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Recommended flood risk reduction solutions

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QUICK FACTS

- The regional flood planning groups identified and evaluated a total of 5,342 flood risk reduction solutions for consideration in the regional flood plans—4,609 of those were recommended as follows:
 - A total of 3,097 flood management evaluations with a total estimated cost of more than \$2.6 billion.
 - A total of 615 flood mitigation projects with a total estimated cost of more than \$49.1 billion.
 - A total of 897 flood management strategies with a total estimated implementation cost of more than \$2.8 billion. Of those, 771 are strategies with non-recurring, non-capital costs, which are the only strategies and costs eligible for the Flood Infrastructure Fund. Together, the 771 strategies have a total cost of \$313 million.
- All recommended evaluations (3,097), projects (615), and strategies with non-recurring, non-capital costs (771) are included in ranked lists.

The regional flood planning groups were tasked with identifying and evaluating a wide range of potential solutions to reduce the risk and impact of flooding across the state. They identified and categorized them into three types of flood risk reduction solutions: flood management evaluations, flood mitigation projects, and flood management strategies.

- **Flood management evaluation** — A proposed study to identify, assess, and quantify flood risk or identify, evaluate, and recommend flood risk reduction solutions.
- **Flood mitigation project** — A proposed structural or non-structural flood project that has a non-zero capital cost or other non-recurring cost and, when implemented, will reduce flood risk or mitigate flood hazards to life or property.
- **Flood management strategy** — Ideas and strategies that do not belong in the flood management evaluation or flood mitigation project categories. Examples may include regulatory enhancements, development of entity-wide buyout programs, and public outreach and education.

Each planning group approved its respective approaches and processes to identify and evaluate potential flood risk reduction solutions, as described in the following sections, at a public meeting. These approaches were documented in their technical memorandums (midway progress reports) and submitted to the Texas Water Development Board (TWDB) in January 2022. Once the planning groups evaluated all identified flood risk reduction solutions, the voting members reviewed and considered their merits before recommending them in the final and amended regional flood plans submitted to the TWDB in January and July 2023, respectively.

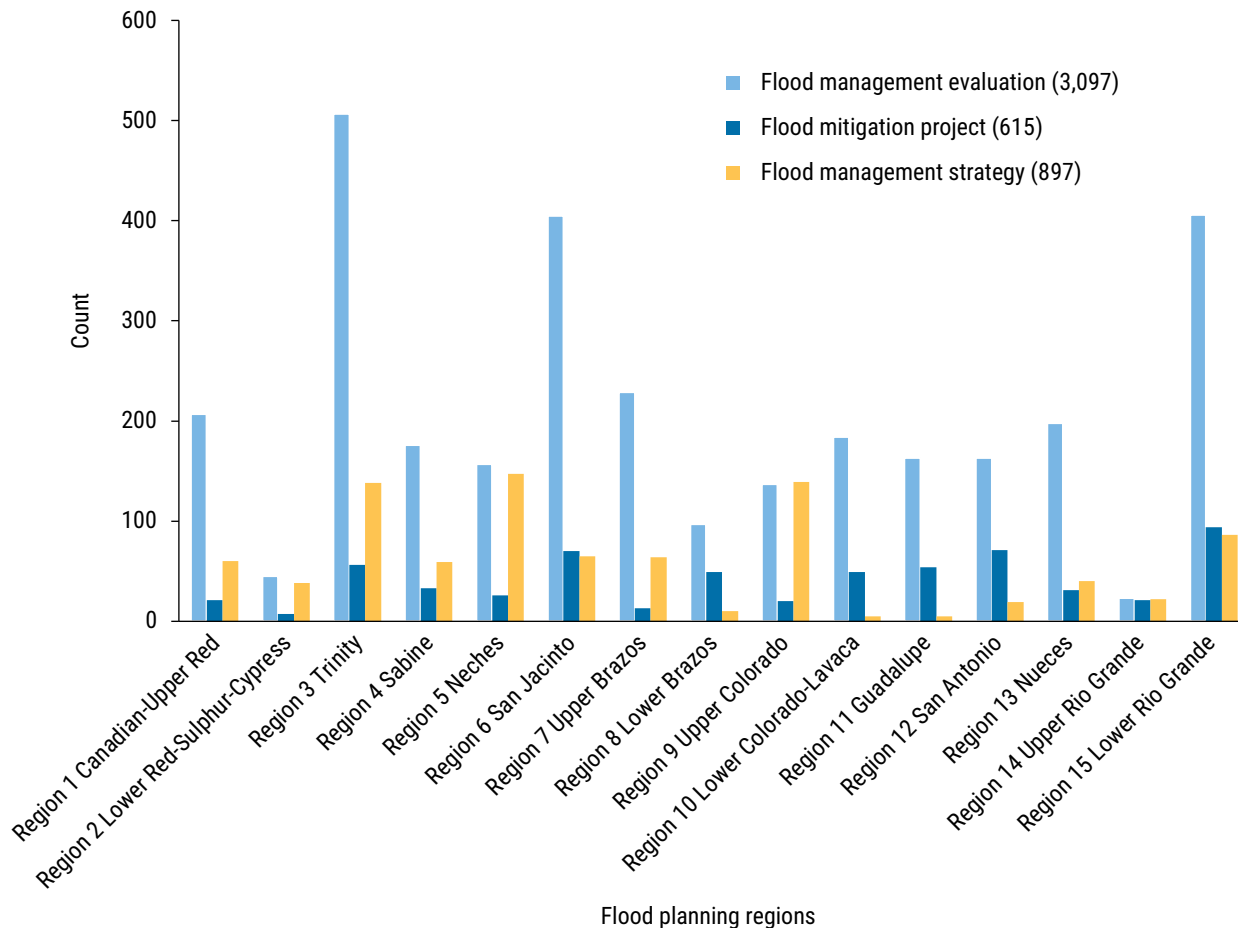
7.1 Summary of recommended flood risk reduction solutions

A total of 4,609 flood risk reduction solutions from all 15 flood planning regions were recommended at an estimated cost of approximately \$54.5 billion (Table 7-1). Approximately 49 percent (\$24 billion) of that total cost is associated with the Galveston Bay Surge Protection Coastal

Table 7-1. Count and cost of recommended flood risk reduction solutions

Flood risk reduction solution	Count	Cost
Flood management evaluations	3,097	\$2.6B
Flood mitigation projects	615	\$49.1B
Flood management strategies*	771	\$2.8B
Total	4,483	\$54.5B

