modeling and the Green-Ampt Method, are favored for effectively capturing specific hydrologic dynamics.

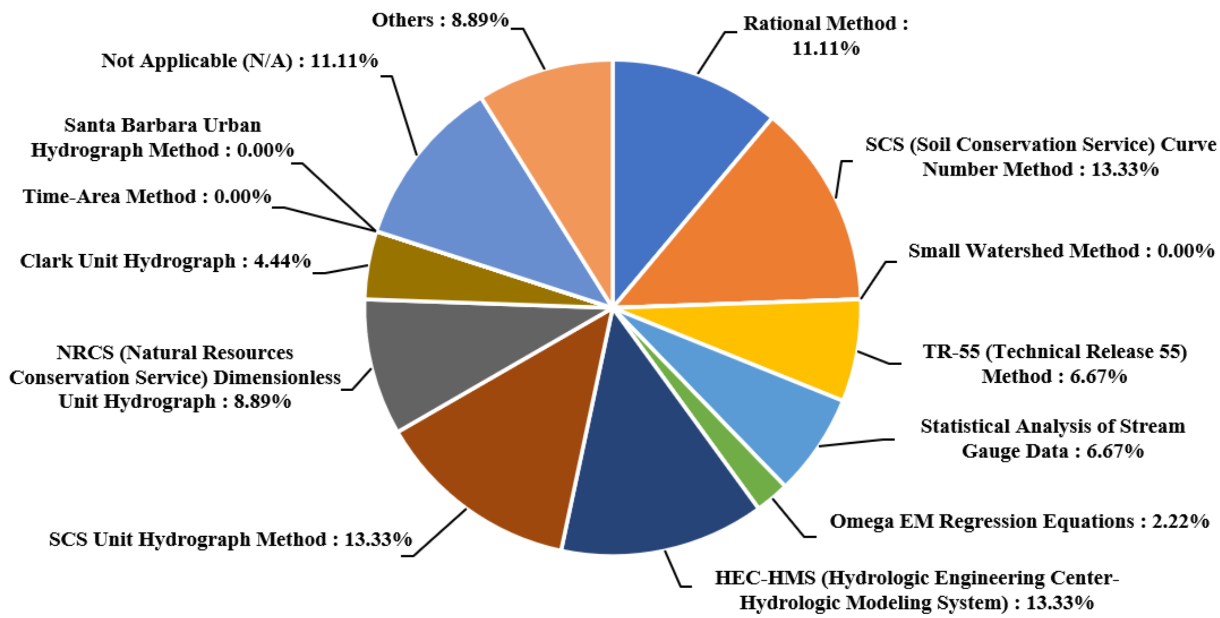


Figure C.23 Methodologies used by participants and their institutions/companies to calculate runoff in playa lakes (Q30.1)

Note: The responses related to karst areas and arid regions are provided in subsequent sections under Q30.2 and Q30.3, respectively.

What is the methodology that you or your institution/company use to calculate the loss in playa lakes/arid areas/karstic zones? (Q31.1)

Figure C.24 shows that the most commonly used methods for calculating loss in *playa lakes* were the Green-Ampt loss model (30%) and the NRCS curve number loss model (20%). A smaller portion of respondents reported using other techniques, including the Initial and Constant-Rate Loss model (5%) and the Texas Initial and Constant-Rate Loss model (5%), while another 5% indicated using "*Other*" methods. Notably, a significant group (35%) stated that calculating loss was not applicable to their work.

One respondent who selected the *"Others"* option provided the following comments:

– *Loss modeling is one of the most difficult choices in H&H modeling. Most models underestimate losses- the Texas Ia/Cl model bears that out. The curve number process is improved by climatic adjustment of curve numbers per TxDOT-sponsored work by Thompson, et al, and by reduction of the Ia ratio as in ASCE Hawkins et al. Green-Ampt is an infiltration model, not a loss model; it does not account for an initial abstraction or other losses. It is widely used mainly because parameters can be estimated without getting out of the designers chair.*

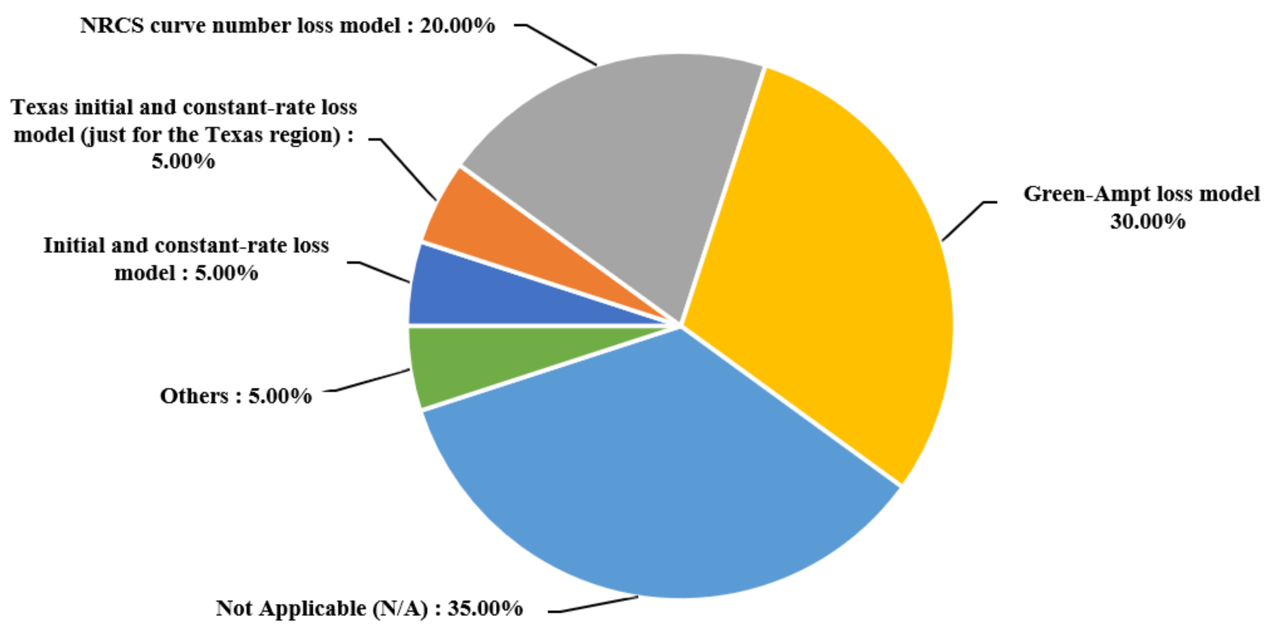


Figure C.24 Methodologies used by participants and their institutions/companies to calculate the loss in playa lakes (Q31.1)

Note: The responses related to karst areas and arid regions are provided in subsequent sections under Q31.2 and Q31.3, respectively.

What is the methodology that you or your institution/company use to calculate the time of concentration in playa lakes/arid areas/karstic zones? (Q32.1)

The methodologies used by respondents to calculate the time of concentration in *playa lakes* are shown in **Figure C.25**. The most frequently cited approaches were the Kerby-Kirpich method (23.8%), NRCS method (23.8%), and the Kinematic Wave Equation (19%). A smaller group of respondents reported using other techniques (9.5%), while 23.8% stated that calculating the time of concentration was not applicable to their practices.

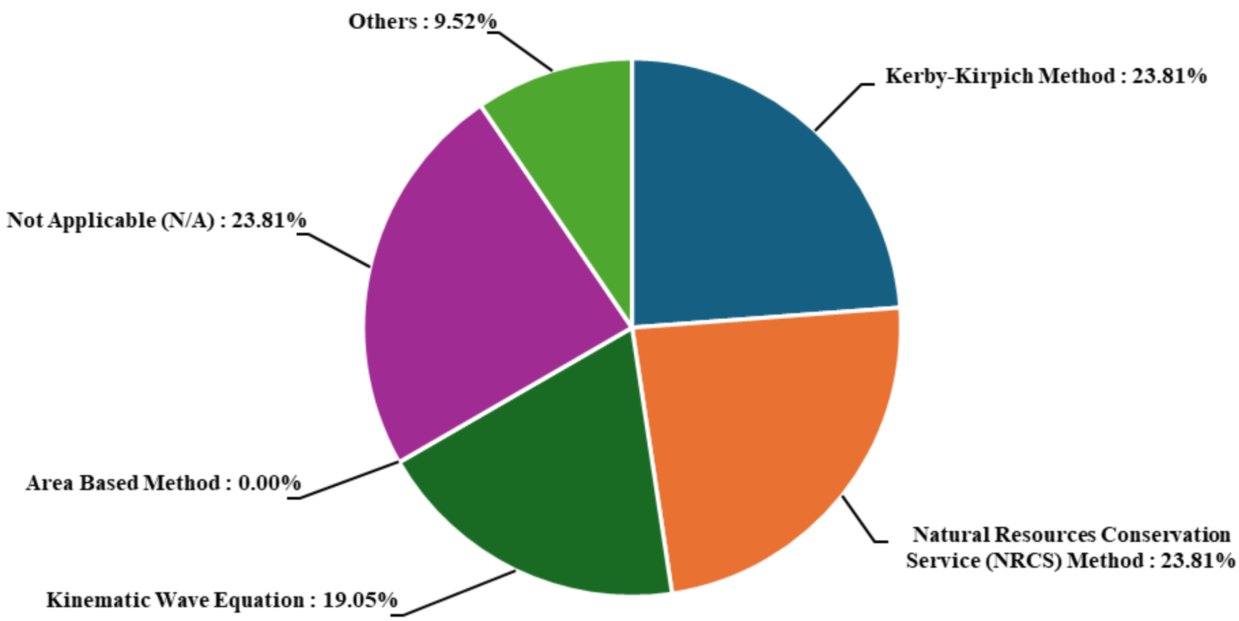


Figure C.25 Methodologies used by participants and their institutions/companies to calculate the time of concentration in playa lakes (Q32.1)

Note: The responses related to karst areas and arid regions are provided in subsequent sections under Q32.2 and Q32.3, respectively.

What is the methodology that you or your institution/company use to calculate the lag time (basin lag) in playa lakes/arid areas/karstic zones? (Q33.1)

Several techniques were employed by respondents for calculating basin lag time in *playa lakes*. **Figure C.26** shows that the most commonly cited methods were the SCS Lag Method (25%), the NRCS Dimensionless Unit Hydrograph (20%), and Snyder's Unit Hydrograph (10%). Additionally, 40% of respondents reported that calculating lag time was not applicable to their work. Other methods, such as the triangular hydrograph and hydrograph separations, were not used for calculating lag time.

Figure C.26 Methodologies used by participants and their institutions/companies to calculate the lag time (basin lag) in playa lakes (Q33.1)

Note: The responses related to karst areas and arid regions are provided in subsequent sections under Q33.2 and Q33.3, respectively.

What flood frequencies have you or your institution/company utilized for drainage impact and flood mitigation studies for urban and infrastructure developments in playa lakes/arid areas/karstic zones? (Check multiple if required)(Q34.1)

Figure C.27 shows that the most frequently used flood return periods for drainage impact and flood mitigation studies in urban and infrastructure developments in *playa lakes* were the 100-year (22%), 50-year (13%), 10-year (13%), and 2-year (9%) floods. A smaller group of respondents reported using other return periods, such as the 500-year (6%), 20-year (3%), and 5-year (6%) floods. The 200-year flood was not used. Additionally, 22% of respondents stated that calculating runoff was not applicable to them. A further 6% indicated using a range of floods beyond the common options, such as the 1-year, 25-year floods, and bankfull discharge.

The following is a list of comments from the respondents:

- *This depends on roadway classification, as per the TxDOT HDM. For cross-drainage structures, usually 10-25 year (we don't use the 20-year, we use 25). The 100-year is a check event.*
- *Estimated dominant/bankfull discharge*

Figure C.27 Flood frequencies used by participants and their institutions/companies in drainage impact and flood mitigation studies for urban and infrastructure developments in playa lakes (Q34.1)

Note: The responses related to karst areas and arid regions are provided in subsequent sections under Q34.2 and Q34.3, respectively.

C.2.4.3. Questions Specific to Hydrologic Approaches to Karst Zones

This section of the survey focused on collecting information about practices and methodologies related to hydrological studies and infrastructure design in *karst zones*. The relevant questions include Q3, Q10, Q11, Q18.2, Q25 to Q28, and Q30.2 to Q34.2.

What are the methods that you or your institution/company use to identify Karstic zones?(Q3)

A variety of methods are employed to identify karstic zones. Field observations are utilized by 16.5% of respondents, while geological mapping is used by 13.9%. Both topographic maps and LIDAR are employed by 10.1% of respondents each. Borehole logging is utilized by 7.6%, and historical hydrological analysis is used by 6.3%. Other methods, including geophysical methods, karst inventories and databases, and remote sensing, range from 3.8% to % 8.9%. Drones/UAVs and hydrochemical analysis are used by 2.5% and 1.3%, respectively. The "*Others*" category, which encompasses unspecified methods, was selected by 3.8% of respondents. Additionally, 10.1% indicated that these methods do not apply to their work (**Figure C.28**).

Participants who selected "*Others*" option provided the following information:

- *Karstic zones are easily identified and are known anecdotally from historical highway design and construction.*
- *We rely heavily on our in-house Geology staff to identify and make recommendations for highway projects in these areas.*
- *Topographic Survey*

The results indicate that institutions and companies employ a diverse array of methods to identify karstic zones, with field observations and geological mapping being the most common. While various techniques, including advanced technologies like LIDAR and drones, are used, a significant proportion of respondents either employ unspecified methods or find that these methods do not apply to their work. This diversity reflects the complexity of karstic zone identification and highlights the need for tailored approaches based on specific regional and geological contexts.

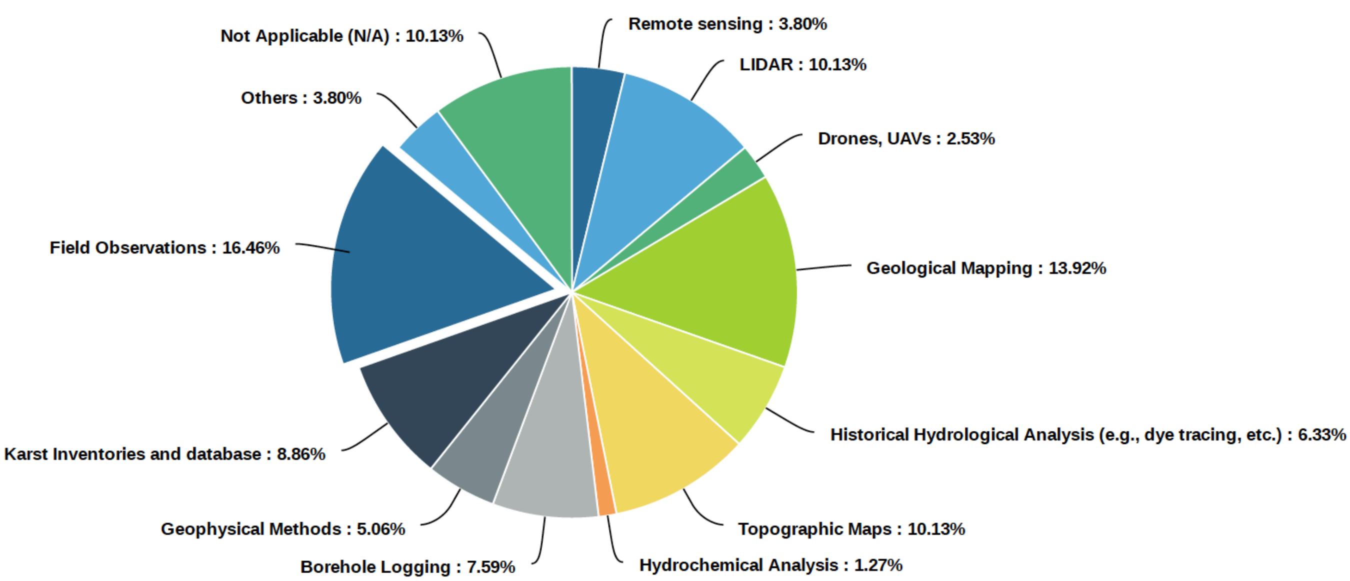


Figure C.28 Responses to the question about the methods used by participants or their institution/company to identify karst zones (Q3)

Have you or your institution/company encountered or are aware of cases where infrastructures were damaged (partially or completely) due to the lack of proper design guidelines or standards for Karstic areas? (Q10)

In response to the question of whether infrastructure damage in karst areas has been linked to inadequate design guidelines, 8.7% of respondents reported having encountered such damage. Conversely, 13% confirmed that they had not experienced any related damage. Additionally, 21.7% acknowledged instances of infrastructure damage but attributed these issues to causes other than inadequate design guidelines. Furthermore, 26.1% were unaware of any incidents connected to design guidelines, and 30.4% found the question not applicable to their experience (**Figure C.29**).

The data indicates that a relatively small proportion of respondents directly link infrastructure damage in karstic areas to insufficient design guidelines. While a notable percentage have not experienced related damage or attributed it to other causes, a significant portion remains uncertain or finds the question irrelevant to their work.

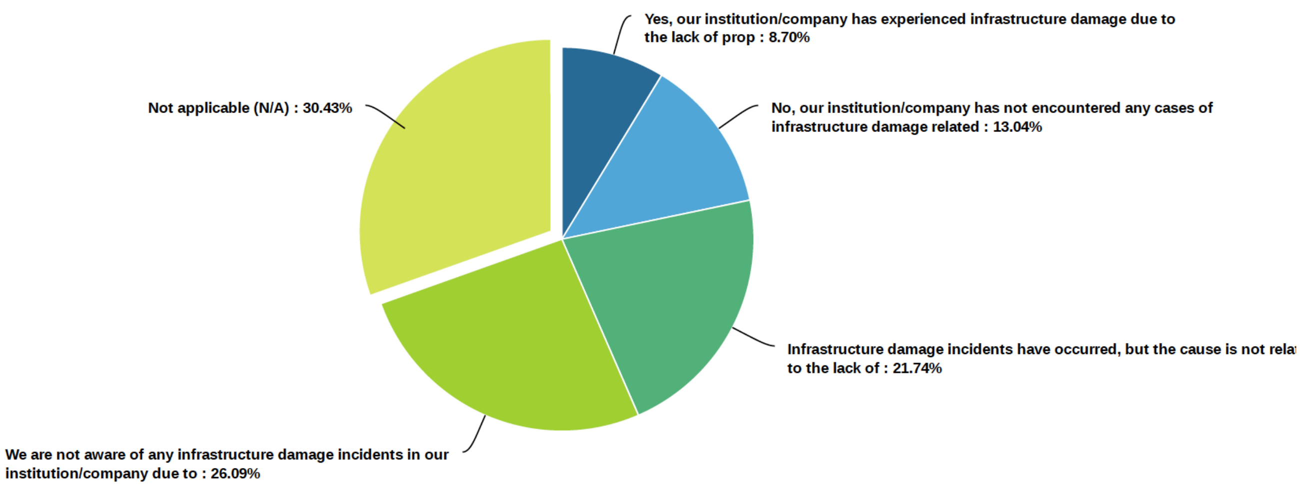


Figure C.29 Responses to the question on whether participants or their institution/company have encountered or are aware of infrastructure damage due to the lack of proper design guidelines or standards for karts areas (Q10)

If your answer to the previous question was "yes", what was the reason(s)?(Q11)

Among the respondents who reported infrastructure damage in karstic areas due to inadequate design guidelines, 25% identified limited or low-quality data collection as a primary cause. Additionally, 16.7% attributed the damage to uncertain hydrology or hydraulic methodology. Issues with the model's capability to consider karst physical properties were noted by 8.3%, while another 8.3% cited insufficient model validation and calibration, and 8.3% mentioned uncertain geological investigation. Furthermore, 33.3% of respondents cited other unspecified reasons for the damage (**Figure C.30**). Notably, no respondents raised concerns related to:

- Future considerations (e.g., anthropogenic and climate change impacts, etc.),
- Disregarding dynamic modeling to simulate transient conditions (dynamic relationship between precipitation, evaporation, runoff, groundwater interaction and flow modeling, etc.),
- Disregarding the spatial and temporal variabilities of effective parameters (e.g., precipitation, temperature, infiltration, sedimentation and bathymetry changes), and
- Failure to consider groundwater interaction.

One respondent provided the following comment:

– *"Karstic areas present problems with unpredictable location of voids within what might be thought of as sound rock. Bridge foundations and rock cut sections are particularly vulnerable to this. Occasional unanticipated water invasion can occur, also."*

The majority of respondents who reported infrastructure damage attributed it to deficiencies in data collection and methodological uncertainties. The lack of concerns related to future modeling and parameter variabilities suggests that the issues may be more foundational or operational rather than associated with advanced modeling techniques. This underscores the need for improved data collection practices and robust methodological frameworks in the design and assessment processes for karstic areas.

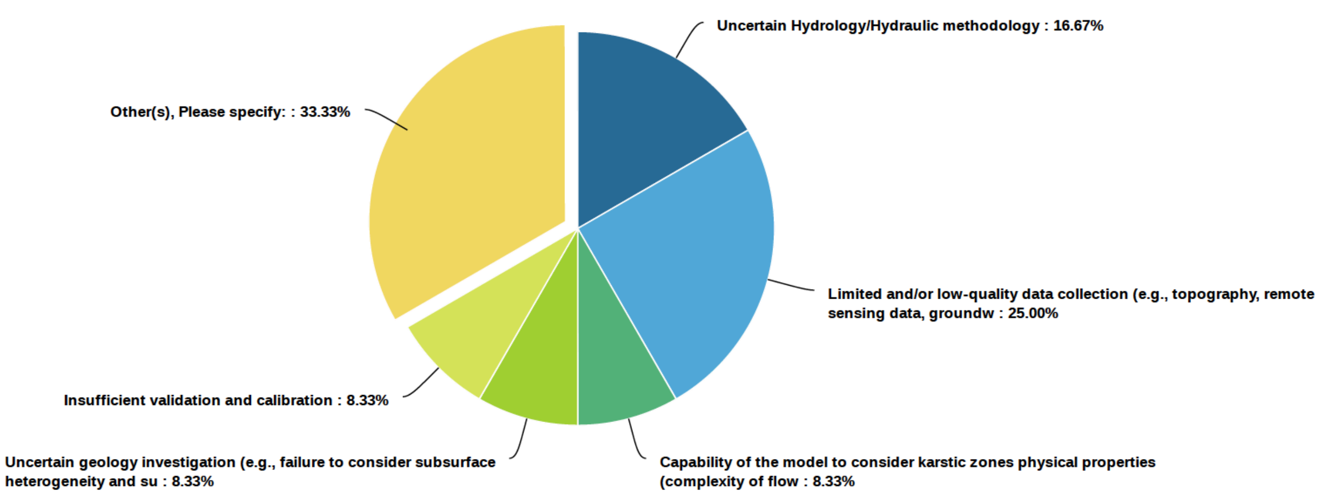


Figure C.30 Responses to questions regarding the reasons for infrastructure damage in karst zones areas (Q11)

Please select if your institution/company use any of the following methods to identify the evolution of karstic zones?(Q18.2)

Participants were asked to select the methods used by their institution or company to identify the evolution of karstic zone. The percentage for each method is as follows:

- Remote Sensing/LIDAR/Drones, UAVs (0.0%)
- Hydrological monitoring (e.g., water surface elevation, gauge monitoring at inflow and outflow boundaries) (21.7%)
- Land use and land cover change analysis (4.4%)
- Ground Penetrating Radar (GPR) (0.0%)

Additionally, 17.4% selected the "*Others*" category, which includes various unspecified methods, while 56.5% indicated that none of these methods are applicable to their work. **Figure C.31** depicts the various approaches employed to track and assess the evolution of playa lakes, as reported by respondents.

Under the "*Others*" category, participants provided the following additional methods or comments:

- *"Identifying karst features that do not present substantial surface manifestations would be an exciting thing. There may be potential for remote sensing/gravimetric methods/GPR/drones, but this would be considered emerging technology."*
- *"DNR tracks, field observations when new holes open."*
- *"We rely on expertise of our in-house Geology staff."*
- *"Near-surface geophysics"*

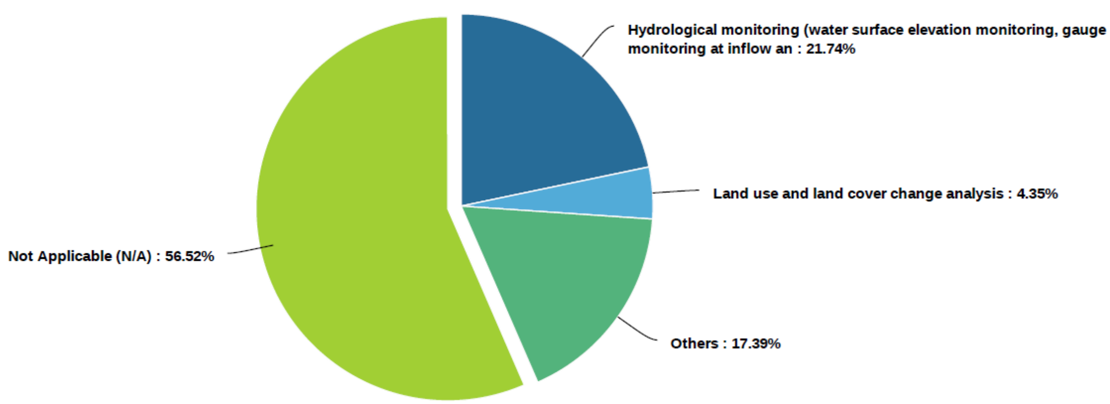


Figure C.31 Responses to questions regarding the methods used by participants or their institutions/companies to identify the evolution of karst zones (Q18.2)

Note: The responses related to playa lakes areas and arid regions are provided in other sections under Q18.1 and Q18.3, respectively.

Please select any of the following models that you used to simulate the hydrology of karstic zones. (Q25)

The participants were asked if they have utilized any of the following models to simulate the hydrology of karst zones:

- SWAT (Soil and Water Assessment Tool)
- KarstMod
- SUFI-2 (Sequential Uncertainty Fitting)
- MIKE SHE (MIKE Soil-Atmosphere-Water)
- KINEROS (KINematic runoff and EROSion)
- EPIC (Erosion-Productivity Impact Calculator)
- CAVE
- MODKARST

Figure C.32 shows that none of the models listed above were utilized by respondents. Instead, 35% of respondents reported using "*Others*" methods to meet their simulation needs. Additionally, 65% of respondents indicated that none of the listed models were applicable to their work.

Figure C.32 Responses to questions on models used by participants or their institutions/companies to simulate the hydrology of karst zones (Q25)

Under the "*Others*" option, participants provided several responses, including the following:

- *"EDYS"*
- *"HydroCAD with storage and an orifice for the sinkhole/outlet"*

- *“Not really a 'model' but TNDOT funded the USGS to delineate karst areas with closed drainage basins for use in TN StreamStats. StreamStats routinely removes closed drainage basins from hydrology calculations, but this is not a method I am happy with.”*
- *“Report by Virginia Dept of Conservation and Recreation, ‘Technical Bulletin No, 2 - Hydrologic Modeling and Design in Karst’ July 2009”*
- *“TR-20, Rational Method”*
- *We usually try to avoid karst/sinkholes. However, we had a project that had a sinkhole that was that area's outfall and we couldn't afford to change the outfall. There were no signs showing erosion or that the outfall was inadequate or unstable. The sinkhole was a cave with federally protected Madison Cave isopods and we had to get the U.S. Fish & Wildlife Service to sign off on our design. With the help of VDCR we added a SWM facility just upstream to help improve the quality of the runoff. So, we used the rational method to get the peak Q and drainage areas and designed a bio-retention facility and everyone signed off on our design. After everyone in the required agencies signed off we had to report the sinkhole to the Federal EPA as an injection well. We did not touch the opening or any part of the sinkhole so we did not have to report it has an improved injection well.”*

The lack of use of the listed models suggests a gap in model applicability or availability for karstic zones. The preference for unspecified "*Other*" models or methods indicates a need for more tailored or specialized solutions in this area. Addressing this gap could involve developing or adapting models specifically for karstic hydrology or enhancing the existing ones to better fit the unique characteristics of these environments.

If any of the above is selected, would it be possible to share a copy of the model setup and project reports?(Q26)

For those respondents who indicated the use of models for simulating hydrology in *karstic zones* (Q25), 11.1% are willing to share both their model setups and project reports. Another 22.2% are open to sharing project reports, but only upon an official request, while none expressed a willingness to share just the model setups. Additionally, 33.3% are unsure about whether they can share these materials, and the remaining 33.3% are unwilling to share any materials (**Figure C.33**).

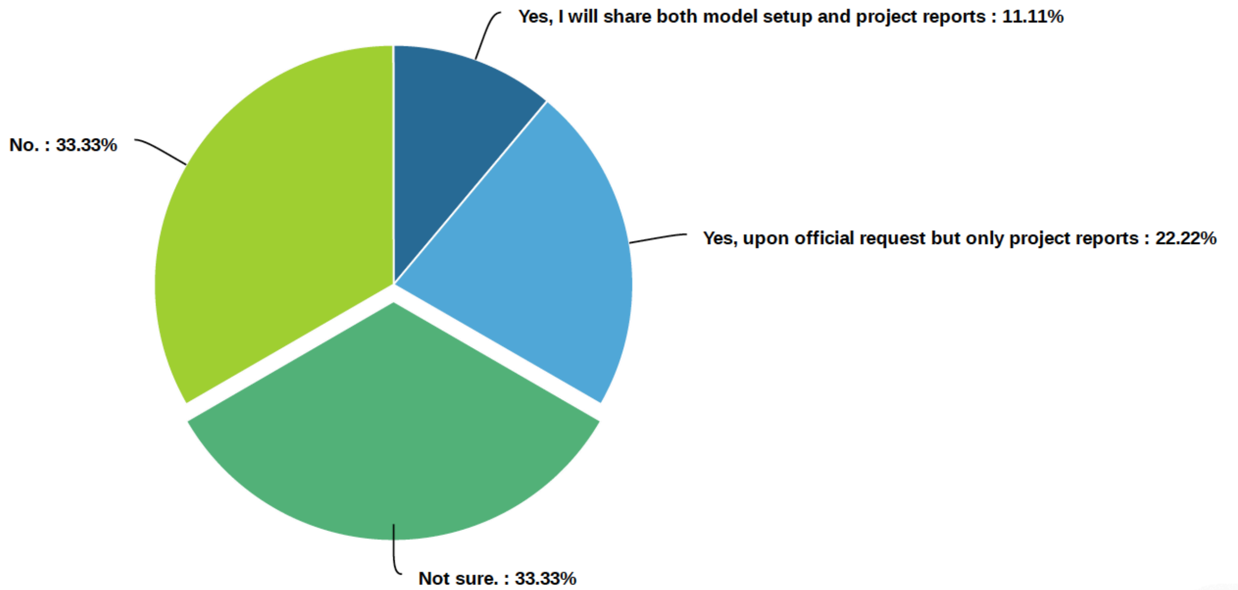


Figure C.33 Responses to the question regarding sharing a copy of the model setup and project reports for karst zones (Q26)

Do you consider the spatial variability of groundwater recharge from Karst zones?(Q27)

In evaluating the spatial variability of groundwater recharge from karst zones, 27.8% of respondents account for this variability in their work. In contrast, 38.9% do not consider it. The remaining 33.3% found the question not applicable to their work (**Figure C.34**).

Participants who responded "*Yes*" provided the following additional information:

- *"Yes, you have to consider the contributing watersheds to the karst features."*
- *"Yes, in some locations. Based on reports from local landowners, others."*

A significant portion of respondents do consider the spatial variability of groundwater recharge in karst zones, but an equally substantial number do not. This distribution indicates a potential area for increased focus and standardization in the assessment of groundwater recharge in karstic environments.

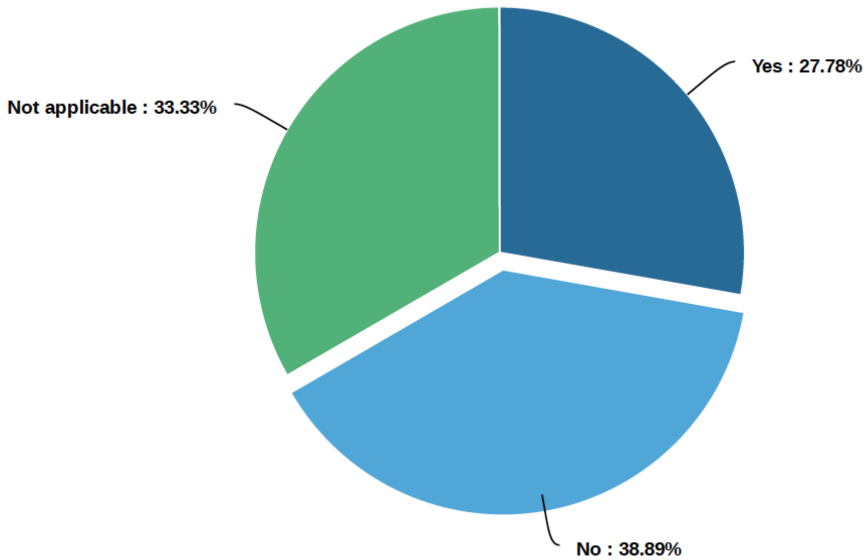


Figure C.34 Responses to the question on whether respondents consider the spatial variability of groundwater recharge from karst zones (Q27)

If you are using any model to simulate flow in Karst areas, how the roughness value is estimated for flow through Karst conduits?(Q28)

In the context of simulating flow in karst areas, 100% of respondents indicated that estimating the roughness value for flow through karst conduits does not apply to their work. The fact that all respondents do not apply methods for estimating roughness values for karst conduits suggests a lack of focus or need for this specific parameter in their current models or approaches. This may indicate either that roughness is not a critical factor in their simulations, or that alternative methods or models are used where roughness estimation is not required. It also highlights an area where further investigation or development may be needed if roughness plays a significant role in karst flow dynamics.

What is the methodology that you or your institution/company use to calculate the runoff in playa lakes/arid areas/karstic zones? (Q30.2)

The methodologies employed for calculating runoff in *karst zones* rely on several techniques. As shown in **Figure C.35**, the most frequently mentioned methods include the Rational Method (16.7%), TR-55 (14.6%), SCS Curve Number (14.6%), and SCS Unit Hydrograph/ NRCS Dimensionless Hydrograph (20.8%). Other cited approaches include Statistical Analysis of Stream Gauge Data (10.4%), and HEC-HMS (8.3%). Less commonly used techniques include the Clark Unit Hydrograph (2.1%) and Omega EM Regression Equations (2.1%). Some respondents indicated that runoff calculations were not applicable to their work (6.3%), while 4.2% reported employing a range of methodologies beyond the commonly listed options.

In a follow-up question the participants were asked "*If you selected other methodologies, please specify those methodologies below*:"

The following comment was provided by one participant:

- *We rely on USGS StreamStats, and (local university) research projects to produce regression equations for peak discharge. This currently accounts for 95% of our hydrology methodology.*

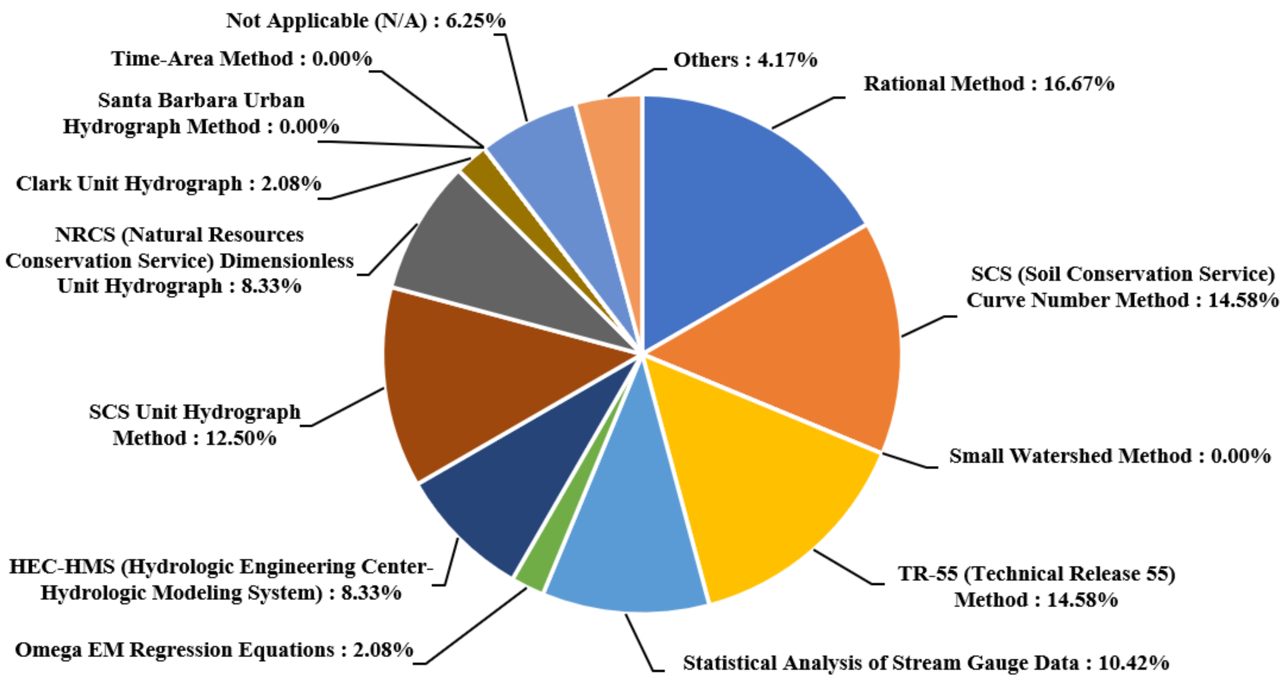


Figure C.35 Methodologies used by participants and their institutions/companies to calculate runoff in karst zones (Q30.2)

Note: The responses related to playa lakes and arid regions are provided in other sections under Q30.1 and Q30.3, respectively.