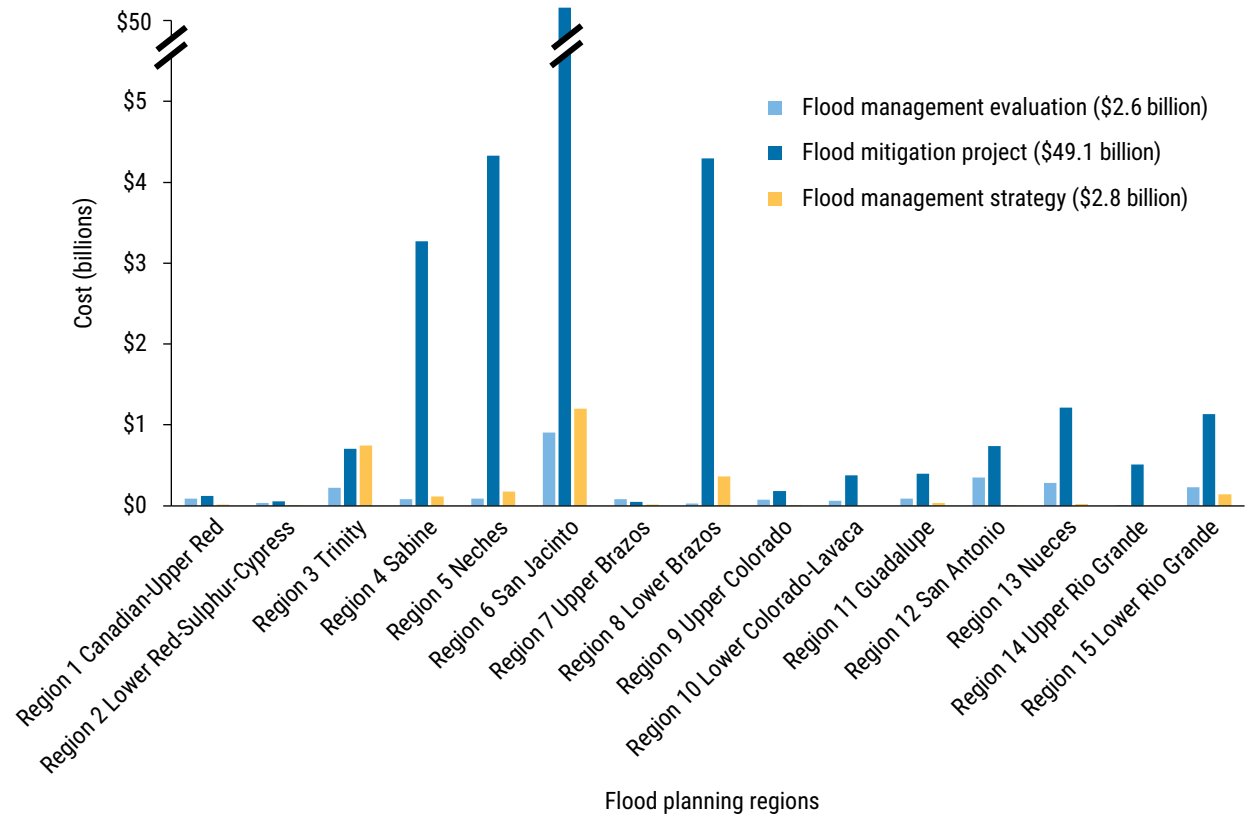
* Includes both implementation costs and non-recurring, non-capital costs.

Figure 7-1. Recommended flood risk reduction solutions by type and region

Note: The flood management strategy count in this table only includes those with non-recurring, non-capital costs.

Storm Risk Management project. The recommended solutions include 771 flood management strategies with non-recurring, non-capital costs for an estimated total cost of \$2.8 billion. A summary of recommended solutions by type and flood planning region is presented in Figure 7-1, while a summary of costs is noted in Figure 7-2 and Figure 7-3. All recommended flood manage-

ment strategies and their implementation costs are presented; however, only flood management strategies with non-recurring, non-capital costs are included in the ranking for the state flood plan. More detailed descriptions of the recommended flood risk reduction solutions are provided later in this chapter.

Figure 7-2. Estimated cost of all recommended flood risk reduction solutions by region

During the first cycle of regional and state flood planning, the planning groups struggled to incorporate fully formulated flood mitigation projects into the regional plans that met all the program requirements due to the short timeframe. In response, and to maximize the number of flood risk reduction solutions recommended in the first state flood plan, the TWDB extended the initial grant contracts by six months and allocated additional grant funding for the planning groups to carry out the following tasks:

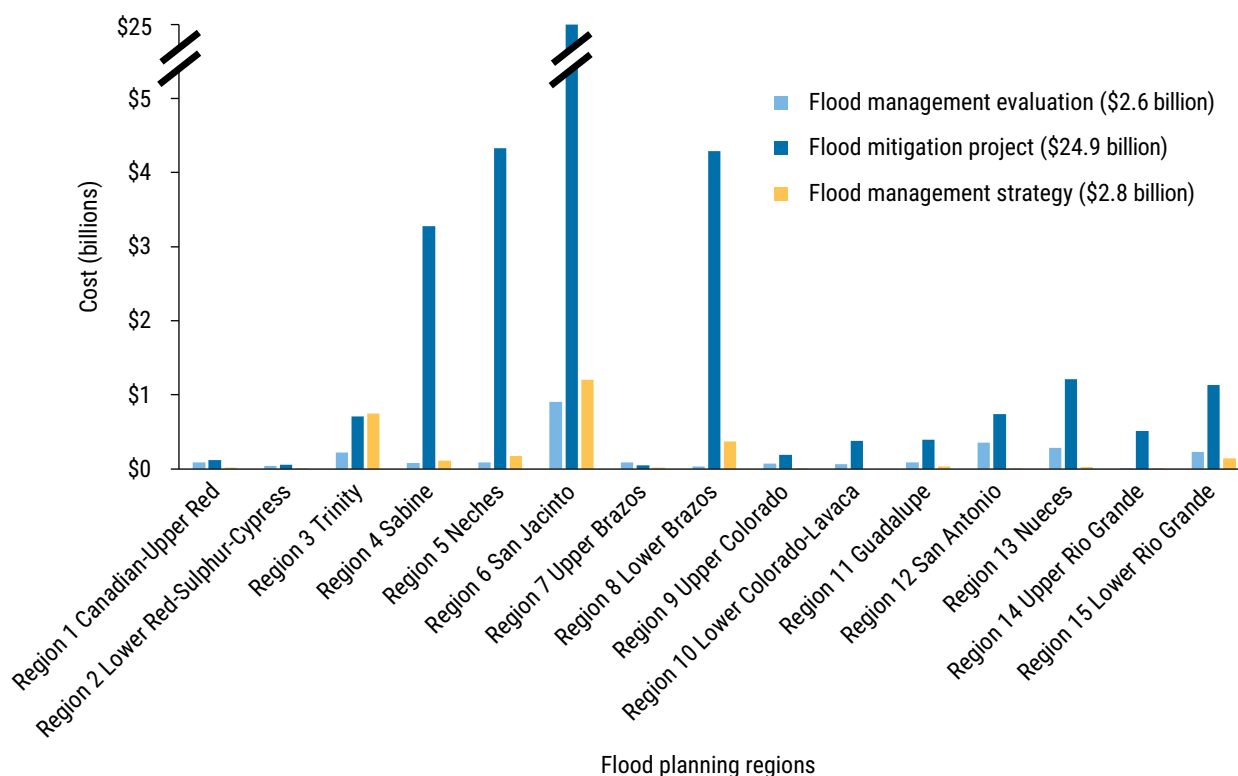
- Perform additional outreach to regional stakeholders to collect data, models, and other relevant technical information
- Perform flood management evaluations to determine flood risks in areas with limited flood risk data
- Evaluate flood risk reduction solutions, including feasibility studies and preliminary engineer-