What is the methodology that you or your institution/company use to calculate the loss in playa lakes/arid areas/karstic zones? (Q31.2)

Figure C.36 shows that the most commonly used methodologies for calculating loss in *karst zones* were the NRCS Curve Number Loss Model (23.5%), Green-Ampt Loss Model (17.6%), and the Texas Initial and Constant-Rate Loss Model (11.8%). No respondents selected the general Initial and Constant-Rate Loss Model. Additionally, 5.9% of participants chose the "*Others*" option. A significant portion, 41.2%, indicated that calculating loss was not applicable to their practices.

One respondent who selected the "Others" option provided the following comment:

- *"We do not account for loss due to karst features, unless that loss is reflected in a stream gauge analysis."*

Figure C.36 Methodologies used by participants and their institutions/companies to calculate the loss in karst zones (Q31.2)

Note: The responses related to playa lakes and arid regions are provided in other sections under Q31.1 and Q31.3, respectively.

What is the methodology that you or your institution/company use to calculate the time of concentration in playa lakes/arid areas/karstic zones? (Q32.2)

The methodologies employed by respondents for calculating time of concentration in karst zones are shown in **Figure C.37**. The most frequently cited approaches include the NRCS Method (29.2%), Kerby-Kirpich Method (20.8%), and the Kinematic Wave Equation (16.7%). A smaller percentage (4.2%) reported using Area-Based Method, while 12.5% of respondents mentioned employing other techniques. Additionally, 16.7% of participants indicated that calculating time of concentration was not applicable to their practices.

One respondent who selected the "*Others*" option provided the following comment:

- *"TR-55, "Time of Concentration of Small Drainage Basins", Modified Rational Method, and VDOT recommends using the Rational Method procedures to calculate time of concentration (tc)"*

Figure C.37 Methodologies used by participants and their institutions/companies to calculate the time of concentration in karst zones (Q32.2)

Note: The responses related to playa lakes and arid regions are provided in other sections under Q32.1 and Q32.3, respectively.

What is the methodology that you or your institution/company use to calculate the lag time (basin lag) in playa lakes/arid areas/karstic zones? (Q33.2)

For calculating basin lag time in *karst zones*, respondents utilized various techniques. As shown in **Figure C.38**, the most frequently cited methods were the NRCS Dimensionless Unit Hydrograph (33.3%) and the SCS Lag Method (27.8%). Other approaches, such as Snyder's Unit Hydrograph, were used by 5.6% of respondents, while another 5.6% selected the "*Others*" option. Notably, methods such as the triangular hydrograph and hydrograph separations were not employed for calculating lag time. Additionally, 27.8% of respondents indicated that calculating lag time was not applicable to their practices.

Figure C.38 Methodologies used by participants and their institutions/companies to calculate the lag time (basin lag) in karst zones (Q33.2)

Note: The responses related to playa lakes and arid regions are provided in other sections under Q33.1 and Q33.3, respectively.

What flood frequencies have you or your institution/company utilized for drainage impact and flood mitigation studies for urban and infrastructure developments in Playa lakes/arid areas/karstic zones? (Check multiple if required) (Q34.2)

Figure C.39 indicates that the most used flood return period for drainage impact and flood mitigation studies for urban and infrastructure developments in *karst zones* were the 100-yrs (23.7%), 50-yrs (13.2%), 10-yrs (13.2%), 500-yrs (10.5%), and 2-yrs (10.5%). A smaller group of respondents also reported the use of other flood frequencies, such as 5-yrs (7.9%) and 20-yrs (2.6%) The 200-year flood was not used. Additionally, 13.1% of respondents stated that calculating runoff was not applicable to them. A further 5.2% indicated using a range of floods beyond the common options, such as the 1-yr, 25-yrs floods, and bankfull discharge.

The following is a list of comments from the respondents:

- *This depends on roadway classification, as per the TxDOT HDM. For cross-drainage structures, usually 10-25 year (we don't use the 20-year, we use 25). The 100-year is a check event.*
- *Check storm considering nonstationarity*
- *1-yr*

Figure C.39 Flood frequencies used by participants and their institutions/companies in drainage impact and flood mitigation studies for urban and infrastructure developments in karst regions (Q34.2)

Note: The responses related to playa lakes and arid regions are provided in other sections under Q34.1 and Q34.3, respectively.

C.2.4.4. Questions Specific to Hydrologic Approaches to Arid Regions

This section of the survey focused on collecting information about practices and methodologies related to hydrological studies and infrastructure design in *arid regions*. The relevant questions include Q4, Q12, Q13, Q18.3, Q19, Q20, Q23, Q24, and Q30.3 to Q34.3.

What are the methods that you or your institution/company use to identify and classify arid regions? (Q4)

A variety of methods are used by the participants to identify arid regions. The largest group of participants reported relying on traditional techniques such as climatology and meteorological data analysis (21.4%) and field observations (19.1%). Fewer participants used emerging methods like drone imagery (4.8%) and remote sensing and satellite data (11.9%). Drought or Aridity Indices were employed by 7.1%, while Global Classification Systems were used by 2.4%. Additionally, 4.8% of respondents reported using other techniques. Notably, 28.6% did not employ any specific method for identifying arid regions (**Figure C.40**). These results suggest variability in practices and a potential lack of standardized approaches in some cases.

Participants who selected "*Others*" option provided the following explanations:

- *"Typically, historical information like Mean Annual Precipitation maps, the prevalence of ephemeral streams/absence of perennial streams are clues. There is no universal definition of 'arid', so the boundaries between arid, semi-arid, dry sub-humid, etc. are very fuzzy and subject to interpretation. The distinctions are not necessarily of interest in design."*
- *"Low annual rainfall totals, lack of vegetation, and other indicators for the western third of the state indicate semi-arid/arid conditions."*

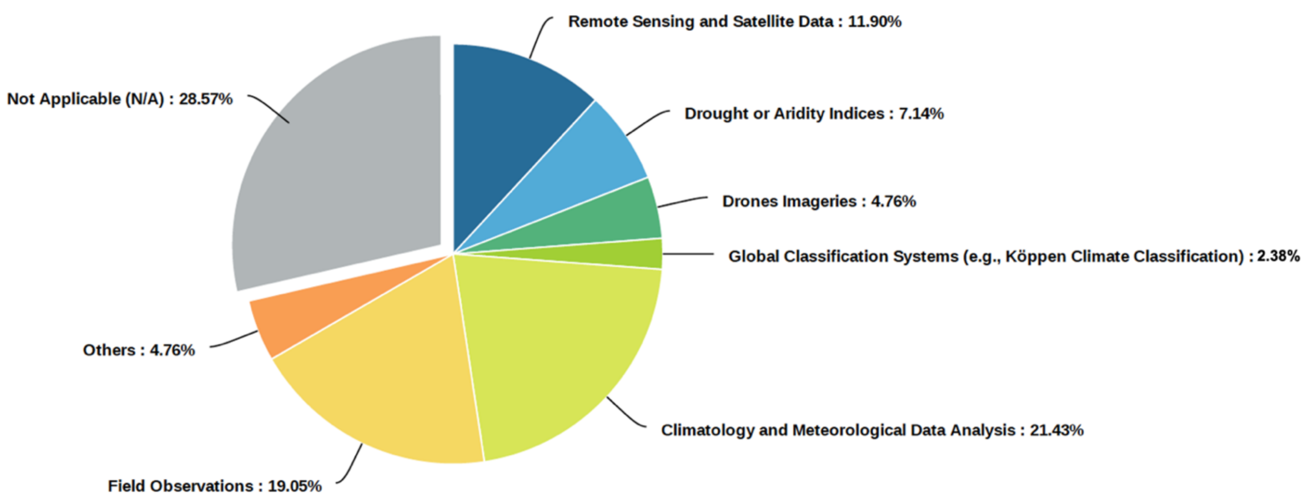


Figure C.40 Responses to the question about the methods used by participants or their institution/company to identify arid regions (Q4)

Have you or your institution/company encountered or are aware of cases where infrastructure was damaged (partially or completely) due to the lack of proper design guidelines or standards for Arid regions?(Q12)

In addressing the impact of inadequate design guidelines for arid regions on infrastructure, 16.7% of respondents reported experiencing infrastructure damage attributed to a lack of proper design guidelines or standards. Meanwhile, 25% indicated they had not encountered such damage, 12.5% were unaware of any related incidents, and 8.3% acknowledged that damage had occurred but was not linked to the absence of design guidelines. Additionally, 37.5% found the question not applicable to their work (**Figure C.41)**. These responses highlight that while a notable portion of respondents have encountered infrastructure damage due to inadequate design guidelines in arid regions, many others have not faced such issues or find the question irrelevant.

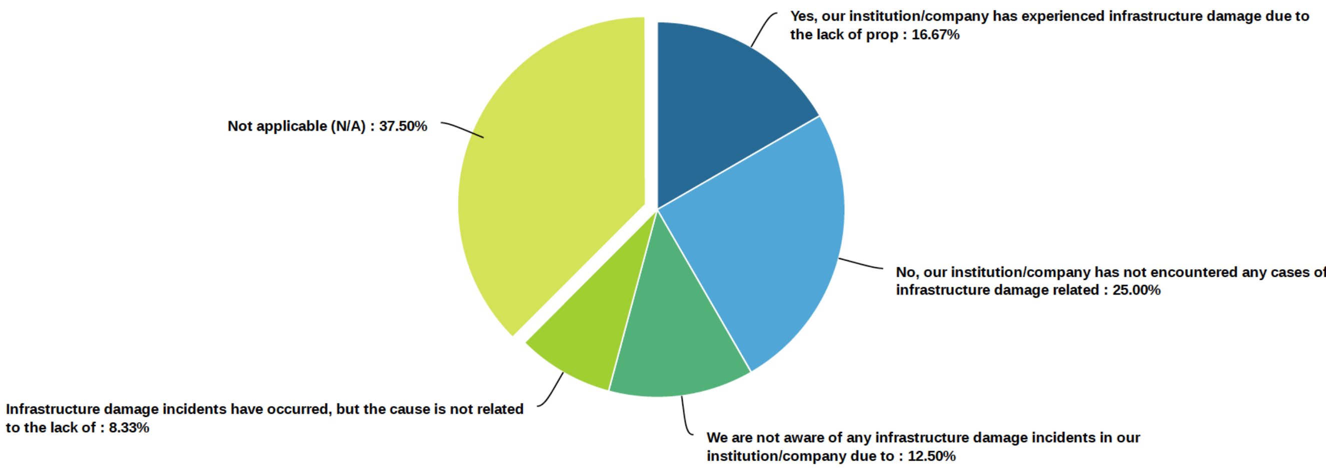


Figure C.41 Responses to the question on whether participants or their institution/company have encountered or are aware of infrastructure damage due to the lack of proper design guidelines or standards for arid region (Q12)

If your answer to the previous question was "yes", what was the reason(s)?(Q13)

Participants were asked to identify reasons for infrastructure damage in arid regions. The percentage for each method is as follows and shown in **Figure C.42**:

- Uncertain Hydrology/Hydraulic methodology (15%)
- Limited and/or low-quality data (e.g., topography, remote sensing data, groundwater and gauge monitoring, soil characteristics, sinkholes and bedrock characteristics, etc.) (15%)
- Capability of a model to consider arid regions' physical properties (e.g., failure to consider evaporation and transpiration, seasonal variability, etc.) (5%)
- Disregarding future considerations (e.g., anthropogenic and climate change impacts, etc.) (10%)
- Disregarding dynamic modeling to simulate transient conditions (dynamic relationship between precipitation, evaporation, runoff, groundwater interaction, etc.) (15%)
- Disregarding the spatial and temporal variabilities of effective parameters (e.g., precipitation, temperature, infiltration, evaporation, etc.) (5%)
- Disregarding the spatial and temporal variabilities of effective parameters (e.g., precipitation, temperature, infiltration, sedimentation and bathymetry changes) (10%)
- Failure to consider groundwater interaction (0%)
- Insufficient validation and calibration (5%)

The reported reasons for infrastructure damage in arid regions largely center around methodological uncertainties, data quality, and modeling limitations. This underscores the need for improved hydrological methodologies, data collection, and model validation specific to arid environments.

Participants also provided additional information, including:

- *"This has been a key interest and research topic of mine for decades. In essence, most of the methods we have for risk-based estimation perform poorly in arid areas. It can be summed up by saying that there is a large disconnect between precipitation frequency and flood frequency; the vast majority of rainfall events produce no runoff at all, yet under some conditions streams in arid areas can produce some of the largest specific discharges known."*
- *"Most infrastructure damage I have seen in arid regions stems from a failure to adequately address the possibility of intense rainfall despite it's classification as arid."*
- *"The design engineer who seals the engineering drawings is ultimately responsible for the design. Every design should consider the local conditions and if design modifications are required that ALWAYS be done as matter of engineering practice."*

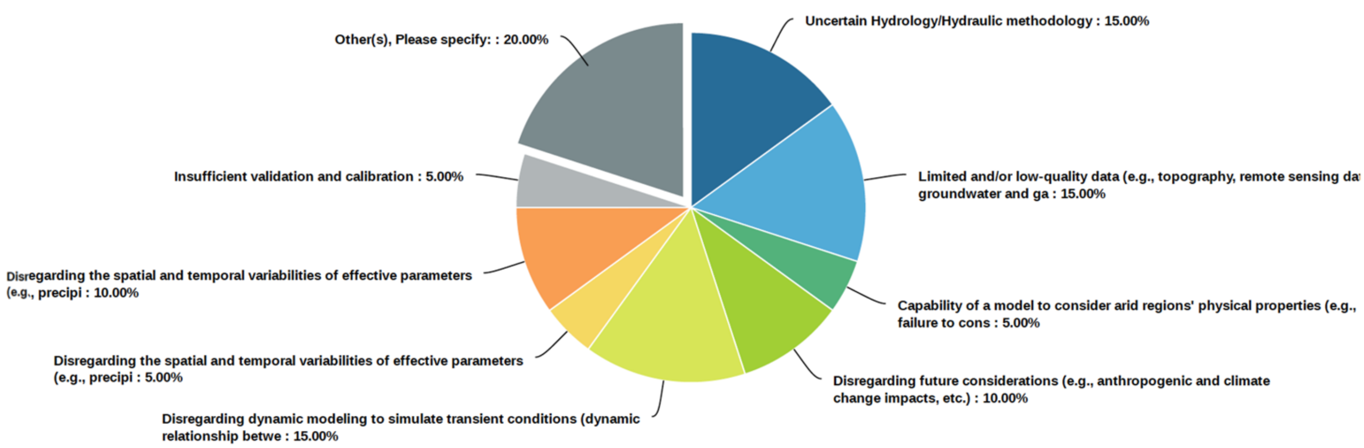


Figure C.42 Responses to questions regarding the reasons for infrastructure damage in arid regions (Q13)

Please select if your institution/company use any of the following methods to identify the evolution of Arid regions?(Q18.3)

Participants were asked to identify the methods their institutions or companies use to track the evolution of arid regions. The responses were as follows:

- Remote Sensing/LIDAR/Drones, UAVs (15.2%)

- Hydrological monitoring (e.g., water surface elevation, gauge monitoring at inflow and outflow boundaries) (21.2%)
- Land use and land cover change analysis (18.2%)
- Ground Penetrating Radar (GPR) (0.0%)

Additionally, 9.1% of respondents selected the "*Others*" category, which includes various unspecified methods, while 36.4% indicated that none of these methods are applicable to their work. **Figure C.43** illustrates the various approaches used to assess the evolution of arid regions, as reported by respondents.

Participants who selected the "Others" category provided the following comments:

- *"At least in west Texas, land cover change over the last century, primarily brush invasion because of wildfire suppression and/or grazing practices, has probably had a great effect on response to rainfall. This likely adds an unknown bias to statistically derived methods."*
- *"As above, aerial photography and field observations."*
- *"NMDOT uses hydrological methods as specified in the NMDOT Drainage Manual (2018)"*

The methods used to track the evolution of arid regions are varied, with a significant reliance on hydrological monitoring and land use analysis. The substantial percentage of respondents for whom these methods do not apply suggests a need for further exploration of effective techniques that are more tailored to the unique challenges of arid environments.

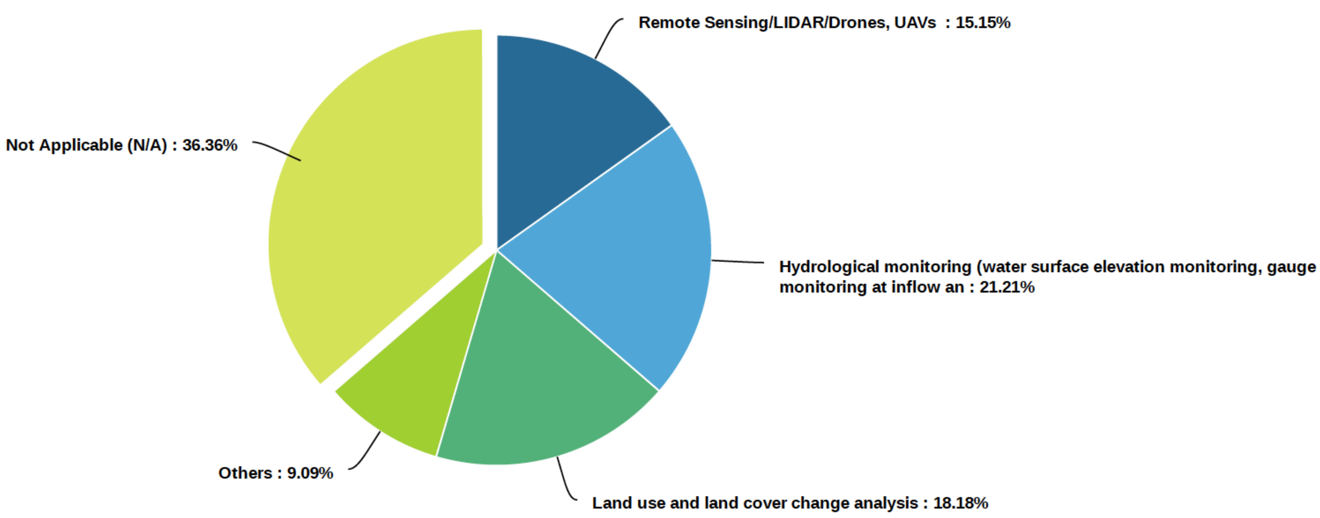


Figure C.43 Responses to questions regarding the methods used by participants or their institutions/companies to identify the evolution of arid regions (Q18.3)

Note: The responses related to playa lakes and karst areas are provided in other sections under Q18.1 and Q18.2, respectively.

Have you and/or your institution/company considered the future changes in the spatial distribution of arid regions in hydrological studies/modeling? (Q19)

In hydrological studies and modeling, the consideration of future changes in the spatial distribution of arid regions varies among respondents: 30.4% have accounted for future changes, 34.8% have not, and 34.8% found this aspect not applicable to their work (**Figure C.44**). While a notable portion of respondents are incorporating future changes into their studies, an equal percentage either overlook it or find it irrelevant, indicating a potential gap in addressing future climate impacts and highlighting the need for broader integration of these considerations in hydrological modeling.

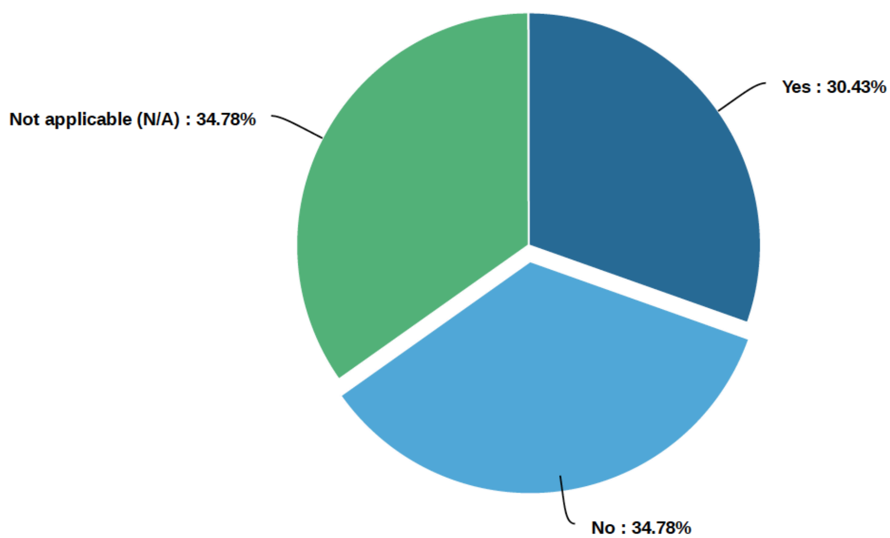


Figure C.44 Responses to the question regarding the consideration of future changes in the spatial distribution of arid regions in hydrological studies/modeling (Q19)

If yes, what are the forecast methods for the future evolution of arid regions you and/or your institution/company considered? (Q20)

For forecasting the future evolution of arid regions, 30% of respondents use climate models, 10% employ hydrological models, and 60% utilize other unspecified methods. Notably, none of the participants reported using Drought Indices, Vegetation Models, Land Use Change Models, Urban Growth Models, or Artificial Intelligence and Machine Learning Models for this purpose. (**Figure C.45**). The majority of respondents rely on climate models, while a smaller portion uses hydrological models.

Participants who selected the "*Others*" category provided the following comments:

- *"Erosion and Sedimentation"*

– *"Geological models"*

– *"As noted earlier, arid regions are difficult to define anyway, so their evolution would be highly uncertain"*

– *"Climate Models EDYS"*

– *"Hydrological Models EDYS"*

– *"Climate Models RCM"*

The variety of methods categorized as "*others*" suggests a range of approaches are being applied, though details are not provided. This indicates both a reliance on established climate modeling techniques and the use of diverse, possibly innovative, methods by some respondents.

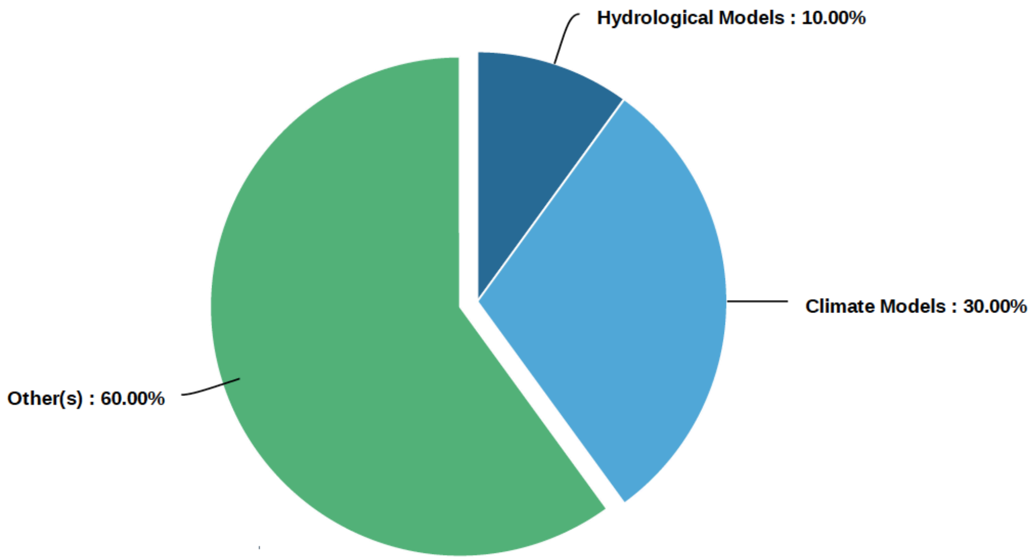


Figure C.45 Responses to the question regarding the methods employed to forecast the future evolution of arid regions (Q20)

Please select any of the following models that you use/have used to simulate the hydrology of arid regions. (Q23)

Participants were asked if they have used any of the following models to simulate the hydrology of arid regions:

- SWAT (Soil and Water Assessment Tool)
- VIC (Variable Infiltration Capacity)
- AWARE (Atmosphere–Water–Ecosystem Model)
- MODFLOW (Modular Ground-Water Flow Model)
- MIKE SHE (MIKE Soil-Atmosphere-Water)

- HEC-HMS
- PRMS (Precipitation-Runoff Modeling System)
- RHESSys (Regional Hydro-Ecologic Simulation System)
- GSSHA (Gridded Surface Subsurface Hydrologic Analysis)

For simulating arid region hydrology, 4.8% of respondents reported using SWAT, while 19.1% used HEC-HMS. Additionally, 23.8% have utilized other unspecified models, and a significant 52.4% indicated that these models do not apply to their work (**Figure C.46**).

Under the "*Others*" option, participants provided several other approaches, including the following:

– *"ICPR"*

– *"Same as Q21: "When I was doing design for playa lakes, we had no access to methods from within TxDOT; I obtained SCS TR-20 (original FORTRAN version) and self-taught on it."*

– *"StreamStats, rain-on-grid modeling using FLO-2D or HEC-RAS 2D"*

– *"ADOT Rational Tool, FCDMC Rational Method guidelines, City of Tucson PC-Hydro. NRCS Curve Number Method for Wildfires, review of 2D Model output."*

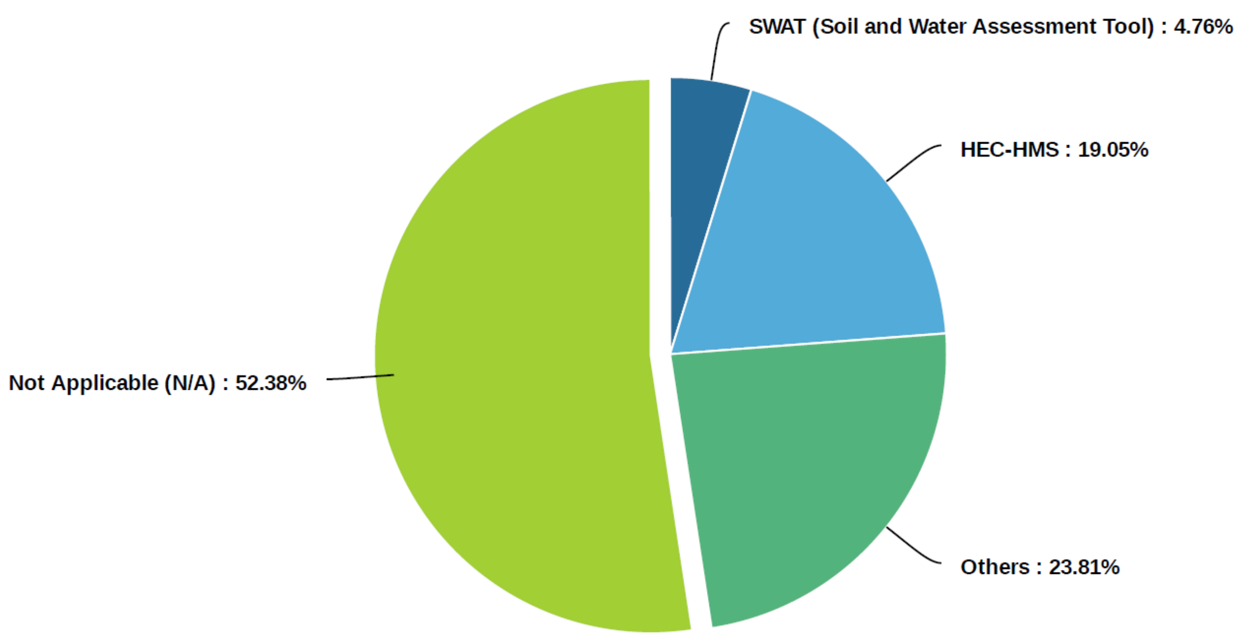


Figure C.46 Responses to questions on models used by participants or their institutions/companies to simulate the hydrology of arid regions (Q23)

If any of the above is selected, would it be possible to share a copy of the model setup and project reports?(Q24)

Among respondents who have conducted studies or used models to simulate arid region hydrology, 20% are willing to share project reports only upon official request, 40% are uncertain about sharing, and 40% are unwilling to share either model setups or project reports (**Figure C.47**) These findings highlight the limited willingness to share such materials. While some respondents are open to sharing under specific conditions, a significant portion remains uncertain or unwilling. One participant explained "*Client confidentiality does not allow us to release project-specific information*" while another noted "*Do not have them*". This underscores the importance of addressing concerns related to data repositories, data sharing, and confidentiality in order to promote greater collaboration and information exchange in hydrological studies in arid regions.

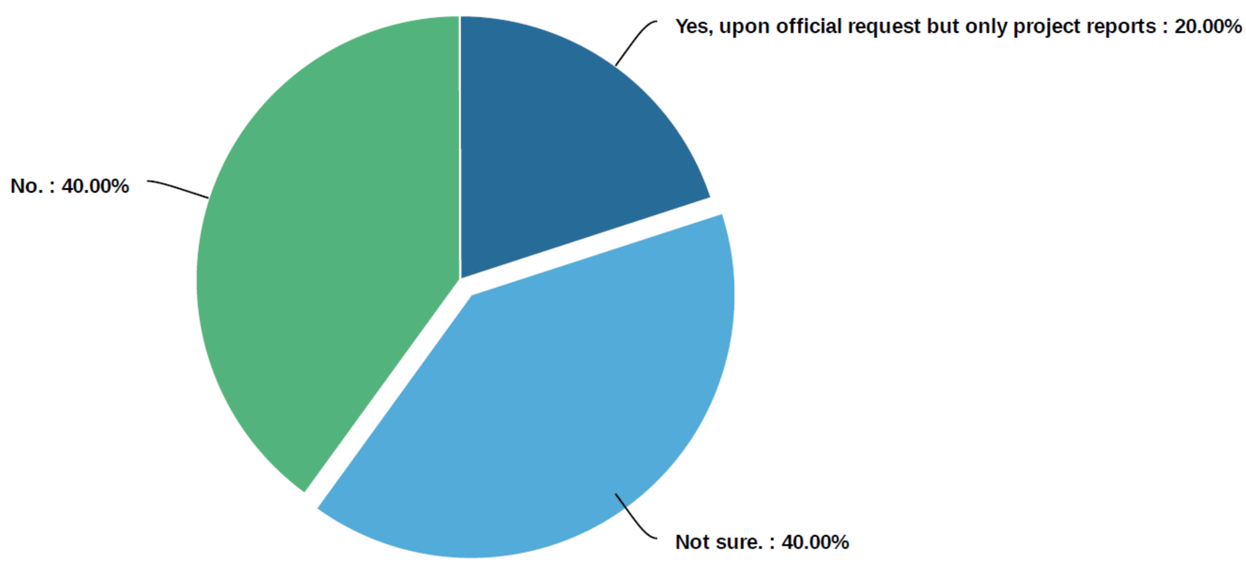


Figure C.47 Responses to the question regarding sharing a copy of the model setup and project reports for arid regions (Q24)

What is the methodology that you or your institution/company use to calculate the runoff in playa lakes/arid areas/karstic zones? (Q30.3)

Participants used various methodologies and models to calculate runoff in *arid regions*. As shown in **Figure C.48**, the most frequently cited approaches included the SCS Unit Hydrograph/NRCS Dimensionless Unit Hydrograph (20.6%), Rational Method (13.2%), SCS Curve Number (13.2%), and HEC-HMS (10.3%). A smaller subset of respondents used the Statistical Analysis of Stream Gauge Data (8.8%), TR-55 method (7.4%), and Clark Unit Hydrograph (5.9%). Less common methods included Omega EM Regression Equations (2.9%), Santa Barbara Hydrograph Method (1.5%), and Small Watershed Methods (1.5%). The Time-Area Method was not reported as being used (0.0%). Additionally, 7.4% of participants indicated that runoff calculation was not applicable to their work, while another 7.4% reported using alternative methods.

In a follow-up question, the participants were asked "*If you selected other methodologies, please specify those methodologies below*:"

The following methods were mentioned by participants:

- *"Green-Ampt method for modeling infiltration and kinematic wave model for rainfall to runoff transformation."*
- *"This question is very ambiguous. HEC-HMS is not a method, it is a modeling software package that incorporates a number of methods. The SCS Curve number method is a part of a method- loss accounting. TR-55 is outdated; the Windows version does not even include the original computations. The SCS Unit Hydrograph and the NRCS Dimensionless Unit Hydrograph are one and the same. The Rational Method is only used on watersheds <200 acres. It is extremely rare in Texas to have gauge data that are pertinent to a design watershed; however transposition of gauge data can be a useful tool. I was instrumental in the development of the Omega-Em regression equations; they are the best regression equations available for Texas, but have limitations. In FHWA HDS-2, the Index Flood Method has been revised and presented. In many cases, the methods available are useful as validation, if not primary methods."*
- *"Streamstats, 2-Dimensional rain-on-grid modeling (HEC-RAS 2D, FLO-2D)"*
- *"Snyder method is also commonly used (USACE prefers the Snyder method)"*
- *"ADOT Ch 4 Hydrology Manual requires Clark UH unless written justification otherwise. In-house design sticks with this. For Consultant design projects, some use different."*

These results suggest that while widely accepted methods like the SCS Unit Hydrograph/NRSC Dimensionless Unit Hydrograph, SCS Curve Number, and models such as HEC-HMS are preferred for their general applicability, less conventional techniques, including 2D Rain-on-Grid Modeling, Snyder method, Clark Unit Hydrograph, and the Green-Ampt Method, are favored for effectively capturing specific hydrologic dynamics.

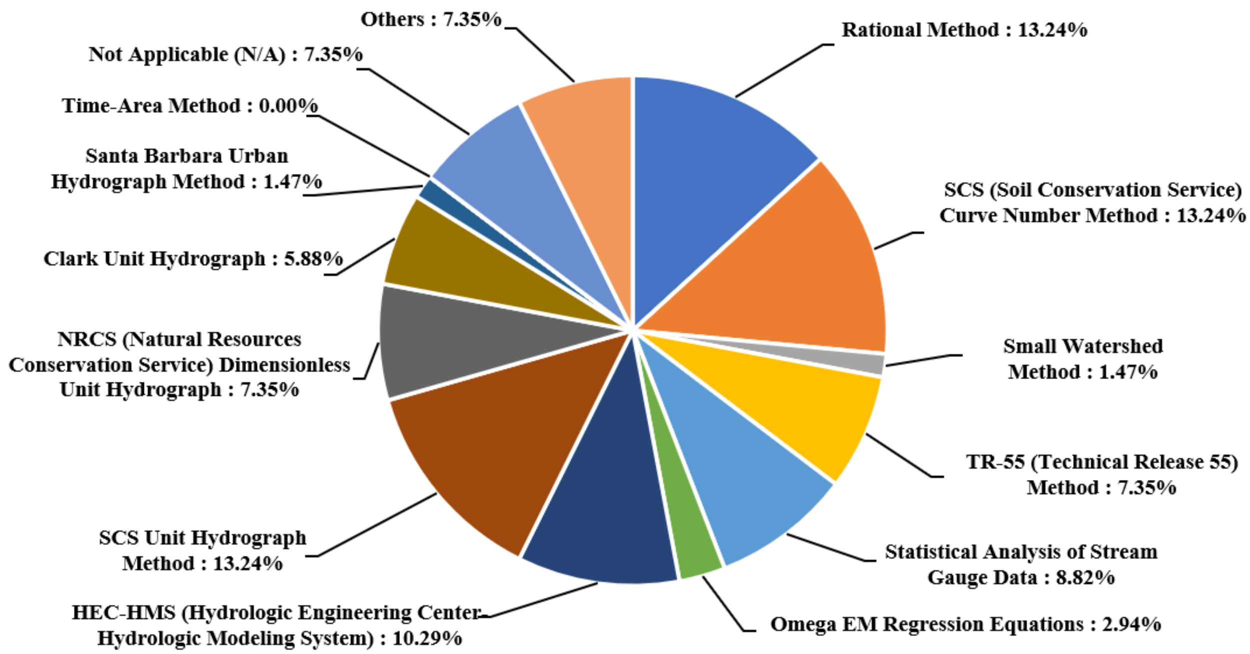


Figure C.48 Methodologies used by participants and their institutions/companies to calculate runoff in arid regions (Q30.3)

Note: The responses related to playa lakes and karst areas are provided in other sections under Q30.1 and Q30.2, respectively.

What is the methodology that you or your institution/company use to calculate the loss in playa lakes/arid areas/karstic zones? (Q31.3)

Figure C.49 shows that the most frequently used methodologies for calculating loss in *arid areas* were the Green-Ampt Loss Model (22.7%) and the NRCS Curve Number Loss Model (22.7%). A smaller group of respondents reported using other techniques, such as the Initial and Constant-Rate Loss Model (9.1%) and the Texas Initial and Constant-Rate Loss Model (9.1%). Additionally, 4.6% of participants selected the "*Others*" option. A significant portion (31.8%) indicated that calculating loss was not applicable to their practices.