ing, to help identify, evaluate, and recommend additional flood mitigation projects

- Prepare and submit amended regional flood plans to incorporate new data and information

The additional time and funding provided to the regional flood planning groups tripled the number of flood mitigation projects identified and significantly increased the number of recommended flood risk reduction solutions that the flood planning groups included in their first regional flood plans. The flood risk reduction solutions identified and recommended in the state flood plan represent a snapshot in time based on best available data. The need for flood risk reduction solutions in the state is greater than what is identified and recommended in the inaugural cycle of regional and state flood planning.

Figure 7-3. Estimated cost of recommended flood risk reduction solutions by region, without the Region 6 Galveston Bay Surge Protection Coastal Storm Risk Management project*



* The figure excludes the Region 6 Galveston Bay Surge Protection Coastal Storm Risk Management project with a reported estimated cost of \$24 billion.

7.2 Identifying and evaluating flood risk reduction solutions

The planning groups followed a multi-step process to identify, evaluate, and recommend flood risk reduction solutions in their regional flood plans. More flood risk reduction solutions were initially identified than were recommended in their final plans. Each planning group determined a process for paring down all the potentially feasible flood risk reduction solutions to meet the technical and programmatic requirements as well as the needs of the communities that will sponsor and benefit from the solutions.

7.2.1 Identifying flood risk reduction solutions

Identifying potential flood risk reduction solutions began with an analysis of flood mitigation needs to identify areas across the state where the greatest gaps in knowledge about flood risk exist and where the planning groups should consider identifying potentially feasible flood risk studies as flood management evaluations. Next, the groups identified areas of greatest known flood risk, thus requiring flood mitigation through recommended flood mitigation projects and flood management strategies.

To identify areas most prone to flooding that threatens life and property, the planning groups used data to perform geospatial analyses that the TWDB then assigned scoring metrics with factors deemed most relevant to flood risk reduction, including but not limited to the number of structures, population, historic flood events, social vulnerability, critical facilities, current floodplain management practices, land use policies, and infrastructure. In determining the greatest flood risk mitigation needs, the planning groups considered ongoing and planned flood risk reduction projects with and without funding.

Following the results of the flood risk mitigation needs analyses, the planning groups used varied data sources, including the list below, to develop lists of flood risk reduction solutions to potentially assess and address each region's needs:

- Existing flood infrastructure, including condition and functionality
- Existing and future condition exposure and vulnerability
- Regional flood planning group-generated floodplain management and flood protection goals
- Unfunded flood studies and projects
- Capital improvement plans
- Drainage master plans
- Hazard mitigation plans
- Information obtained through stakeholder engagement

The flood planning groups were tasked with categorizing identified flood risk reduction solutions into one of the three types of solutions: flood management evaluations, flood mitigation projects, or flood management strategies. The TWDB provided a flow chart (Figure 7-4) as a guide.

Flood management evaluation: A flood management evaluation is a proposed flood study of a specific flood prone area to assess flood risk and/or determine if potentially feasible flood mitigation projects or flood management strategies are needed. There are four general categories of

flood management evaluations: (1) project planning, (2) studies on flood preparedness, (3) watershed planning, and (4) other. The flood management evaluations in these four categories serve as assessments to identify and quantify flood hazard studies or to evaluate and recommend flood risk reduction solutions. The level of flood management evaluations may range from studies initially identifying areas of flood risk to studies considering specific mitigation solutions that may have up to a 30 percent level of design. Identified flood management evaluations and descriptions are provided in Table 7-2.

Flood mitigation project: A flood mitigation project is a proposed project, either structural or non-structural, that has capital or other non-recurring costs and, when implemented, will reduce flood risk and mitigate flood hazards to life and/or property. The regional flood planning groups were strongly encouraged to consider nature-based flood risk reduction solutions, which also fall into this category.

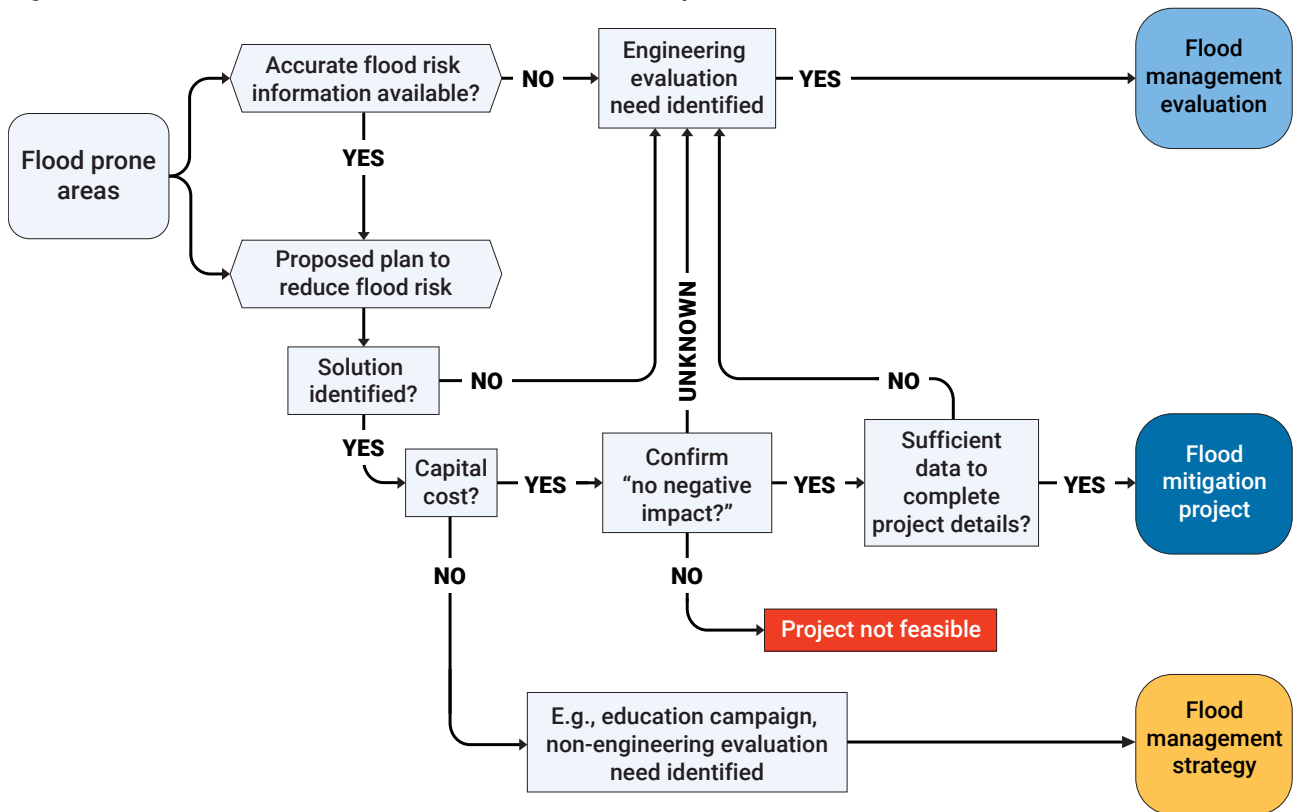
Statute requires that a regional flood plan does not negatively affect a neighboring area.³⁶ To be recommended in a regional flood plan, rules require that flood planning groups demonstrate that potential projects will not negatively affect a neighboring area.³⁷ Essentially, reducing the flood risk to one location cannot increase the risk of flooding to neighboring upstream or downstream locations. In addition, a potential flood mitigation project must be permissible, constructable, and implementable if included in a regional flood plan. Flood mitigation projects are generally categorized as either structural or non-structural.

Structural flood mitigation projects involve building or modifying infrastructure to reduce flood risk. These projects may require an advanced level of analysis and design prior to construction and/or implementation. The structural flood mit-

³⁶ TWC § 16.062(j)(2)

³⁷ 31 TAC § 361.38(h)(7)

Figure 7-4. Flood risk reduction solution classification process



igation projects identified by the planning groups are detailed in Table 7-3.

Non-structural flood mitigation projects are actions that reduce the impact of flooding without relying solely on physical infrastructure. These projects focus on strategies that do not involve constructing physical barriers or altering the natural flow of water. The general types of non-structural flood mitigation projects that the planning groups considered are included in Table 7-4.

Flood management strategy: A flood management strategy is a proposed plan to reduce flood risk or mitigate flood hazards to life or property and is not a flood management evaluation or flood mitigation project. Flood management strategies may require implementing associated flood mitigation projects. The planning groups were given some flexibility on how they used flood management strategies in the regional

flood planning process. For example, the planning groups could choose to not recommend any flood management strategies. Table 7-5 includes general descriptions of each flood management strategy type as well as the number of each type initially identified and evaluated by the planning groups.

Also, the planning groups included the total costs and the non-recurring, non-capital costs for flood management strategies in their regions. Total costs include the initial one-time, non-recurring, non-capital costs and eventual capital costs needed to implement a recommended strategy as a flood mitigation project. One-time, non-recurring, non-capital costs are those necessary to develop and/or implement the strategy. Examples include program development cost; education campaign cost; non-engineering studies such as floodplain regulation development, flood authority, or revenue raising studies; and public awareness programs, amongst others.

Table 7-2. Number and types of flood management evaluations identified by the regional flood planning groups

FME type	Description	Count	Cost range
Engineering project planning	The process of strategically organizing and establishing a framework for the successful implementation of flood-related projects. This planning phase focuses on defining the basic structure and direction of the project, providing a general understanding of the project's requirements and feasibility at the early stages of design. These studies fall into two main categories: feasibility assessments and preliminary engineering.	2,251	\$2,000–\$65,673,000
Flood preparedness studies	Comprehensive assessments to evaluate the level of readiness and resilience of a community or area facing potential flooding events. These studies aim to identify existing strengths and weaknesses in terms of flood preparedness and response capabilities. A study typically involves analyzing various factors, such as the local flood history, vulnerability of infrastructure and critical facilities, emergency management systems, communication networks, hurricane evacuation plans, flood warning systems, and coordination among relevant stakeholders.	91	\$10,000–\$3,799,000
Watershed planning	Studies that quantify flood risk in areas where significant flood risk is thought to exist but where there is insufficient or no flood risk data. Examples of this type of flood management evaluation include hydrologic and hydraulic modeling, flood risk mapping, and regional watershed studies.	1,077	\$14,500–\$92,079,000
Other	This category includes additional types of studies or assessments, not captured in the previous categories, needed to either identify and quantify flood hazard and studies or evaluate and recommend flood risk reduction solutions. The types of studies in this category vary across regions but generally included dam evaluations, developing geographic information system inventories on existing infrastructure, and other general data collection.	167	\$25,000–\$2,000,000

FME = Flood management evaluation

Table 7-3. Structural flood mitigation projects identified by the 15 planning groups*

Structural flood mitigation project type	Count	Cost range
Low water crossings or bridge improvements	101	\$38,000–\$57,548,152
Infrastructure (channels, ditches, ponds, stormwater pipes, etc.)	174	\$73,000–\$421,681,184
Regional detention	74	\$224,000–\$550,000,000
Regional channel improvements	82	\$258,023–\$994,000,000
Storm drain improvements	50	\$511,000–\$72,072,000
Dam improvements, maintenance, and repair	5	\$1,705,000–\$28,000,000
Flood walls and levees	5	\$300,000–\$2,270,099,968
Coastal protections	2	\$1,200,168,960–\$24,107,063,296
Nature-based projects (living levees , increasing storage, dune management, river restoration, etc.)	8	\$120,000–\$2,719,130
Comprehensive regional project – includes a combination of projects intended to work together	83	\$642,000–\$1,150,000,000

* Not all available types of structural flood mitigation projects were identified by the flood planning groups.