Respondents who selected the *"Others"* option provided the following comments:

- *"Loss modeling is one of the most difficult choices in H&H modeling. Most models underestimate losses- the Texas Ia/Cl model bears that out. The curve number process is improved by climatic adjustment of curve numbers per TxDOT-sponsored work by Thompson, et al, and by reduction of the Ia ratio as in ASCE Hawkins et al. Green-Ampt is an infiltration model, not a loss model; it does not account for an initial abstraction or other losses. It is widely used mainly because parameters can be estimated without getting out of the designers chair."*

- *"NRCS hydrograph method is preferred because the methodology is relatively transparent and different engineers modeling the same watershed will most likely arrive at similar result for flows."*
- *"ADOT Hydrology Manual Chapter 3 recommends Green-Ampt and in areas where G-A is not applicable, Initial and Constant Loss Method. A written request would be needed to use other."*

Figure C.49 Methodologies used by participants and their institutions/companies to calculate the loss in arid regions (Q31.3)

Note: The responses related to playa lakes and karst areas are provided in other sections under Q31.1 and Q31.2, respectively.

What is the methodology that you or your institution/company use to calculate the time of concentration in playa lakes/arid areas/karstic zones? (Q32)

The methodologies employed by respondents for calculating time of concentration in arid areas were shows in **Figure C.50.** The most frequently cited approaches were the Kerby-Kirpich Method (24%), NRCS Method (28%), and Kinematic Wave Equation (20%) methods. A smaller group of respondents reported using other techniques (8%), while 20% stated that calculating the time of concentration was not applicable to their practices.

Respondents who selected the "*Others*" option provided the following comments:

- *"There are actually 2 methods shown by NRCS, neither of which are reliable. Chapter 15 of NEH 630 explicitly states that the velocity method (3 components) tends to underestimate travel time,* *leading to increased peak discharges. TxDOT-funded research (reflected in the TxDOT HDM) demonstrated that Kerby-Kirpich gives the best estimates of time of concentration of several methods evaluated."*

- *"Papdakis & Kazan, 1987 for Rational, See Ch 4.2.1 of ADOT Hydrology Manual for Clark UH Tc calcs equations."*

Figure C.50 Methodologies used by participants and their institutions/companies to calculate the time of concentration in arid regions (Q32.3)

Note: The responses related to playa lakes and karst areas are provided in other sections under Q32.1 and Q32.2, respectively.

What is the methodology that you or your institution/company use to calculate the lag time (basin lag) in playa lakes/arid areas/karstic zones? (Q33.3)

For calculating basin lag time in *arid areas*, several techniques were employed by respondents. **Figure C.51** shows that the most frequently cited approaches were the SCS Lag Method (24%), NRCS Dimensionless Unit Hydrograph (20%), Snyder's Unit Hydrograph (12%), and the Triangular Hydrograph Method (4%). Additionally, 8% of respondents selected the "*Others*" option, while 32% indicated that calculating lag time was not applicable to their practices.

One respondent who selected the "*Others*" option provided the following comment:

- *"San Bernardino County Hydrographs for Desert Areas, and USBR S-graph"*

Figure C.51 Methodologies used by participants and their institutions/companies to calculate the lag time (basin lag) in arid regions (Q33.3)

Note: The responses related to playa lakes and karst areas are provided in other sections under Q33.1 and Q33.2, respectively.

What flood frequencies have you or your institution/company utilized for drainage impact and flood mitigation studies for urban and infrastructure developments in Playa lakes/arid areas/karstic zones? (Check multiple if required) (Q34.3)

Figure C.52 indicates that the most used flood frequencies for drainage impact and flood mitigation studies for urban and infrastructure developments in *arid areas* were the 100-yrs (20.5%), 50-yrs (13.6%), 10-yrs (11.4%), and 2-yrs (9.1%). A smaller group of respondents also reported the use of other flood frequencies, such as 500-yrs (9.1%), 200-yrs (4.6%), 20-yrs (2.3%), and 5-yrs (6.8%). A group stated that calculating runoff was not applicable to them (15.9%). 6.8% of respondents provide a range of flood frequencies used for drainage impact and flood mitigation studies for urban and infrastructure developments in arid areas beyond the commonly listed options such as 1-yr, 25-yrs, and bankfull discharge.

The following is a list of comments from the respondents:

- *"For roadway drainage, we use 25-year event"*
- *"This depends on roadway classification, as per the TxDOT HDM. For cross-drainage structures, usually 10-25 year (we don't use the 20-year, we use 25). The 100-year is a check event."*
- *"Estimated dominant bankfull discharge"*

Figure C.52 Flood frequencies used by participants and their institutions/companies in drainage impact and flood mitigation studies for urban and infrastructure developments in arid areas (Q34.3)

Note: The responses related to playa lakes and karst areas are provided in other sections under Q34.1 and Q34.2, respectively.

CHAPTER C3: FOLLOW-UP INTERVIEWS ON HYDROLOGIC APPROACHES TO PLAYA LAKES, KARST GEOLOGY, AND ARID REGIONS

The research team conducted follow-up interviews with selected survey participants to gather detailed information on hydrologic approaches to playa lakes, arid areas, and karst zones, as well as to identify recommendations for the next steps, such as developing guidelines for hydrologic studies in these environments. These interviews aimed to assess the current state of practice. This section presents the selection process of interviewees, instructions for conducting the interviews, the interview questions, and the results obtained.

C.3.1. Selection of Interviewees

The following criteria were applied in selecting interviewees for follow-up discussions:

- *Willingness to Participate*: Preference was given to individuals who expressed interest and were willing to engage in the follow-up interviews.
- *Relevant Experience*: Candidates were chosen based on their significant experience in conducting hydrologic studies focused on playa lakes, arid regions, and karst zones, ensuring that the selected interviewees had specialized knowledge and practical insights.
- *Quality of Survey Responses*: Respondents who provided the most detailed and comprehensive information in the initial survey were prioritized. Their in-depth responses indicated a strong understanding of hydrologic challenges and methodologies, making them valuable contributors to the next phase of the research.

Based on these criteria, the research team conducted seven interviews with participants from the Departments of Transportation (DOTs) in Kansas, Minnesota, New Mexico, and Virginia, as well as one researcher, one consultant, and an individual with a diverse background that includes experience as a former TxDOT engineer, university faculty, and consultant. These interviewees were chosen for their expertise and experience in hydrologic studies in playa lakes, arid regions, and karst zones.

C.3.2. Interview Questions

The interview questions were developed based on insights from the literature review and survey results. These questions were designed to fill gaps in information that were not fully addressed in the survey responses. To maintain consistency, the interview questions mirrored the survey's structure. A total of 11 questions were formulated and organized into three sections:

- *Introduction and Personal Experience*: Focused on the interviewees' professional background and specific experience related to playa lakes, arid areas, and karst zones.
- *Current Guidelines and Standards:* Examined the existing guidelines and standards for conducting hydrological studies in playa lakes, arid areas, and karst zones.

- *Hydrological Studies and State of Practice*: Investigated the methods used in hydrological studies for these environments, including modeling practices, data availability, and gaps in current methodologies.

The specific interview questions are as follows:

Introduction and Personal Experience

1. Could you please introduce yourself, your affiliation, and share your personal experience with hydrology and hydraulic studies or modeling related to Playa Lakes, arid regions, and karstic zones?

Guidelines or Standards

2. Does your institution or company follow federal or state guidelines or standards for hydrology and hydraulic studies or modeling in these areas?
3. If so, which specific federal or state guidelines or standards do you use?
4. Do these guidelines or standards provide sufficient information for designing infrastructure in playa lakes, arid regions, and karstic zones?
5. If not, what do you find lacking in these guidelines or standards?
6. In your opinion, is there a need for developing national guidelines or standards specifically for playa lakes, arid regions, and karstic zones?

Studies or Modeling

7. Does your institution or company conduct studies or modeling related to the hydrology of Playa Lakes, arid regions, and karstic zones?
8. Could you provide examples of projects you have worked on in these areas, such as roads and bridges, reservoirs, or stormwater systems?
9. Do the current hydrology and hydraulic models adequately simulate flow characteristics in these areas, such as peak flow, runoff volume, and timing?
10. If yes, is there sufficient data available to calibrate and validate these models?
11. If not, in your opinion, what are the reasons for the lack of capable models? For example, could it be due to limited interest from the scientific community or stakeholders (e.g., DOTs, cities), the complexity of the problem, or a lack of funding?

The letter of invitation and the full set of interview questions are provided in **Appendix C Supplemental Materials.**

C.3.3. Interview Results

The interview results are summarized based on the three areas of questions listed above and are further organized by their relevance to the three focus areas: playa lakes, arid regions, and karst zones.

C.3.3.1. Interview with Kansas DOT Professionals

<u>Introduction and Personal Experience</u>

In this interview, a team of two professional engineers from the Kansas Department of Transportation (KDOT) (the current and former Hydraulics Engineer) shared their insights on the hydrology of areas with *playa lakes*, *arid regions*, and *karst zones*. Both engineers have background in hydraulic and hydrology, which has been essential for their work on bridge project modeling at KDOT. Their experience encompasses a range of hydrological challenges, including floodplain mapping that addresses sinkhole considerations. They have faced significant issues related to playa lakes, especially in the western part of the state, characterized by low-lying areas and sandy soils with high permeability. This flat landscape complicates runoff estimation, making reliable modeling results difficult to achieve. Additionally, they have encountered challenges in karst areas in the southeastern part of the state, which present their own unique difficulties. A summary of the key points from their discussion is provided below

<u>Guidelines or Standards</u>

While some guidelines exist, they are broad and do not specifically address the complexities found in karst, playa lakes, or arid regions. Each site in these regions is so unique that standard guidelines are difficult to apply, leading to a heavy reliance on engineering judgment, local knowledge, and site-specific testing.

<u>Karst Regions:</u>

- KDOT engineers confirmed that they are not aware of standardized guidelines that comprehensively address the unique challenges of karst areas, which often involve complex hydrologic systems with springs, sinkholes, and unpredictable water paths.
- In practice, KDOT relies heavily on geotechnical and geological input. Geotechnical teams provide insights into the presence of voids, historical water paths, and potential hazards like sinkholes. This local insight, often supported by field testing, guides the hydrologic assessments more than standardized methods do.
- The lack of a standardized approach means that engineers must use site-specific testing and geotechnical collaboration to estimate runoff, as the conditions in karst regions can vary significantly from site to site.

Playa Lakes and Arid Regions:

- The hydrologic conditions in playa lakes and arid regions can vary drastically depending on whether the lakes are dry or filled with water, which complicates runoff estimations. The variability affects key factors such as runoff coefficients, storage capacity, and time of concentration.
- KDOT uses tools such as USGS StreamStats and regression equations for estimating runoff in these regions. However, these tools are general and not specifically tailored to address the unique complexities of playa Lakes or arid zones.
- Existing guidelines (such as HEC-18, 20, and 23, and FHWA publications) provide some insights but do not fully address the detailed hydrologic behavior specific to playa lakes, especially regarding the impact of their filled or dry states on hydrologic calculations.

Studies or Modeling

The current federal and state guidelines do not adequately address the hydrologic needs these unique regions. This has resulted in a significant gap between existing guidelines and the actual requirements for studies, modeling, and engineering design in karst, playa lakes, and arid zones.

Karst Regions:

- *Data Gaps*: Karst areas are particularly challenging because of the unpredictable nature of water flow through springs and sinkholes. There is often insufficient hydrologic data to accurately model these systems. KDOT engineers pointed out that local surveyors and long-term landowner observations are often used to supplement data gaps. However, they also acknowledged that memory and anecdotal evidence are not always reliable.
- *Lack of Comprehensive Models*: Current models often overlook critical factors such as unpredictable water loss through sinkholes or springs. This results in a reliance on geotechnical teams, as no standardized hydrologic models or guidelines exist for these environments.

Playa Lakes and Arid Regions:

- *Data Gaps*: In arid regions and areas with playa lakes, the data on loss soil absorption rates and runoff behavior is limited. It was discussed that the SCS/NRCS methods typically apply a 20% initial abstraction rate, but in many arid regions, this figure is significantly different. The lack of accurate absorption data results in skewed calculations, making existing models less reliable for these areas.

  Additionally, there is a lack of comprehensive data on rainfall and soil characteristics, particularly for playa lakes and arid zones. This scarcity impacts the ability to properly calibrate models for hydrologic behavior in these regions.

- *Lack of Comprehensive Models*: It was pointed out that there are no reliable, comprehensive hydrologic models that account for the unique conditions of playa lakes, or arid regions. The available tools, such as 1D and 2D models, do not handle the complexities of these systems well. For instance, playa lakes require models that can adjust for the significant hydrologic differences when the lakes are dry versus when they are full.

  For arid regions, standard modeling tools like USGS StreamStats do not account for the higher initial absorption rates or the rapidly changing hydrologic conditions. The tools rely on generalized assumptions that may not apply to the unique circumstances of these environments.

<u>*Funding and Research Gaps:*</u>

- It was emphasized that lack of funding is a key reason why more research and specialized models for these regions have not been developed. Additionally, the hydrology of these areas is complex, and the necessary research is often not prioritized by federal or state agencies.

C.3.3.2. Interview with Minnesota DOT Professional

<u>Introduction and Personal Experience:</u>

The interviewee is the State Hydraulic Engineer at MnDOT, with over 13 years of experience and 10 years as a licensed water resource engineer. They focus on hydrology and hydraulic studies in urban areas, particularly flood management and stormwater control. While their direct work with playa lakes or arid regions is limited, they have dealt with hydrological challenges, including areas with karst features. Though their experience with karst is mainly related to designing infiltration and filtration basins or stormwater treatment ponds, they offer a solid understanding of hydraulic design. The interviewee provided responses to the survey and interview questions based on their own experience as well as input from colleagues at MnDOT. A summary of the key points from the discussion is provided below

<u>Guidelines or Standards:</u>

There are no specific federal or state guidelines for hydrologic modeling in karst areas, so each case is handled individually, adapting general hydrologic practices to the unique characteristics of the site.

- MnDOT follows its own state Drainage Manual, which is based on the ASSHTO Model drainage manual and approved by the Federal Highway Administration (FHWA), granting them stewardship over its content.
- Local cities and municipalities often rely on MnDOT's guidance for hydrology and hydraulics.
- A Federal Register rule that prohibits major ponding for a 50-year event, which MnDOT follows as a federal requirement, but other standards are largely delegated to the state.

- MnDOT is subject to various water resource regulations, including stormwater permits from the Minnesota Pollution Control Agency and Municipal Separate Storm Sewer System (MS4) permits. While karst is not explicitly covered in state permits, it may influence decisions on stormwater BMP locations, especially where groundwater contamination is a concern.
- Minnesota has over 40 watershed districts, each with its own specific rules that MnDOT must comply with, though these guidelines do not specifically address karst.

Studies or Modeling:

Lack of Modeling Guidelines or Standard:

- MnDOT utilizes various models but faces challenge due to the complexities involved in modeling karst areas, which are prevalent in certain regions of Minnesota.
- There are no formal guidelines or standards for H&H modeling in karst areas, which leads engineers to rely on personal judgment when selecting models. This raises concerns about potential underestimation or overestimation of peak flows, timing, and volumes. For example, in Minnesota's southeast region (District 6), where karst features like sinkholes are more prevalent, H&H practices have been modified to manage runoff without oversizing infrastructure like culverts. However, these adaptations lack formal guidance or model calibration.
- Most practices involve comparing pre- and post-development runoff conditions, without conducting in-depth studies on karst-specific H&H modeling.
- The Department of Natural Resources focuses more on landscape and habitat impacts rather than formal H&H modeling in karst regions.
- It is generally advised not to use karst features, such as sinkholes, for runoff storage due to the maintenance problems they often cause, unless they are properly lined and packed.
- MnDOT has worked on specific projects, such as at the Rapidan Dam site, where understanding rock formation behavior under flowing water was crucial. However, these instances are more about addressing rock competency than routine H&H modeling in karst.

Reasons for Issues with Lack of Modeling Guidelines or Standard:

- The lack of national or state-level guidelines for karst areas might stem from the site-specific nature of these issues, making it challenging to develop high-level or general standards.
- There has not been a deep dive into examining different practices, and the approach has generally been to avoid placing infrastructure like treatment systems in karst areas.
- The USGS regression equations sometimes factor in storage and nearby streams, and it is possible that karst landscapes or pothole areas are indirectly included in these models, although this is uncertain.

- It would be beneficial to explore whether existing models or guidelines could be adjusted to account for karst-related features when designing new culverts or infrastructure, ensuring that they are not oversized and possibly taking advantage of natural storage features.
- Additionally, there may be changes in karst features if concentrated water flows or development are introduced to these areas, suggesting a need to understand potential impacts better.

Adequacy of H&H Models:

- MnDOT primarily uses StreamStats for hydrologic and hydraulic (H&H) studies, particularly to obtain flow rates when there is insufficient gauge data. A recent update to their regression equations was made, but there is no clear indication that karst features were specifically considered in that update. Local USGS offices may have more detailed information about karst considerations, but nothing related to karst has been a major focus in MnDOT's current practices.
- MnDOT expresses a subjective confidence in their modeling approach. They primarily use the rational method for estimating flows in main streets and ditches, while employing more advanced models like USGS, XP SWMM, and HydroCAD for larger waterways and culverts.
- The effectiveness of the models is contingent upon the calibration process with known reference data. They acknowledge that models can only be as accurate as the data used to calibrate them.
- MnDOT is currently focusing on resiliency and understanding how future trends in hydrology may impact existing infrastructure. They express concerns about how increased flow may interact with karst features and potentially lead to issues like sinkholes.
- There is uncertainty regarding how karst affects their models, especially in relation to storage capabilities and how future water flow increases might influence the landscape. They note that the lack of clear understanding about karst interactions means they cannot definitively state whether their models are adequate for those specific conditions.
- Overall, MnDOT feels their modeling is "more or less adequate", but they recognize that significant gaps remain in understanding karst-related dynamics and future hydrological changes.

Adequacy of Data:

- MnDOT has access to high-quality LiDAR data and numerous GIS layers that help characterize surface features and roughness, which are essential for model calibration.
- They perform extensive bathymetric surveys and have partnerships with USGS and private firms to obtain the necessary data for complex modeling, particularly for larger waterways.

- While they have good gauge information for larger river systems (e.g., near the Red River), smaller tributaries often lack adequate stream gauges. This is particularly evident in karst areas, where slopes can be steeper, leading to more rapid changes in water levels.
- To address the gaps in gauge data, MnDOT is exploring the development of low-cost sensors to record water surface elevations. They aim to use synthetic rating curves to enhance understanding of water dynamics.
- Focus on Resiliency: Their efforts are geared toward improving resilience to flooding and understanding the impacts of water on infrastructure, indicating a need for more comprehensive data collection and modeling capabilities.
- MnDOT is considering the establishment of a flood center, similar to Iowa's, and is interested in leveraging advanced technologies from states like Texas for inundation mapping and event forecasting, particularly in areas that are vulnerable to both flooding and karst-related issues.