These are the only costs associated with flood management strategies that will be eligible for TWDB funding and, thus, were the only strategies included in the ranked list described later in this chapter.

7.2.2 Screening and evaluating identified flood risk reduction solutions

The regional flood planning groups identified a total of 5,342 flood risk reduction solutions. However, not every flood management evaluation, flood mitigation project, or flood management strategy was recommended in the regional flood

Table 7-4. Non-structural flood mitigation projects identified by the 15 planning groups*

Non-structural flood mitigation project type	Count	Cost range
Property or easement acquisition	13	\$550,000–\$56,159,648
Elevation of individual structures	4	\$894,000–\$10,000,000
Flood readiness and resilience	55	\$11,000–\$826,000
Other	3	\$21,000–\$37,238,000

* Not all available types of non-structural flood mitigation projects were identified by the flood planning groups.

Table 7-5. Flood management strategies identified by the 15 planning groups

Flood management strategy type	Description	Count	Cost range
Education and outreach	Creation and implementation of programs to educate and/or inform the public on the hazards and risks of flooding.	137	\$500–\$4,000,000
Flood measurement and warning	Installation and operation of stream gages, monitoring stations, and early warning alert systems to provide flood hazard information to the public and decision-makers.	145	\$500–\$9,541,000
Infrastructure programs	Establishing a program, plan, or standards to facilitate future flood infrastructure projects.	127	\$5,000–\$360,000,000
Property acquisition and structural elevation program	Program administration to acquire, remove, or elevate structures currently within flood hazard areas.	85	\$50,000–\$500,000,000
Regulatory and guidance	Creating ordinances, development criteria, building codes, and/or design standards to help prevent an increase to flood risk through new development.	348	\$500–\$50,000,000
Other programs	May include maintenance and inspection programs of flood infrastructure to ensure design level of service is maintained.	255	\$500–\$30,000,000

plans. Before making their recommendations, the groups were required to develop and adopt a process for evaluating the feasibility of each potential solution to ensure it met all technical requirements so that limited resources could be directed efficiently to implement those solutions.

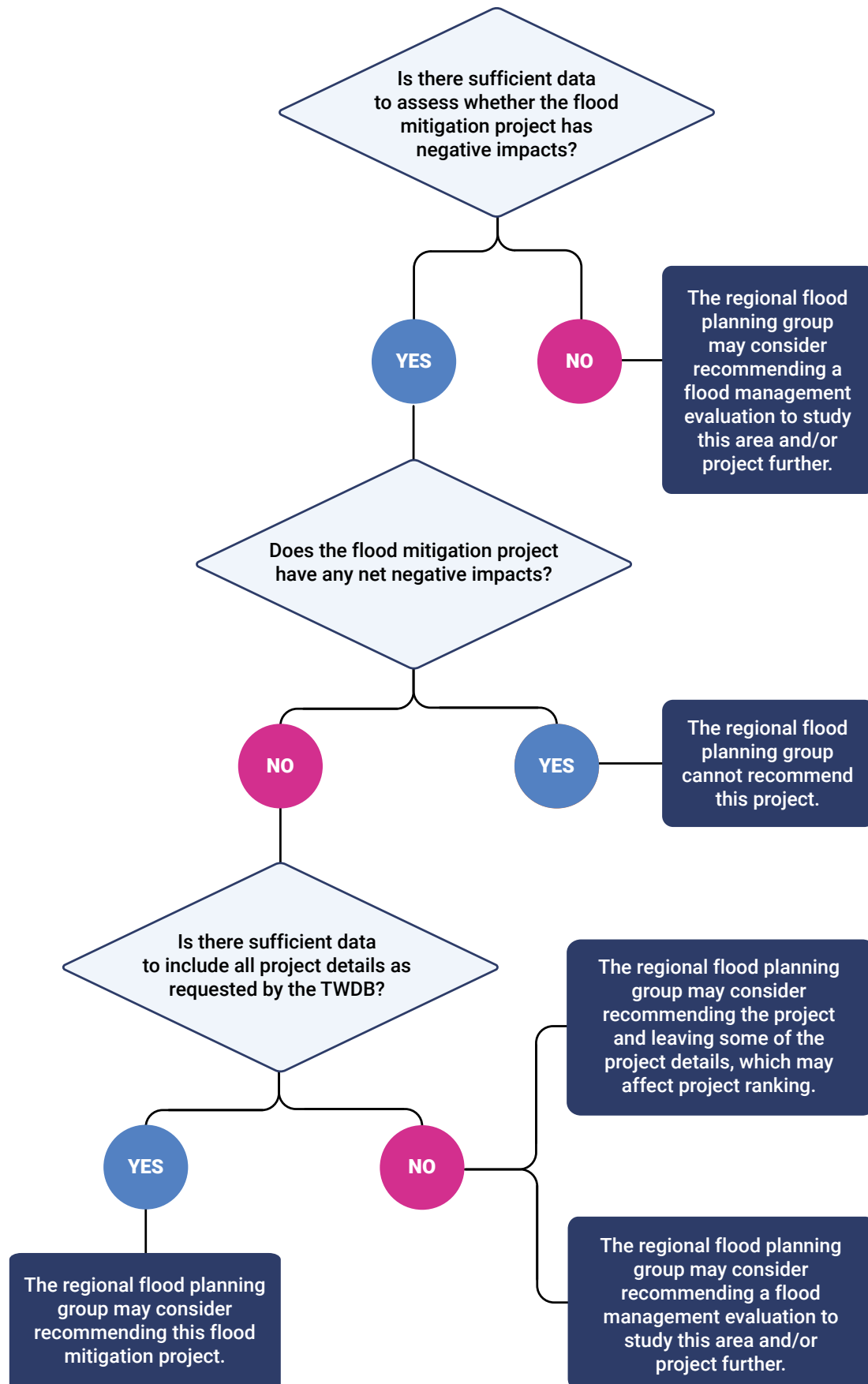
As a result, this process varied by region within the overall TWDB rule and guidance framework. For example, some planning groups relied on technical committees to develop and recommend a process for the group's approval, while others relied on several full-group meetings to come to a consensus. These processes were documented and included in the draft and final adopted regional flood plans.³⁸ Despite these variations,

each group's process generally included the same types of screening and evaluation criteria (Figure 7-5).