Reasons for Lack of Capable Models in Karst Areas:

- Diverse Interests: There is significant interest from various stakeholders, but these interests often differ. Each group may prioritize different modeling objectives, leading to fragmented efforts rather than a unified approach.
- Model Variability: Many agencies, including MnDOT and the Department of Natural Resources (DNR), are developing their own models independently. This variability can result in a lack of consistency and sharing of methodologies, which complicates collaboration.
- Complexity of the Problem: The challenges associated with modeling in karst areas are inherently complex, which may deter some stakeholders from engaging deeply with the issue. Existing models from past decades may require significant updates and corrections.
- Funding Limitations: There is a perpetual struggle for funding in government projects. While there are ongoing efforts to secure specific drainage funding, including improvements to stream gauges, budget constraints hinder comprehensive modeling initiatives.
- Need for Modernization: Existing floodplain maps and modeling techniques are outdated and require modernization. The complexity of karst landscapes further necessitates the development of more sophisticated and rigorous models.
- Collaborative Efforts: Despite the challenges, there is a recognition of the need to foster collaboration among various stakeholders to enhance modeling efforts and address the complex hydrological dynamics in karst areas.

MnDOT's Approach to Mapping Karst Areas

MnDOT actively maps areas susceptible to karst-related issues during environmental documentation and project scoping, identifying potential challenges with infiltration and related projects. The southeastern part of Minnesota, with its significant carbonate rock and exposed bluffs, is a primary area of concern for karst issues. While MnDOT has internal applications for accessing karst data, they also use publicly available sources from the DNR and the University of Minnesota for mapping and assessments. To ensure the quality of riprap materials, particularly limestone, MnDOT evaluates the carbonate content of quarry sources for durability. Additionally, to address potential particle size issues, the agency is exploring advanced photo analysis software for quality assurance and control. Finally, assumptions made in hydrology and hydraulics (H&H) modeling regarding riprap size and roughness must consider the longevity of the materials, ensuring that riprap does not degrade over time due to karst conditions.

C.3.3.3. Interview with New Mexico DOT Professional

Introduction and Personal Experience

The interviewee is a registered engineer at the New Mexico Department of Transportation (NMDOT) Drainage Design Bureau, with several decades of experience in hydrology and hydraulics. In their practice, they face challenges related to the design of roads, bridges, and drainage systems in arid regions, playa lakes and karst areas.

Guidelines or Standards

Playa Lakes

- NMDOT is focusing on managing playas as inland seas, effectively removing them from drainage areas as there is no guidelines or standards for design infrastructure in these areas.
  - In the southwest, playas pose dust control challenges, whereas playas in the eastern part mainly cause ponding issues, with around 80% grass cover. There have been accidents along Interstate 10, which runs near several playas close to the Arizona border. New Mexico's Environmental Bureau recommends planting grasses near the interstate, though much of the land is privately owned.
- Playas are often overgrazed resulting in change in runoff.
- NMDOT drainage section has mainly focused on designing culverts for equalization rather than comprehensive management strategies.

Arid Regions

- New Mexico features two types of arid areas: mountainous regions and flatlands in the eastern part of the state. The eastern region often experiences high flow rates (Q's), prompting modifications in project designs.
- Traditionally, the Kirpich equation was used for flow calculations, but the Lag Time equation is now being implemented to yield more reasonable Q estimates.
  - Current flow calculations are being compared against USGS regression equations.

Karst Zones

- New Mexico currently lacks state standards for karst and is unaware of any national standards in the United States. Previous inquiries to TxDOT regarding hydrology in flat areas and karst yielded no useful insights. The focus on karst considerations is growing, especially in Eastern New Mexico projects.

Studies or Modeling

Playa Lakes

- NMDOT consultants perform hydraulic and hydrologic analyses to assess playa storage capacity using HECHMS.
- Current analyses utilize the 30-m USGS DEM, while available Lidar data has not yet been applied to large watersheds due to high computational demands

Arid Areas

- The eastern part of New Mexico lacks stream gauges, making hydrological measurement challenging due to the absence of rivers.
- In ongoing projects, the Lag Time equation helps bring flow estimates in line with observed storm events and local flooding history.

Karst Zones

- NMDOT is starting to address challenges related to karst areas, primarily in Southeastern New Mexico. This initiative began approximately five years ago, prompted by a project in Jal, New Mexico.
- For a current project on US 380, consultants agreed to adopt a methodology from Virginia, which included a table detailing the percentage of karst based on information from the Virginia Department of Conservation and Recreation.

Adequacy of Data

- There is a concern that sufficient data may not be available for model calibration.
- There is a need for more data to validate flow calculations, particularly given that professionals may not have experienced significant flooding during their tenure, despite high calculated Q values.
- Nexrad data has been considered by NMDOT for hydrological analysis, particularly for forensic purposes following significant storms. This data helps estimate rainfall depth in flooded areas, although it is often used in conjunction with existing gauge data. The most commonly used gauge for validation is the Cucuro gauge, which may not always be available.

- The approach taken involves indirectly determining water production and resulting flow through available rainfall data and gauges.

<u>*Reasons for Lack of Models, Guideline and Standard*</u>

- Much of the foundational research was conducted in the 1950s through the 1970s when the federal government invested significantly in environmental studies.
- Current funding priorities have shifted, resulting in decreased financial support for playa lake research. As a result, practitioners are often reliant on outdated data and methodologies, hindering progress in developing updated standards and guidelines.

C.3.3.4. Interview with Virginia DOT Professional

<u>Introduction and Personal Experience</u>

The interviewee is a State Hydraulics Engineer at the Virginia Department of Transportation (VDOT) with extensive experience in water resource management, stormwater management, and hydraulic and hydrology studies. They encounter challenges in designing stormwater systems specifically in *karst areas*.

<u>Guidelines or Standards</u>

- VDOT drainage manual include some sections on karst, however the Virginia Department of Environmental Quality (DEQ) recently updated its regulations incorporating new information on karst areas.
- The DEQ has combined several manuals, including the Stormwater Management Handbook, the Erosion and Sedimentation Control Handbook, and the Drainage Manual, into one comprehensive manual.
- The new regulations include updated requirements for the general construction permit and an updated drainage manual. Chapters 10 and 11 of the drainage manual, focusing on erosion and sediment control and stormwater management respectively, will be rewritten to comply with the new regulations. New slip requirements have been introduced due to contractors improperly releasing dewatering facilities, leading to the discharge of suspended solids into runoff. Turbidity monitoring and testing are now mandated as part of the updated regulations.
- Current practices mostly involve registering with the Environmental Protection Agency (EPA) when sinkholes are used as outfalls, categorizing them as injection wells. This process avoids the need for detailed hydrological models or specific guidelines related to karst formations.
- Despite the absence of formal guidelines, the discussion pointed out VDOT's avoidance strategy, which primarily focuses on steering clear of karst areas due to their complexity and cost implications. When karst areas are unavoidable, additional measures, such as bio-

retention systems upstream of sinkholes, are implemented to improve the water quality before it enters the sinkhole.

- VDOT does not have any guidelines for designing a bridge, road, or culvert in karst area

Studies or Modeling

Avoidance Strategy and Challenges

- VDOT's primary strategy is avoiding karst areas in their projects, due to the cost-effectiveness and simplicity of this approach.
- When karst areas are unavoidable, VDOT registers with the EPA when using sinkholes as outfalls. In some cases, like those involving protected species, additional measures like bio-retention systems upstream are implemented to improve water quality before it enters a karst sinkhole.

Project Examples and Modeling

- A specific example was where VDOT had to manage runoff for a 700-acre watershed drained into a sinkhole, and redirecting the flow was too costly. Since the sinkhole housed a federally protected species, requiring approval from federal wildlife agencies, the project involved improving the quality of runoff through bio-retention without touching the sinkhole itself due to cost and environmental concerns. The project enhanced the runoff without altering the sinkhole itself, unlike other cases where the solution often involves filling and stabilizing the karst area.
- The team did not model the sinkhole's flow since there was no sign of problem, such as erosion, scouring, or marsh formation. The sinkhole appeared to handle the drainage effectively without causing any issues. Upstream of the sinkhole, a bioretention system was installed to improve the quality of runoff. Typically, karst areas are backfilled and stabilized by district teams, but in this case, no such intervention was required.

Needs for Modeling and Guideline for Karst Area

- The lack of specific modeling or guidelines for dealing with karst areas in VDOT's projects, indicate a broader issue of limited interest or resources for developing such models or guidelines.
- The interviewee suggests that a guideline for sinkhole management might only be necessary if engineers are redirecting or adding flow to a sinkhole. Their team typically maintains the same flow levels and uses sinkholes as outfalls without increasing the drainage into them. In cases where flow is redirected or altered, additional considerations might be needed, especially if a protected species is present or if registration with the EPA as an "injection

well" is required. However, since they have not added flow to a sinkhole before, they don't feel a need for extensive guidelines under current practices.

- VDOT approach for calculating stormwater runoff in karts area typically involves determining the time of concentration. Once the time of concentration is established, rainfall intensity data specific to the area is used to calculate the peak runoff (Q), which is essential for designing.
- Scientific Interest: The conversation touched on the role of scientific interest in driving the development of models and guidelines, with potential for future research if significant issues arise or funding becomes available.
- FHWA's Role: The possibility of the Federal Highway Administration (FHWA) providing funding for research into karst areas was considered, highlighting the agency's potential influence on the development of new models and guidelines.

C.3.3.5. Interview with the University Researcher #1 (Former TxDOT Engineer)

<u>Introduction and Personal Experience</u>

The interviewee has a diverse background that includes experience as a former TxDOT engineer, university faculty, and consultant with several decades of research and practical experience in hydrology of arid regions, playa lakes, and karst zones.

An expert with over two decades of experience at the Texas Department of Transportation (TxDOT), this individual began their career in 1988, serving in the Amarillo District, specifically in the Pampa Area Office. During the first nine years, they were involved in design and construction project management in the unique playa lake terrain of the Texas Panhandle and South Plains, an arid region with approximately 18 inches of mean annual precipitation. Later, they moved to the San Angelo District, which covers areas on the western edge of the Edwards Plateau, also known for its karst terrain. Their work spanned from the Eden, TX area to the Pecos River, and they gained significant experience in hydrologic challenges related to both arid regions and karst environments. After retiring from TxDOT, they completed a PhD and went on to teach hydrology, water systems, and graduate statistics at Texas Tech for about seven years. They now work as a consultant, bringing their expertise in playa lakes and karst hydrology to various projects.

<u>Guidelines and Standards</u>

Current guidelines and standards fail to address challenges specific to playa lakes, karst zones, and arid regions due to several key factors:

- In many states, there is insufficient emphasis on robust hydrology practices, particularly in areas with less frequent rainfall. States with more rainfall tend to prioritize hydrology more, while arid regions often overlook its importance.
- One challenge is that hydrology is seen as a different and complex science that many avoid.

- Additionally, hydrological approaches that work in one region, like Houston, are not suitable for others, like El Paso, due to vastly different rainfall patterns. Texas exemplifies this diversity, with mean annual precipitation ranging from over 60 inches in Port Arthur to less than 10 inches in El Paso, making it difficult to apply uniform policies across the state.

Studies or Modeling:

Playa Lakes

- One challenge we encounter is the perception of probability in relation to events like flooding from playa lakes. Typically, when discussing probability and statistics, we assume that occurrences are randomly distributed. However, the behavior of playa lakes is not random. During a wet year, multiple rainstorms may occur, sometimes leading to two or three consecutive wet years. This is when playas become problematic, as they can overflow and block roadways. For instance, a playa south of Tahoka in the Lubbock District has repeatedly flooded US 87, causing prolonged road closures. Statistically, one might think the likelihood of such flooding is low, but it happens due to the cyclical nature of wet and dry periods. In arid regions, these wet episodes often alternate with extended dry spells, making flooding events particularly impactful during wet years.
- To gain meaningful insights about playas, it would be beneficial to analyze periods of consecutive wet years, perhaps two or three in a row, rather than focusing on drought years, which are less relevant. Identifying wet episodes is crucial; for example, the monthly rainfall data for Lubbock clearly indicates unusually wet years or months. Specifically, examining rainfall patterns in September and May, two months that tend to cause issues, could provide valuable information. Rainfall patterns do not consistently correlate with phenomena like El Niño or La Niña, nor with other global climate cycles. However, one can generate a 24-month running sum of rainfall data to identify significant peaks that warrant further investigation. Additionally, utilizing NOAA Atlas 14 allows us to access rainfall depth data for periods up to 60 days, which is a significant improvement over previous data that typically only covered up to seven days. With these enhanced tools, we have the opportunity to conduct more in-depth analyses if there is a commitment to do so.
- There is also a significant flaw in our logic: we often assume that events are randomly distributed when, in reality, they exhibit serial correlation. They closely resemble a Markov chain, where today's events are heavily influenced by yesterday's occurrences. For instance, tomorrow's weather is not random; it is directly related to today's conditions. This is a critical factor that is often overlooked in our analyses. Recognizing this interdependence represents a shift in thinking and poses a greater challenge in our understanding and modeling of hydrological events.
- Unlike in some other parts of the world, Texas playas typically do not overflow, as most lack outlets, though some may connect to others. These playas have high retention rates due to thick layers of clay at the bottom, which limits runoff. About half of the water in playas

evaporates, while the other half infiltrates. In Lubbock, many playas were deepened in the 1970s and 80s to increase volume, cutting through clay layers and allowing water to infiltrate down to the Ogallala Aquifer. This caused some dry playas to become water table lakes, with constant water levels, even flooding areas like South Plains Mall. To manage this, Lubbock built conduits connecting multiple playas, eventually draining water into Yellow House Canyon. These structures and conduits were constructed in the early 2000s and can be seen at various lakes in the parks.

Arid Regions

- Initial Abstraction in SCS Curve Number Method: The standard method considers 20% (0.2S) of initial abstraction; however, this may not hold true for curve numbers below 70, as 0.2S can become disproportionately large.
- Lambda Concept: The ASCE publication "Curve Number Hydrology" discusses the initial abstraction ratio, referred to as Lambda, and highlights the need to adjust curve numbers when changing this ratio. In arid regions, initial abstraction can be excessively large, leading to minimal runoff from rainfall events, which indicates the necessity for more precise adjustment in curve numbers.
- Recommendation for Formalization: It is suggested that further research and formalization of initial abstraction processes and related rules are needed, particularly for arid lands.
- Climatic Adjustment of Curve Numbers: A study by Dave Thompson, sponsored by researchers, emphasizes the need to reduce the curve numbers as one moves westward in Texas. The publication includes equations for converting curve numbers based on varying initial abstraction ratios, specifically recommending a ratio of 0.05S for arid areas.

Karst Zones

- Karst hydrology presents unique challenges for highway engineering and risk-based hydrology due to unpredictable water movement. Water may disappear into the karst environment, which can be beneficial as it goes underground; however, it can also re-emerge unexpectedly in problematic locations.
- Traditional assumptions about watersheds, where only precipitation within the boundaries contributes to outlets, do not hold in karst environments, complicating predictions. In karst regions, water may traverse topographic watershed boundaries, making hydrological predictions more difficult.
- Engineers are encouraged to observe project areas during rainstorms to understand real-world water behavior and validate expectations. By comparing stream geomorphology to topographic watersheds, engineers can identify whether water levels are higher than anticipated, indicating additional flow sources.
- Engineers often overestimate watershed flow, leading to oversized drainage structures, which can waste resources. This principle encourages conservative estimates, but it can result

in unnecessary expenditure on infrastructure. Many existing structures, often over 60 years old, may not require replacement with equally large structures, despite their age. Replacement of drainage structures is expensive, and there is resistance to downsizing, which could save money. Understanding geomorphology is essential for accurate hydrological assessments; engineers should critically evaluate whether proposed structures are truly necessary based on the actual stream channel width.

Need for National Guidelines

- There is a need for a national guideline and standard for these challenging areas. Historical hydrology studies predominantly focused on the eastern seaboard of the U.S., leading to a lack of relevant data, especially for arid regions. The need for increased funding for studies in arid lands is critical due to limited available data, which often results in underestimating their hydrological significance.
- Wetter areas typically see a more moderate increase (~5 times) in discharge between return periods (e.g., 100-year vs. 10-year floods), while arid areas exhibit steeper flood frequency curves, showing larger differences in discharge (up to 20-30 times) during intense rainfall events. Intense rainfall in arid areas leads to significantly higher discharges compared to wetter regions.
- The importance of conducting further research to understand these patterns better, including an analysis of discharge variability and the influence of climatic factors.

Incorporating Risk in Design Guidelines

- In bridge or culvert design, engineers often focus on design discharge events and check against the 100-year flood out of habit, without fully considering the actual consequences. It is essential to think ahead about potential damages, such as prolonged road closures, and consider what can happen when infrastructure is overtopped by floods. Site visits often reveal instances where overtopping led to damage, which could have been mitigated with proper planning.
- Engineers should aim to control the type of damage, ensuring that infrastructure like embankments can be repaired quickly, while more critical elements, such as bridges, are preserved. Addressing these considerations requires a balance of hydrological understanding and sound policy decisions, as simplistic hydrological approaches can lead to flawed policy outcomes.

C.3.3.6. Interview with the University Researcher #2

Introduction and Personal Experience

The interviewee is a retired professor from Texas Tech University (retired in 2022, currently serving as a part-time instructor) with a background in civil engineering and water resources, along with extensive expertise in hydrology, groundwater studies, and playa lakes. Their consulting work, which spans many years, has primarily focused on the interactions between groundwater and surface water in arid regions, particularly in West Texas. They have significant experience in groundwater modeling and aquifer recharge, especially regarding playa lakes. Their research has addressed challenges related to suspended solids that impede recharge systems and has involved collaboration with USDA and ARS to monitor water infiltration and evaporation, resulting in published findings in the Texas Water Tunnel. Additionally, with over 13 years collaboration with the Texas State Soil and Water Conservation Board, they have concentrated on brush control programs to enhance water yield in watersheds and have conducted ecohydrological modeling to assess the impacts of invasive woody plants on hydrological cycles, particularly in karst areas like Medina County.

Guidelines and Standards

The interviewee acknowledges their limited familiarity with design guidance as a university professor and emphasizes that arid regions in Texas are unavoidable since they encompass a significant portion of the state. However, they highlight the necessity of avoiding development around playas and karst formations. They stress the importance of exercising caution and finding alternative routes to bypass these sensitive areas.

Studies and Modeling

Typical characteristics of playa basins and the associated challenges include:

- *Topography*: Playa basins in Texas generally exhibit an elevation difference of around 6 to 20 feet from the playa floor to the edges of the surrounding catchment areas. Under natural conditions, the topography helps delineate where water flows and pools within the playas.
- *Soil Characteristics*: The playa floor is typically identified by Randall clay, a soil type widely recognized in soil surveys. In areas where the surrounding soils have been disturbed through agricultural activities, such as cultivation, these soils can erode and flow into the playa basin, filling it with sediments. This accumulation can reduce the playa's capacity to hold water, impacting its function as a wildlife habitat.
- *Sediment Impact*: While the sedimentation may be detrimental to wildlife by reducing water retention, it may improve groundwater recharge. If the incoming sediments are sandier than the Randall clay, they can fill desiccation cracks and create more permeable pathways for water to infiltrate the aquifer.
- *Hydrological Challenges*: Playas can retain water for extended periods compared to streams, which presents challenges for construction, particularly for highways and infrastructure. The interviewee cited examples of roadways built through playas that were prone to frequent inundation until engineers raised the road level.
- *Construction Considerations*: The interviewee emphasized that it is generally best to avoid constructing through playas due to the natural tendency of water to accumulate in these areas, leading to potential long-term maintenance and repair challenges. Additionally, variations in soil composition within the playa could complicate construction efforts.

- *Dust Issues*: The majority of dust in the region comes from land areas surrounding the playa lakes, rather than the playas themselves. In the Southern High Plains, there is approximately one playa lake per square mile, but these lakes typically cover less than 100 acres of the 640 acres in a section.
- *Erosion Control Measures*: Although natural wind erosion cannot be completely eliminated, practices such as no-till cultivation are being implemented to help stabilize the soil and reduce dust storms. Leaving plant residues on the surface helps hold soil in place, potentially leading to a decrease in the frequency and intensity of dust storms over time.
- *Comparison to Other Regions*: The interviewee cautioned against directly comparing dust issues in the High Plains of Texas to those in the Middle East due to significant differences in soil types and environmental conditions.
- *Salt Issues:*
    - *Limited Saline Playas*: In the High Plains, salt issues related to playas are minimal. While there are fewer than 50 saline playas among the 22,000 identified in the region, most playas primarily receive water from surface runoff rather than groundwater.
    - *Salinity in Other Regions*: The interviewee mentioned that saline playas, such as those found in Saudi Arabia, often have a different hydrological regime. These playas may receive water directly from aquifers, leading to significant salt accumulation over thousands of years. This contrasts with the High Plains playas, which do not contribute to salt issues in the same way.
- *Flow Estimation In playas*

  The analysis of flow in playas typically involves considering how watersheds contribute to streams, but playas often act as dead ends with no outlet. In rural areas, significant rainfall is needed for playa basins to overflow into adjacent ones, whereas urban areas may experience different dynamics. Roadways represent a small portion of the overall area, which means their runoff characteristics (e.g., high curve numbers indicating all water runs off) have minimal impact on the playa's water balance. However, roads that intersect playa basins require infrastructure, such as bridges and culverts, to facilitate water flow from upstream areas to the playa.

C.3.3.7. Interview with a Consultant

<u>Introduction and Personal Experience</u>

The interviewee is the Hydrology and Hydraulics Division Manager at a consulting firm, with over 30 years of experience in water resource engineering and management. Their expertise spans large-scale local, regional, national, and international projects. Core competencies include hydraulic engineering, watershed and river basin hydrology, and water resources management. They have recently authored a comprehensive book on applied hydrology and are currently working on another book on applied hydraulics. The interviewee has worked on several projects in arid regions, and playa lakes

Guidelines or Standards

While the FHWA has some publications, there are limited guidelines on hydrology or hydraulics for arid regions, leading them to rely on their own expertise and justifications in their work. In Texas, there is no specific guidelines for hydrological practices in arid regions, such as those used in TXDOT projects. The common methods, like the Curve Number method for unit hydrographs in the DFW area and Clark's unit hydrograph in Houston, may not be suitable for arid regions. Drawing from their experience, the interviewee prefers using the kinematic wave model, particularly in places like Odessa, and has successfully justified this choice to clients. They acknowledge that

Studies and Modeling

Arid Area

- *Kinematic wave model*: An investigation for the EPA into a severe storm and devastating flood in Las Cruces, New Mexico, in 2000 showed that the kinematic wave model was more effective than other models for calculating runoff in arid areas.
- *Sediment Transport*: Sediment transport is one of the biggest challenges in arid region hydrology due to the lack of vegetation. During short, high-intensity rainfall events, significant amounts of sediment are carried by the water, often causing more damage than the water itself. In one project in Odessa, Texas, it was discovered that oversized culverts, improperly modeled, led to the formation of standing waves and hydraulic jumps. This resulted in sediment deposition, with unsorted materials ranging from boulders to fine sand accumulating in front of the culverts. Properly addressing sediment transport is critical in arid region hydrology, alongside rainfall-runoff considerations.
- *Sediment Transport Modeling*: HEC-HMS has integrated an erosion and sedimentation module, allowing for 2D modeling of overland flow and enabling the calculation of erosion potential. The models developed in HMS are effective for sediment erosion and sedimentation. Conversely, HEC-RAS primarily focuses on riverine systems, making it more suitable for sediment transport within rivers or channels rather than overland flow scenarios. However, HEC-HMS excels in modeling sediment transport in overland flow and canals. The choice between HEC-HMS and HEC-RAS depends on the specific problem being addressed, and recent advancements have expanded modeling capabilities significantly compared to a few years ago.

Playa Lake

- *Delineation*: A significant challenge in playa lake studies is to accurately delineate flow paths around these playa lakes, emphasizing that while automated GIS tools can simplify area delineation, careful attention is necessary. The presence of highways complicates topography and divides flow, which can lead to errors in the delineation process. If proper due diligence is not taken, computations may misdirect flow, resulting in incorrect assessments of hydrological patterns. It is recommended that engineers conduct field visits to verify flow paths and assess drainage areas, especially in areas with playas. These field assessments are crucial for ensuring accurate modeling and understanding of the hydrological dynamics in such regions.

Data Gaps

The interviewee highlights a significant challenge in arid regions: the lack of data for model calibration. Unlike cities like Houston, Dallas, Austin, and San Antonio, which have abundant gauge data, arid areas mainly contain ephemeral streams that do not provide the same level of reliable data. In their work with the kinematic wave model, the interviewee overcame this gap by spending considerable time in the field, measuring sediment deposits and estimating water surface elevations to calibrate their model. They emphasize that many engineers may lack the experience or inclination to conduct fieldwork, preferring to work from the office instead.

Needs for Developing Guidelines

The interviewee emphasizes the necessity of developing comprehensive guidelines for hydraulic design, advocating for case studies that identify specific events to gather data. They suggest testing various methods to determine which yields the most realistic results in the absence of gauge data. The speaker critiques existing hydraulic manuals, for being too generic and lacking specific recommendations tailored to different situations. While acknowledging a guideline exists regarding drainage areas, they note that this rigid approach may not always be suitable, as some unique problems might require alternative methods. Ultimately, the speaker argues that any new guidelines should be based on thorough research and calibration rather than simply compiling standard criteria. The guidelines should reflect technological advancements, ensuring they are applicable to the methods employed by today's workforce.

CHAPTER C4: SUMMARY

A survey was conducted to evaluate current hydrological practices concerning playa lakes, arid areas, and karstic zones. The survey targeted 76 experts, including representatives from 30 state Departments of Transportation (DOTs), 13 university faculty members, 12 consultants, and 21 other entities (federal, state, cities, and local agencies). Ultimately, 24 responses were collected, providing valuable insights into the effectiveness of current guidelines and modeling approaches related to the hydrology of playa lakes, arid regions, and karst zones.

Additionally, the research team conducted follow-up interviews with select participants from the initial survey to gain deeper insights into hydrological practices in these areas. The interviews involved seven participants from the Departments of Transportation in Kansas, Minnesota, New Mexico, and Virginia, along with a researcher, a consultant, and an individual with diverse experience, including a background as a former TxDOT engineer and university faculty member.

The key insights from the survey and interviews are summarized in the following section.

C.4.1. Survey

The key insights from the survey, reflecting the perspectives of field experts, are summarized in the following section. This summary highlights the main findings on the effectiveness of current hydrological practices related to playa lakes, arid areas, and karstic zones, identifies gaps in knowledge, and suggests areas for further research and improvement.

- *Study Area Focus and Engagement*

  The survey revealed varying levels of engagement in studies across different geographic areas. Karstic zones garnered the most attention, with 42.4% of respondents involved in research. Arid regions followed with 27.3% engagement, while Playa Lakes received the least attention at 21.2%. These findings highlight a strong interest in understanding karstic zones and arid regions, while Playa Lakes remain a less explored area.

- *Information Sharing and Collaboration*

  Approximately 40% of respondents expressed a willingness to share documentation or resources related to identifying playa lakes, karstic zones, or arid regions. However, conditions like official requests or confidentiality restrictions may limit information sharing. This suggests a potential for collaboration and knowledge exchange, but strategies like direct contact and institutional requests may be necessary to access relevant resources.

- *Infrastructure Assets and Environmental Challenges*

  Infrastructure assets are prevalent in karstic zones (32.4%), followed by arid regions (29.7%) and playa lakes (21.6%). These findings highlight the importance of infrastructure resilience and risk management in these regions due to environmental challenges such as drought, flooding, and geological instability.

- *Hydrology and Hydraulic Studies*

  A significant portion of respondents (52%) have conducted hydrology and hydraulic studies in these areas, indicating a moderate level of expertise and documentation. Many expressed a willingness to share their reports, facilitating knowledge transfer. However, confidentiality restrictions and the absence of reports in some cases limit accessibility.

- *Expert Knowledge and Experience*

  A substantial majority of respondents (71.4%) have personal experience in hydrology and hydraulic studies, highlighting a strong foundation of expertise. However, a lack of expert referrals among those without personal experience indicates potential knowledge gaps and limited connections within the field.

- *Guidelines and Standards*

  Federal or state guidelines are used by a portion of respondents for hydrology and hydraulic studies in these regions. However, a significant number (34.4%) find them not applicable, suggesting the need for more tailored guidance. Many respondents believe that current guidelines are inadequate for infrastructure design, emphasizing the need for updates and revisions to address specific challenges.

- *Hydrology Studies and Modeling*

  The focus of hydrology studies varies, with a notable emphasis on arid regions and a more specialized interest in karstic zones and playa lakes. The validation of hydrological models primarily relies on hydrograph comparisons but also includes other techniques. However, a significant portion of respondents use "*Other*" methods or find the question not applicable, highlighting the need for tailored validation strategies.

- *Runoff Calculation Methodologies*

  The Rational Method, SCS Curve Number Method, and TR-55 Method are the most commonly used methodologies for calculating runoff. However, other techniques like HEC-HMS and the SCS Unit Hydrograph Method are also employed, reflecting the diversity of approaches used in these complex environments. The choice of methodology is influenced by factors such as accuracy, data availability, and specific study area characteristics

C.4.2. Follow-up Interviews

The key insights from the interviews, reflecting the perspectives of field experts, are summarized in the following section. This summary highlights the main findings on the effectiveness of current hydrological practices related to playa lakes, arid areas, and karstic zones. It identifies gaps in knowledge, reveals best practices, and suggests areas for further research and improvement.

Playa Lakes and Arid Regions

- *General Tools and Guidelines: USGS StreamStats and regression equations are used for estimating runoff in playa lakes and arid regions, but these tools are generalized and not specifically tailored for these unique environments.*
- *Inadequate Hydrological Models: Current methods, such as SCS (NRCS) Curve Number Method, often assume high initial abstractions, which do not reflect actual hydrological behavior, particularly in arid regions and playa lakes*
- *Soil Absorption: There is limited data on soil absorption rates, particularly in arid regions. General models like SCS often inaccurately estimate runoff, leading to skewed results*
- *DEM Data: The 30m USGS DEM data used for identifying and modeling playa lakes is too coarse necessitating better data like Lidar to accurately map and model these regions*
- *Rainfall Data: The lack of comprehensive rainfall data in arid zones impacts hydrological modeling and makes model calibration difficult.*
- *Retention Capacity: Playa lakes possess retention capacity, making overflow events rare. However, past projects have inadvertently caused issues such as groundwater infiltration, highlighting the need for specific guidelines.*
- *Urban Development: In urban areas, such as Lubbock and Amarillo, overflow between playa lakes due to urban development poses challenges, leading to drainage solutions.*
- *Flash Flooding: Arid regions often experience flashier hydrological events, but current tools overestimate runoff, which leads to overbuilt infrastructure.*
- *Need for Research: Further research and funding are essential for improving models in arid regions, particularly to refine the understanding of sediment transport and rainfall clustering patterns.*

– *Karst Regions*

- *Lack of Standardization: There are no comprehensive guidelines addressing karst regions. Engineers rely on geotechnical teams to assess hydrological risks like sinkholes and unpredictable water flow.*
- *Avoidance Strategy: Some DOTs, such as Virginia DOT, adopt an avoidance strategy due to the complexity of karst regions. When construction is unavoidable, mitigation measures are implemented. A principle in karst regions is to avoid development due to the unpredictability of water movement underground*
- *Data Gaps: Hydrological models for karst systems are particularly weak due to the unpredictable nature of water flow through springs and sinkholes. Insufficient data makes accurate modeling difficult, and reliance on local knowledge*
- *Limited Guidelines and Models: There is a lack of detailed, actionable guidelines and comprehensive hydrological models for karst regions. Most hydrological tools fail to account for the underground water movement typical of karst landscapes*
- *Unpredictable Hydrology: Karst areas present a hydrological challenge because water flows unpredictably through underground systems, making traditional watershed models inadequate*

APPENDIX C SUPPLEMENTAL MATERIALS

Letter of Invitation and Survey Questionnaire

Survey on Hydrologic Approaches to Playa Lakes, Areas of Significant Karst Geology, and Arid Regions

You are invited to participate in our survey for Hydrologic Approaches to Playa Lakes, Areas of Significant Karst Geology, and Arid Regions. It will take approximately 30 minutes to complete the questionnaire. Your participation in this study is completely voluntary. There are no foreseeable risks associated with this project. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point. It is very important for us to learn your opinions, knowledge, and recommendations about the current situation of H&H design in Playa Lakes, Areas of Significant Karst Geology, and Arid Regions. Your survey responses will be strictly confidential and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential. If you have questions at any time about the survey or the procedures, you may contact Dr. Habib Ahmari and/or Dr. Saman Baharvand by email at the email address specified below.

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Please add your name and contact information

Name:

Email:

Organization:

Location

1. ***Please check below if your institution/company is engaged in work or research in the areas of Playa Lakes, arid regions, and karstic zones.***

☐	Playa lakes
☐	Arid regions
☐	Karstic zones
☐	Not Applicable (N/A)

2. ***What are the methods that you or your institution/company use to identify the Playa Lake location?***

☐	Remote sensing	☐	Historical Hydrological Analysis (e.g., analysis of precipitation patterns and runoff characteristics to identify potential playa lakes, etc.)
☐	LIDAR	☐	Topographic Maps
☐	Drones, UAVs	☐	Field Surveys and Ground Truthing
☐	Soil and Ground Depression Surveys	☐	Geophysical Methods
☐	Others		
☐	Not Applicable (N/A)		
Please explain if "others" is selected:			

3. ***What are the methods that you or your institution/company use to identify Karstic zones?***

☐	Geological Mapping	☐	Hydrogeological Surveys (e.g., dye tracing, etc.)
☐	Remote Sensing	☐	Borehole Logging
☐	LIDAR	☐	Geophysical Methods
☐	Topographic Maps	☐	Karst Inventories and database
☐	Hydrochemical Analysis	☐	Field Observations
☐	Others		
☐	Not Applicable (N/A)		
Please explain if "others" is selected:			

4. ***What are the methods that you or your institution/company use to identify and classify arid regions?***

☐	Remote Sensing and Satellite Data	☐	Global Classification Systems (e.g., Köppen Climate Classification)
☐	Drought or Aridity Indices	☐	Climatology and Meteorological Data Analysis
☐	Drones Imageries	☐	Others
☐	Not Applicable (N/A)		
Please explain if "others" is selected:			

5. ***Would it be possible to share documentation/manuals/resources that you and/or your company/institution use to identify Playa lakes/karstic zones/arid regions?***

☐ Yes, will share
☐ Yes, upon official request
☐ Not sure
☐ No
☐ Not Applicable (N/A)

Infrastructure Design and Damages

6. ***Does your institution/company have infrastructure assets in Playa lakes, arid regions, and karstic zones?***

<table>
<tr><td>☐</td><td colspan="2">Yes (Please select one or all that are applicable)</td><td colspan="2">If yes, what type of infrastructure?</td></tr>
<tr><td></td><td>☐</td><td>Playa lakes</td><td>☐</td><td>Roadway</td></tr>
<tr><td></td><td>☐</td><td>Arid regions</td><td>☐</td><td>Railways</td></tr>
<tr><td></td><td>☐</td><td>Karstic zones</td><td>☐</td><td>Bridges</td></tr>
<tr><td rowspan="4"></td><td rowspan="4">☐</td><td rowspan="4">None of the above</td><td>☐</td><td>Aviation and airport</td></tr>
<tr><td>☐</td><td>Soft infrastructures (banks, schools, colleges, hospitals, etc.)</td></tr>
<tr><td>☐</td><td>Other(s)</td></tr>
<tr><td colspan="2">Specify:</td></tr>
<tr><td>☐</td><td colspan="4">Not aware of and not aware of anyone for referral to help</td></tr>
<tr><td>☐</td><td colspan="4">Not aware of but I can refer you to:</td></tr>
<tr><td></td><td colspan="4">Name:</td></tr>
<tr><td></td><td colspan="4">Title:</td></tr>
<tr><td></td><td colspan="4">Email:</td></tr>
<tr><td></td><td colspan="4">Phone:</td></tr>
<tr><td>☐</td><td colspan="4">Not Applicable (N/A)</td></tr>
</table>

7. ***Do you have any specific Hydrology & Hydraulic study reports or design considerations for the design of infrastructures in playa lakes, arid regions, and/or karstic zones? If yes, would it be possible to share any reports or design considerations?***

☐	Yes, will share
☐	Yes, upon official request
☐	Not sure
☐	No
☐	Not applicable (N/A)

8. ***Have you or your institution/company encountered or are aware of cases where infrastructures were damaged (partially or completely) due to the lack of proper design guidelines or standards for Playa lakes?***

☐	Yes, our institution/company has experienced infrastructure damage due to the lack of proper design guidelines or standards.
☐	No, our institution/company has not encountered any cases of infrastructure damage related to the lack of design guidelines or standards.
☐	We are not aware of any infrastructure damage incidents in our institution/company due to the lack of proper design guidelines or standards.
☐	Infrastructure damage incidents have occurred, but the cause is not related to the lack of design guidelines or standards.
☐	Not applicable

9. If your answer to the previous question was "yes", what was the reason(s)?

☐	Uncertain Hydrology/Hydraulic methodology
☐	Limited and/or low-quality data collection (e.g., topography, lake storage area, remote sensing data, groundwater and gauge monitoring, soil characteristics, etc.)
☐	Capability of model to consider Playa Lakes physical properties (e.g., storage area calculation, temporal infiltration estimation, recharge consideration, etc.)
☐	Uncertain geology investigation (e.g., failure to consider subsurface heterogeneity)
☐	Disregarding future considerations (e.g., anthropogenic and climate change impacts, etc)
☐	Disregarding dynamic modeling to simulate transient conditions (dynamic relationship between precipitation, evaporation, runoff, groundwater interaction, lake response, etc.)
☐	Disregarding the spatial and temporal variabilities of effective parameters (e.g., precipitation, temperature, infiltration, sedimentation and bathymetry changes)
☐	Failure to consider groundwater interaction
☐	Insufficient validation and calibration
☐	Other(s), Please specify:

10. Have you or your institution/company encountered or are aware of cases where infrastructures were damaged (partially or completely) due to the lack of proper design guidelines or standards for Karstic areas?