Stakeholder outreach

The initial screening process often began with direct stakeholder outreach regarding identified potential solutions to ensure all information was correct and up to date. For example, planning groups disqualified potential flood management evaluations, flood mitigation projects, and flood management strategies if they were already completed or no longer needed or wanted by the sponsoring community. The planning groups were required to identify who would sponsor each potential solution, which includes direct financing and implementation. Flexibility was granted with

³⁸ www.twdb.texas.gov/flood/planning/plans/index.asp

Figure 7-5. Example process of how regional planning groups screened flood risk reduction solutions

sponsorship, as both financing and implementation could involve more than one entity and funding source.

Screenings based on rules, technical guidelines, and other criteria

Each potential flood risk reduction solution was screened and evaluated based on a variety of factors and criteria derived from the TWDB rules and guidance requirements and other factors that the planning groups considered relevant. This generally included:

1. **Flood mitigation and floodplain management goals:** The groups evaluated whether the potential solution aligned with a flood mitigation or floodplain management goal. All recommended flood management evaluations, flood mitigation projects, and flood management strategies were required to be associated with goals adopted by the regional flood planning groups (see Chapter 6 for more on goals).
2. **Emergency need:** The planning groups were given the flexibility during the first cycle of regional flood planning to determine whether a potential solution met an emergency need in the region. Determining emergency need varied significantly from region to region.
3. **Drainage area:** The planning groups were directed to consider flood risk reduction solutions with a contributing drainage area greater than or equal to 1 square mile, except in instances of flooding of critical facilities or transportation routes, or for other reasons, including levels of risk or project size, determined by the planning groups.
4. **No negative impact:** TWDB rules define “negative effect” (in this plan referred as “negative impact”) as an increase in flood-related risks to life and property, either upstream or downstream of the proposed project. A determination of no negative impact, therefore, means that a flood risk reduction solution will not increase flood risk of surrounding areas. The planning groups were asked to measure

any increases in flood risk by the 1 percent (100-year) annual chance storm event water surface elevation and peak discharge using the best available data. For the purposes of flood planning, a determination of no negative impact was required to recommend a flood mitigation project. The following criteria were required to establish no negative impact, as applicable:

- a. Stormwater does not increase inundation in areas beyond the public right-of-way, project property, or easement.
- b. Stormwater does not increase inundation of storm drainage networks, channels, and roadways beyond design capacity.
- c. Maximum increase of 1-D water surface elevation must round to 0.0 feet (< 0.05 feet) measured along the hydraulic cross section.
- d. Maximum increase of 2-D water surface elevations must round to 0.3 feet (< 0.35 feet) measured at each computational cell. Maximum increase in hydrologic peak discharge must be < 0.5 percent measured at computational nodes (sub-basins, junctions, reaches, reservoirs, etc.). This discharge restriction does not apply to a 2-D overland analysis.
- e. Note that potential negative impacts of a solution could be internally mitigated as part of an overall flood mitigation project.

The regional flood planning groups had flexibility to accommodate additional negative impact for requirements listed above based on an engineer’s professional judgment and analysis given any affected stakeholders are informed and accept the impacts.

5. **Feasibility:** The regional flood planning groups were required to confirm that all recommended flood mitigation projects are permittable, constructable, and implementable.
6. **Water supply benefit:** The regional flood planning groups were required to evaluate whether a potentially feasible flood risk reduction

solution had any impact (positive or negative) on water supply development. Recommended flood mitigation projects and flood management strategies may not negatively impact an entity's water supply. Further, recommended flood mitigation projects that will contribute to water supply may not result in an overallocation of a water source based on the water availability allocations in the most recently adopted state water plan.

7. **Flood risk reduction:** To be considered for recommendation, each flood mitigation project and flood management strategy must demonstrate a flood risk reduction benefit. Multiple criteria were used to measure the flood risk reduction benefit of each potentially feasible project and strategy after implementation, including reduction of land area at risk of flooding; reduction and removal of structures at risk of flooding; reduction and removal of residential structures at risk of flooding; removal of population at risk of flooding; removal of critical facilities at risk of flooding; removal of road miles at risk of flooding; reduction of road closures at risk of flooding; removal of active farmland and ranchland acres at risk of flooding; estimated reduction in flood-related fatalities, when available; estimated reduction in flood-related injuries, when available; reduction in expected annual damages from residential, commercial, and public property; and other benefits as deemed relevant by the regional flood planning group, including those related to the environment, navigation, recreation, agriculture, erosion, and sedimentation.
8. **Benefit-cost analysis:** A benefit-cost analysis, which is the method used to determine the future benefits of a hazard mitigation project compared to its costs, was required for each recommended flood mitigation project, when applicable. The result is a benefit-cost ratio, a numerical expression of the cost-effectiveness of a project, calculated by a project's total benefits divided by its total costs. A solution is generally considered cost effective

when the benefit-cost ratio is 1.0 or greater, indicating the benefits of a prospective hazard mitigation project are sufficient to justify the costs (FEMA, 2009). The planning groups utilized previously calculated benefit-cost ratios when available; however, they were given a user-friendly, TWDB-developed benefit-cost analysis input tool for projects lacking an existing calculation. Some groups also chose to utilize the Federal Emergency Management Agency (FEMA) benefit-cost analysis toolkit to generate benefit-cost ratio values. While it is preferable that planning groups recommend flood mitigation projects with a benefit-cost ratio greater than 1.0, they were given the flexibility to recommend projects with a benefit-cost ratio score of less than 1.0 with additional justification.

Project details

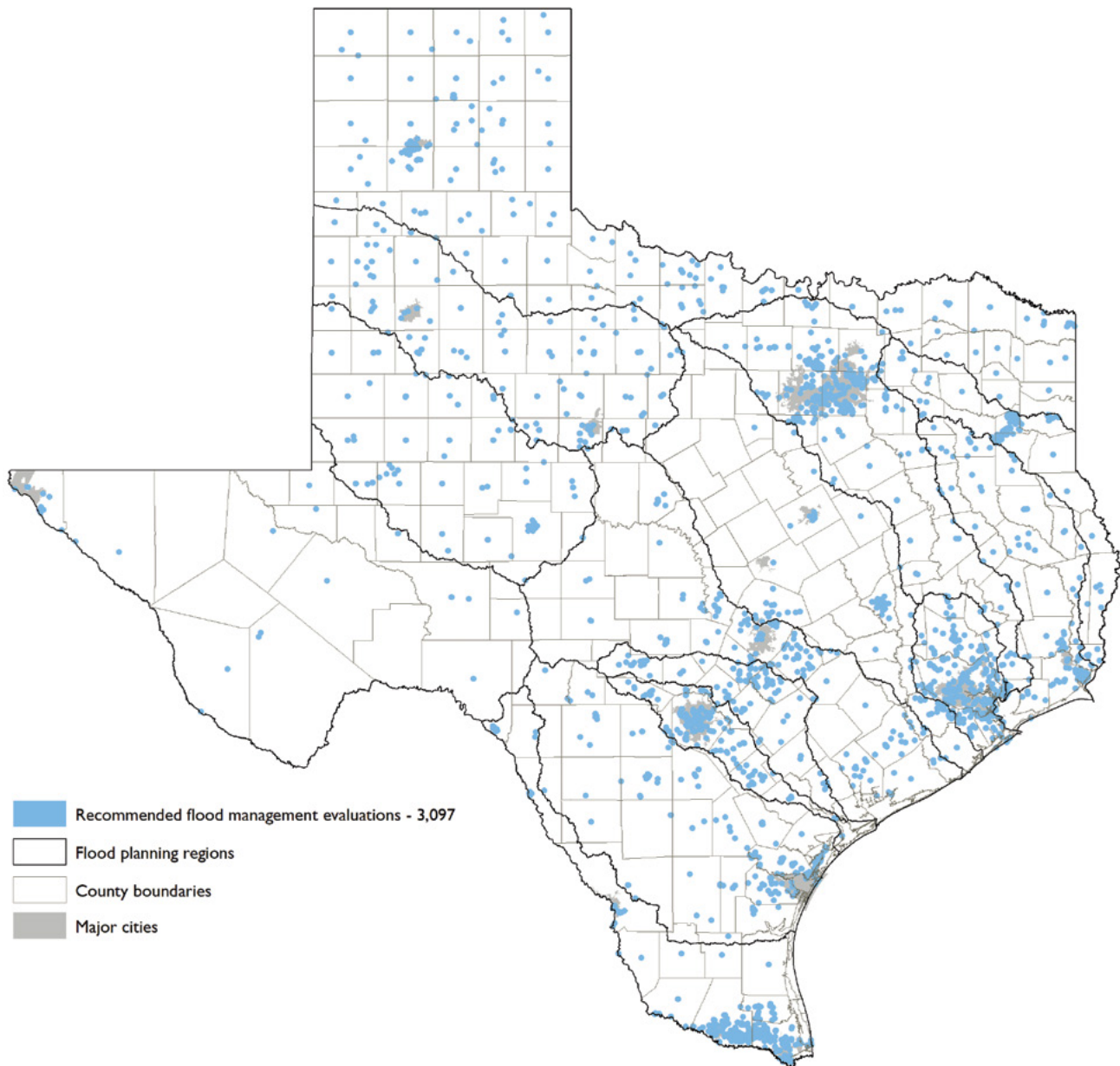
Project details are more complex project scores computed by planning groups using raw data. To enable the state flood project ranking and inform the planning groups' screening and evaluation process, optional project details were generated for each recommended flood risk reduction solution, including but not limited to the following:

- Flood severity metrics
- Flood risk and damage metrics
- Flood solution benefits
- Estimated capital, operation, and maintenance costs
- Benefit-cost ratio values
- Environmental benefits and impacts
- Implementation constraints
- Water supply benefits

Information on identified flood management evaluations, flood mitigation projects, and flood management strategies deemed infeasible by the regional flood planning groups is available on the Interactive State Flood Plan Viewer.³⁹

³⁹ [Texasstatefloodplan.org](https://texasstatefloodplan.org)

Figure 7-6. Locations of flood management evaluations recommended by the regional flood planning groups

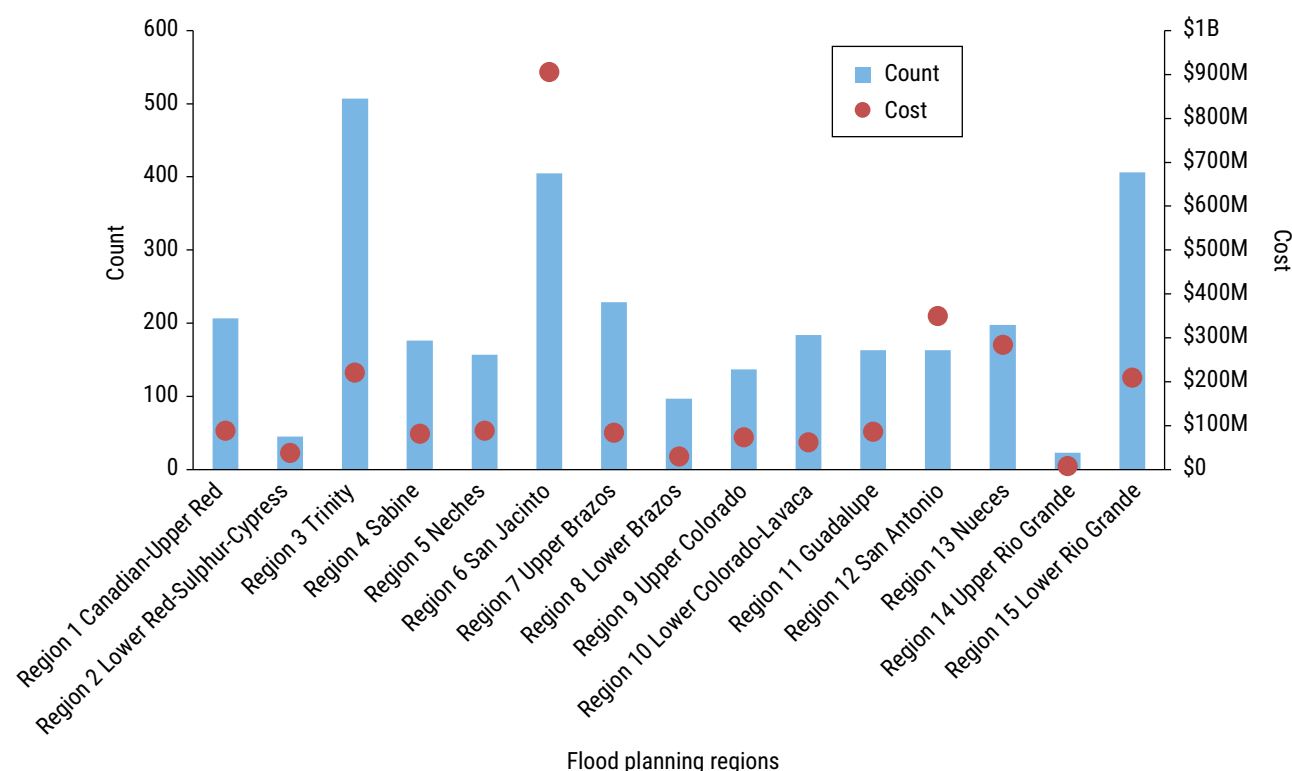


7.3 Recommended flood management evaluations

The planning groups screened and evaluated all identified potential flood management evaluations. Recommendations were made for the flood management evaluations that met programmatic requirements, including alignment with regional flood planning group goals and sponsorship.