☐	Yes, our institution/company has experienced infrastructure damage due to the lack of proper design guidelines or standards.
☐	No, our institution/company has not encountered any cases of infrastructure damage related to the lack of design guidelines or standards.
☐	We are not aware of any infrastructure damage incidents in our institution/company due to the lack of proper design guidelines or standards.
☐	Infrastructure damage incidents have occurred, but the cause is not related to the lack of design guidelines or standards.
☐	Not applicable

11. If your answer to the previous question was "yes", what was the reason(s)?

☐	Uncertain Hydrology/Hydraulic methodology
☐	Limited and/or low-quality data collection (e.g., topography, remote sensing data, groundwater and gauge monitoring, soil characteristics, sinkholes and bedrock characteristics, etc.)
☐	Capability of the model to consider karstic zones physical properties (complexity of flow paths, conduit flow (groundwater) recharge consideration, heterogeneity, and the dynamic nature of conduits., etc.)
☐	Uncertain geology investigation (e.g., failure to consider subsurface heterogeneity and subsidence probability)
☐	Disregarding future considerations (e.g., anthropogenic and climate change impacts, etc.)
☐	Disregarding dynamic modeling to simulate transient conditions (dynamic relationship between precipitation, evaporation, runoff, groundwater interaction and flow modeling, etc.)
☐	Disregarding the spatial and temporal variabilities of effective parameters (e.g., precipitation, temperature, infiltration, sedimentation and bathymetry changes)
☐	Failure to consider groundwater interaction
☐	Insufficient validation and calibration
☐	Other(s), Please specify:

12. ***Have you or your institution/company encountered or are aware of cases where infrastructure was damaged (partially or completely) due to the lack of proper design guidelines or standards for Arid regions?***

☐	Yes, our institution/company has experienced infrastructure damage due to the lack of proper design guidelines or standards.
☐	No, our institution/company has not encountered any cases of infrastructure damage related to the lack of design guidelines or standards.
☐	We are not aware of any infrastructure damage incidents in our institution/company due to the lack of proper design guidelines or standards.
☐	Infrastructure damage incidents have occurred, but the cause is not related to the lack of design guidelines or standards.
☐	Not applicable

13. ***If your answer to the previous question was "yes", what was the reason(s)?***

☐	Uncertain Hydrology/Hydraulic methodology
☐	Limited and/or low-quality data (e.g., topography, remote sensing data, groundwater and gauge monitoring, soil characteristics, sinkholes and bedrock characteristics, etc.)
☐	Capability of a model to consider arid regions' physical properties (e.g., failure to consider evaporation and transpiration, seasonal variability, etc.)
☐	Disregarding future considerations (e.g., anthropogenic and climate change impacts, etc.)
☐	Disregarding dynamic modeling to simulate transient conditions (dynamic relationship between precipitation, evaporation, runoff, groundwater interaction, etc.)
☐	Disregarding the spatial and temporal variabilities of effective parameters (e.g., precipitation, temperature, infiltration, evaporation, etc.)
☐	Failure to consider groundwater interaction
☐	Insufficient validation and calibration
☐	Other(s), Please specify:

Studies, Standards, and Modeling

14. ***Do you have personal experience in hydrology and hydraulic studies/modeling of Playa Lakes, arid regions, and karstic zones?***

☐	Yes (Please select one or all that apply)	
	☐	Playa lakes
	☐	Arid regions
	☐	Karstic zones
	☐	Not Applicable (N/A)
☐	No	
	☐	But I can refer to:
		Name:
		Title:
		Email:
		Phone:

15. Do you or your institution/company use federal/state guidelines or standards for hydrology/hydraulic study and modeling in Playa Lakes, arid regions, and karstic zones?

☐	**Playa lakes**	Which federal/state guidelines or standards does your institution/company use?
	If selected, specify	
☐	**Arid regions**	
	If selected, specify:	
☐	**Karstic zones**	
	If selected, specify:	
☐	Not Applicable (N/A)	

16. Do these guidelines or standards provide adequate information for designing infrastructures in Playa Lakes, arid regions, and karstic zones?

Area of Improvement		**Playa Lakes**	**Karstic zones**	**Arid areas**
		☐ Yes. Standards/guidelines provide adequate design as is.	☐ Yes. Standards/guidelines provide adequate design as is.	☐ Yes. Standards/guidelines provide adequate design as is.
		☐ No. Standards/guidelines need modification or revision in the following areas:	☐ No. Standards/guidelines need modification or revision in the following areas:	☐ No. Standards/guidelines need modification or revision in the following areas:
☐	Hydrology and runoff calculations	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure
☐	Hydrology models	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure
☐	Hydraulic models	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure
☐	Data collection methods	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure
☐	Geology and detection techniques	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure	Specify the need: ☐ Minor ☐ Major ☐ Not sure

17. ***Do you or your institution/company conduct any studies or modeling related to hydrology in any of the following areas?***

☐	**Yes**	
	☐	Playa lakes
	☐	Arid regions
	☐	Karstic zones
	☐	None of above
☐	**Not aware of and not aware of anyone for referral to help**	
☐	**Not aware of but I can refer you to:**	
	Name:	
	Title:	
	Email:	
	Phone:	
☐	Not Applicable (N/A)	

18. ***Do you or your institution/company use any of the following methods to identify the evolution of Playa Lakes, arid regions, and karstic zones?***

Playa Lakes (Q 18.1)			**Karstic zones (Q 18.2)**		**Arid areas (Q 18.3)**	
☐	**Yes (Select those apply)**		☐	**Yes (Select those apply)**	☐	**Yes (Select those apply)**
	☐	Remote Sensing	☐	Remote sensing	☐	Remote sensing
	☐	LIDAR	☐	Drone and historical aerial imageries	☐	Drone and historical aerial imageries
	☐	Drones, UAVs	☐	Land use and land cover change analysis	☐	Land use and land cover change analysis
	☐	Hydrological monitoring (water surface elevation monitoring, gauge monitoring at inflow and outflow boundaries, etc.)	☐	Hydrological modeling and monitoring	☐	Hydrological modeling and monitoring
	☐	Bathymetric surveys	☐	Drought and vegetation indices analysis	☐	Drought and vegetation indices analysis
	☐	Ground Penetrating Radar (GPR)	☐	Ground Penetrating Radar (GPR)	☐	Ground Penetrating Radar (GPR)
	☐	Others	☐	Others	☐	Others
	If selected others, please specify:			If selected others, please specify:		If selected others, please specify:
☐	No		☐	No	☐	No
☐	Not Applicable (N/A)		☐	Not Applicable (N/A)	☐	Not Applicable (N/A)

19. ***Have you and/or your institution/company considered the future changes in the spatial distribution of arid regions in hydrological studies/modeling?***

☐	Yes
☐	No
☐	Not applicable (N/A)

20. If yes, what are the forecast methods for the future evolution of arid regions you and/or your institution/company considered?

☐	**Hydrological Models**		☐	**Climate Models**	
	☐	SWAT (Soil and Water Assessment Tool)		☐	CESM (Community Earth System Model)
	☐	MIKE SHE (MIKE Soil-Atmosphere-Water)		☐	RCMs (Regional Climate Models)
	☐	VIC (Variable Infiltration Capacity)		☐	HadGEM (Hadley Centre Global Environmental Model)
	☐	Others Specify:		☐	Others Specify:
☐	**Drought Indices**		☐	**Vegetation Models**	
	☐	SPI (Standardized Precipitation Index)		☐	IBIS (Integrated Biosphere Simulator)
	☐	PDSI (Palmer Drought Severity Index)		☐	VISIT (Vegetation Integrated Simulator for Imaging Time-Series)
	☐	SPEI (Standardized Precipitation-Evapotranspiration Index)		☐	LPJ-GUESS (Lund-Potsdam-Jena General Ecosystem Simulator)
	☐	Other Specify:		☐	Other Specify:
☐	**Land Use Change Models**		☐	**Urban Growth Models**	
	☐	CLUE (Conversion of Land Use and its Effects)		☐	SLEUTH (Slope, Land use, Exclusion, Urbanization, Transportation, and Hillshade)
	☐	SLEUTH (Slope, Land use, Exclusion, Urbanization, Transportation, and Hillshade)		☐	CA-Markov (Cellular Automata - Markov Chain)
	☐	LCM Land Change Modeler		☐	LEAM (Land-use Evolution and Impact Assessment Model)
	☐	Other Specify:		☐	Other Specify:
☐	**Artificial Intelligence and Machine Learning**		☐	**Any other methodology?**	
	☐	Kernel-based methods		Specify:	
	☐	Ensemble methods			
	☐	Deep learning methods			
	☐	Other Specify:			

Hydrology and Hydraulic Models

21. Please select any of the following models that you use/have used to simulate the hydrology of playa lakes.

☐	**SWAT** (Soil and Water Assessment Tool)	☐	**HEC-HMS**
☐	**VIC** (Variable Infiltration Capacity)	☐	**PRMS** (Precipitation-Runoff Modeling System)
☐	**MODFLOW** (Modular Ground-Water Flow Model	☐	**RHESSys** (Regional Hydro-Ecologic Simulation System)
☐	**MIKE SHE** (MIKE Soil-Atmosphere-Water)	☐	**PRC** (Pond and Reservoir Routing Model
☐	Others Specify:		
☐	Not Applicable (N/A)		

22. If any of the above is selected, would it be possible to share a copy of the model setup and project reports?

☐	Yes, I will share both model setup and project reports
☐	Yes, upon official request but only project reports
☐	Yes, upon official request but model setup.
☐	Not sure.
☐	No.

23. Please select any of the following models that you used to simulate the hydrology of arid regions.

☐	**SWAT** (Soil and Water Assessment Tool)	☐	**HEC-HMS**
☐	**VIC** (Variable Infiltration Capacity)	☐	**PRMS** (Precipitation-Runoff Modeling System)
☐	**AWARE** (Atmosphere–Water–Ecosystem Model)	☐	**RHESSys** (Regional Hydro-Ecologic Simulation System)
☐	**MIKE SHE** (MIKE Soil-Atmosphere-Water)	☐	**GSSHA** (Gridded Surface Subsurface Hydrologic Analysis)
☐	Others Specify:		
☐	Not Applicable (N/A)		

24. If any of the above is selected, would it be possible to share a copy of the model setup and project reports?

☐	Yes, I will share both model setup and project reports
☐	Yes, upon official request but only project reports
☐	Yes, upon official request but model setup.
☐	Not sure.
☐	No.

25. ***Please select any of the following models that you used to simulate the hydrology of karstic zones.***

☐	**SWMM** (Storm Water Management Model)	☐	**KINEROS** (KINematic runoff and EROSion)
☐	**KarstMod**	☐	**EPIC** (Erosion-Productivity Impact Calculator)
☐	**SUFI-2** (Sequential Uncertainty Fitting)	☐	**CAVE**
☐	**MIKE SHE** (MIKE Soil-Atmosphere-Water)	☐	**MODKARST**
☐	Others Specify:		
☐	Not Applicable (N/A)		

26. ***If any of the above is selected, would it be possible to share a copy of the model setup and project reports?***

☐	Yes, I will share both model setup and project reports
☐	Yes, upon official request but only project reports
☐	Yes, upon official request but the model setup
☐	Not sure
☐	No

27. ***Do you consider the spatial variability of groundwater recharge from Karst zones?***

☐	Yes Please explain:
☐	No
☐	Not applicable

28. ***If you are using any model to simulate flow in Karst areas, how the roughness value is estimated for flow through Karst conduits?***

☐	Yes Please explain:
☐	Not applicable.

29. ***How do you validate your hydrological models of any areas with Playa Lakes, Karst region, and/or arid areas?***

☐	Hydrograph comparison with field observation or gauge data
☐	Validation of individual model components (infiltration, evapotranspiration, routing, etc.)
☐	Agency and data repository resources Specify:
☐	Spatial validation of water surface elevation (WSE) for different flood events with recorded observation or remotely sensed data
☐	Other(s):
☐	Not Applicable (N/A)

Hydrologic and Hydraulic Parameters

30. What is the methodology that you or your institution/company use to calculate the runoff in playa lakes/arid areas/karstic zones?

	(Q 30.1) **Playa Lakes**	*(Q30.2)* **Arid Areas**	*(Q30.3)* **Karstic Zones**
Rational Method	☐	☐	☐
SCS (Soil Conservation Service) Curve Number Method	☐	☐	☐
Small Watershed Method	☐	☐	☐
TR-55 (Technical Release 55) Method	☐	☐	☐
Statistical Analysis of Stream Gauge Data	☐	☐	☐
Omega EM Regression Equations	☐	☐	☐
HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System)	☐	☐	☐
SCS Unit Hydrograph Method	☐	☐	☐
NRCS (Natural Resources Conservation Service) Dimensionless Unit Hydrograph	☐	☐	☐
Clark Unit Hydrograph	☐	☐	☐
Santa Barbara Urban Hydrograph Method	☐	☐	☐
Time-Area Method	☐	☐	☐
Not applicable (N/A)	☐	☐	☐
Others	☐	☐	☐
Specify if selected “others”:			

31. What is the methodology that you or your institution/company use to calculate the loss in playa lakes/arid areas/karstic zones?

	(Q 31.1) **Playa Lakes**	*(Q31.2)* **Arid Areas**	*(Q31.3)* **Karstic Zones**
Initial and constant-rate loss model	☐	☐	☐
Texas initial and constant-rate loss model (just for the Texas region)	☐	☐	☐
NRCS curve number loss model	☐	☐	☐
Green-Ampt loss model	☐	☐	☐
Not Applicable (N/A)	☐	☐	☐
Others	☐	☐	☐
Specify if selected “others”:			

32. ***What is the methodology that you or your institution/company use to calculate the time of concentration in playa lakes/arid areas/karstic zones?***

	(Q 32.1) **Playa Lakes**	*(Q32.2)* **Arid Areas**	*(Q32.3)* **Karstic Zones**
Kerby-Kirpich Method	☐	☐	☐
Natural Resources Conservation Service (NRCS) Method	☐	☐	☐
Kinematic Wave Equation	☐	☐	☐
Area based method	☐	☐	☐
No Applicable (N/A)	☐	☐	☐
Others	☐	☐	☐
Specify if selected "others":			

33. ***What is the methodology that you or your institution/company use to calculate the lag time (basin lag) in playa lakes/arid areas/karstic zones?***

	(Q 33.1) **Playa Lakes**	*(Q33.2)* **Arid Areas**	*(Q33.3)* **Karstic Zones**
Snyder's Unit Hydrograph	☐	☐	☐
NRCS Dimensionless Unit Hydrograph	☐	☐	☐
Triangular Hydrograph Method	☐	☐	☐
SCS (Soil Conservation Service) Lag Method	☐	☐	☐
Hydrograph Separation Methods	☐	☐	☐
No Applicable (N/A)	☐	☐	☐
Others	☐	☐	☐
Specify if selected "others":			

34. ***What flood frequencies have you or your institution/company utilized for drainage impact and flood mitigation studies for urban and infrastructure developments in Playa lakes/arid areas/karstic zones? (Check multiple if required).***

	(Q 34.1) **Playa Lakes**	*(Q34.2)* **Arid Areas**	*(Q34.3)* **Karstic Zones**
500-yr	☐	☐	☐
200-yr	☐	☐	☐
100-yr	☐	☐	☐
50-yr	☐	☐	☐
20-yr	☐	☐	☐
10-yr	☐	☐	☐
5-yr	☐	☐	☐
2-yr	☐	☐	☐
Other event(s):	☐	☐	☐
Not Applicable (N/A)	☐	☐	☐

Recommendations/Suggestions

35. ***What recommendations do you have for improving hydrological models in playa lakes/arid areas/karstic zones?***

☐	Playa lakes	Specify:
☐	Karstic zones	Specify:
☐	Arid regions	Specify:
☐	Not Applicable (N/A)	

36. ***What resources do you use to stay up to date with the latest research in playa lakes/arid areas/karstic zones?***

☐	Playa lakes	Specify:
☐	Karstic zones	Specify:
☐	Arid regions	Specify:
☐	Not Applicable (N/A)	

Interview Participation

37. ***Would you be willing to participate in an interview to discuss your personal experience regarding hydrology and hydraulic study/modeling in Playa lakes/arid areas/karstic zones?***

☐	Yes	
	☐	Playa lakes
	☐	Karstic zones
	☐	Arid regions
☐	No	

Letter of Invitation and Sample Interview Questions

Interview on Hydrologic Approaches to Playa Lakes, Areas of Significant Karst Geology, and Arid Regions

You are invited to participate in a follow-up interview for the research on Hydrologic Approaches to Playa Lakes, Areas of Significant Karst Geology, and Arid Regions. Having received your responses to our questionnaire, we believe that a follow-up interview will allow us to learn about your knowledge and experience in this research area more thoroughly, enabling us to better benefit from your expertise.

The interview is expected to take approximately 30 minutes and will be conducted via Microsoft Teams platform. If you agree to participate, we will collaborate with you to determine a suitable time for the interview that fits into your schedule.

We have provided sample questions that you may anticipate during the interview. Please note that the questions may be slightly modified to align with the background of each interviewee.

Your participation in this study is completely voluntary. There are no foreseeable risks associated with this project. However, if you feel uncomfortable answering any questions, you can withdraw from the interview at any point. It is very important for us to learn your opinions, knowledge, and recommendations about the current situation of H&H design in Playa Lakes, Areas of Significant Karst Geology, and Arid Regions. Your responses will be strictly confidential and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential. If you have questions at any time about the survey or the procedures, you may contact Dr. Habib Ahmari and/or Dr. Saman Baharvand by email at the email address specified below.

Email addresses:

1- Habib.ahmari@uta.edu

2- Saman.baharvand@mavs.uta.edu

Interview Sample Questions:

1. **Location:**

    - Is your institution/company located in areas of Playa Lakes, arid regions, and karstic zones?

2. **Infrastructure:**

    - Does your institution/company have infrastructure assets in Playa Lakes, arid regions, and karstic zones?

3. **Study or Modeling:**

    - Does your institution/company conduct any studies or modeling related to the hydrology of Playa Lakes, arid regions, and karstic zones?

4. **Guidelines or Standards:**

    - Does your institution/company use federal/state guidelines or standards for hydrology/hydraulic study/modeling in these areas?
    - If yes, which federal/state guidelines or standards does your institution/company use?
    - Do these guidelines or standards provide adequate information for designing infrastructures in Playa Lakes, arid regions, and karstic zones?

5. **Infrastructure Damage:**

    - Has your institution/company encountered cases where infrastructure was damaged (partially or completely) due to the lack of proper design guidelines or standards for these areas?

6. **Personal Experience:**

    - Do you have personal experience in the hydrology and hydraulic study/modeling of Playa Lakes, arid regions, and karstic zones?