The planning groups identified and evaluated a total of 3,586 potential flood management evaluations. Of those, 3,097 were ultimately recommended in the amended regional flood plans, representing a combined total of approximately \$2.6 billion in flood management evaluation needs across the state. A map of recommended flood management evaluations is presented in Figure 7-6. The full list of recommended flood management evaluations is included in the ranked list, and their supporting technical data,

Figure 7-7. Count and estimated cost of recommended flood management evaluations by flood planning region



including location and sponsorship, are included in the Interactive State Flood Plan Viewer.

Figure 7-7 shows the number of recommended flood management evaluations and the total approximate cost to implement all recommended evaluations per region. While Region 3 Trinity and Region 15 Lower Rio Grande recommended the most evaluations, at 507 and 406, respectively, Region 6 San Jacinto and Region 12 San Antonio have the highest cumulative costs for implementing their recommended flood management evaluations. The number and types of flood management evaluations recommended by the planning groups are summarized in Figure 7-8.

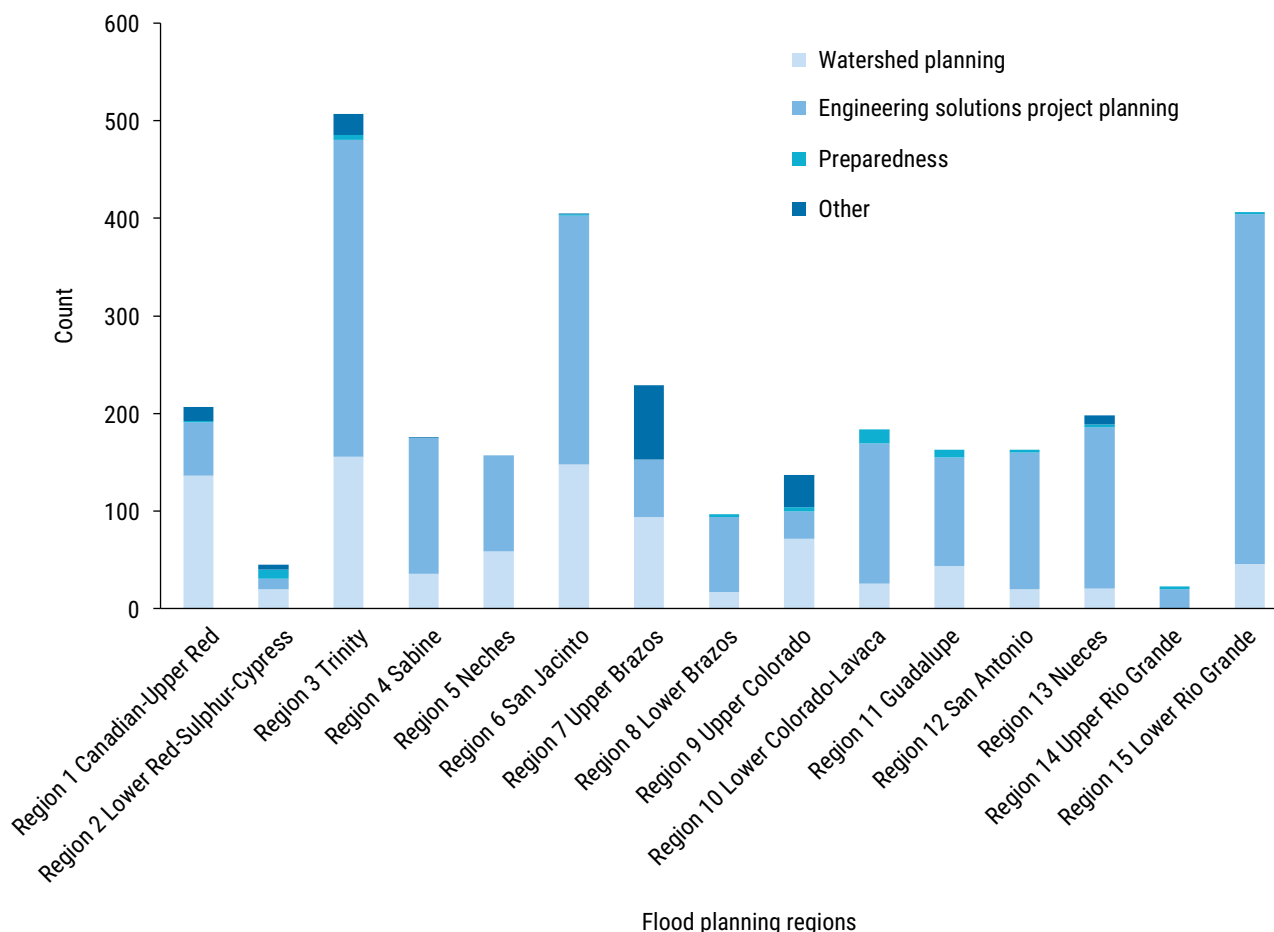
7.4 Recommended flood mitigation projects

Of the 659 projects initially identified and evaluated as potentially feasible, the regional flood planning groups ultimately chose to recommend

a total of 615 in the 15 regional flood plans at a total cost of approximately \$49.1 billion. Figure 7-9 shows the location of all recommended flood mitigation projects across the state. Figure 7-10 shows the number of recommended flood mitigation projects and the total approximate cost to implement all recommended projects per region. The full list of recommended flood mitigation projects is included in the ranked list, and their supporting technical data, including location and sponsorship, are included in the Interactive State Flood Plan Viewer.

No negative impact determination

As required by statute, a determination of no negative impact was required for all recommended flood mitigation projects. “No negative impact” means that a project will not increase the flood risk of surrounding properties. For the purposes of the flood planning effort, using best available data, the increase in flood risk was required to be measured by the 1 percent annual chance event water surface elevation and peak discharge.

Figure 7-8. Types of recommended flood management evaluations by flood planning region

A determination of no negative impact could be established if stormwater did not increase inundation of such infrastructure as residential and commercial buildings and structures for a 1 percent (100-year) annual chance storm event. Additional requirements and flexibility associated with inundation areas, peak discharge and water surface elevation are listed in Section 7.2.2.

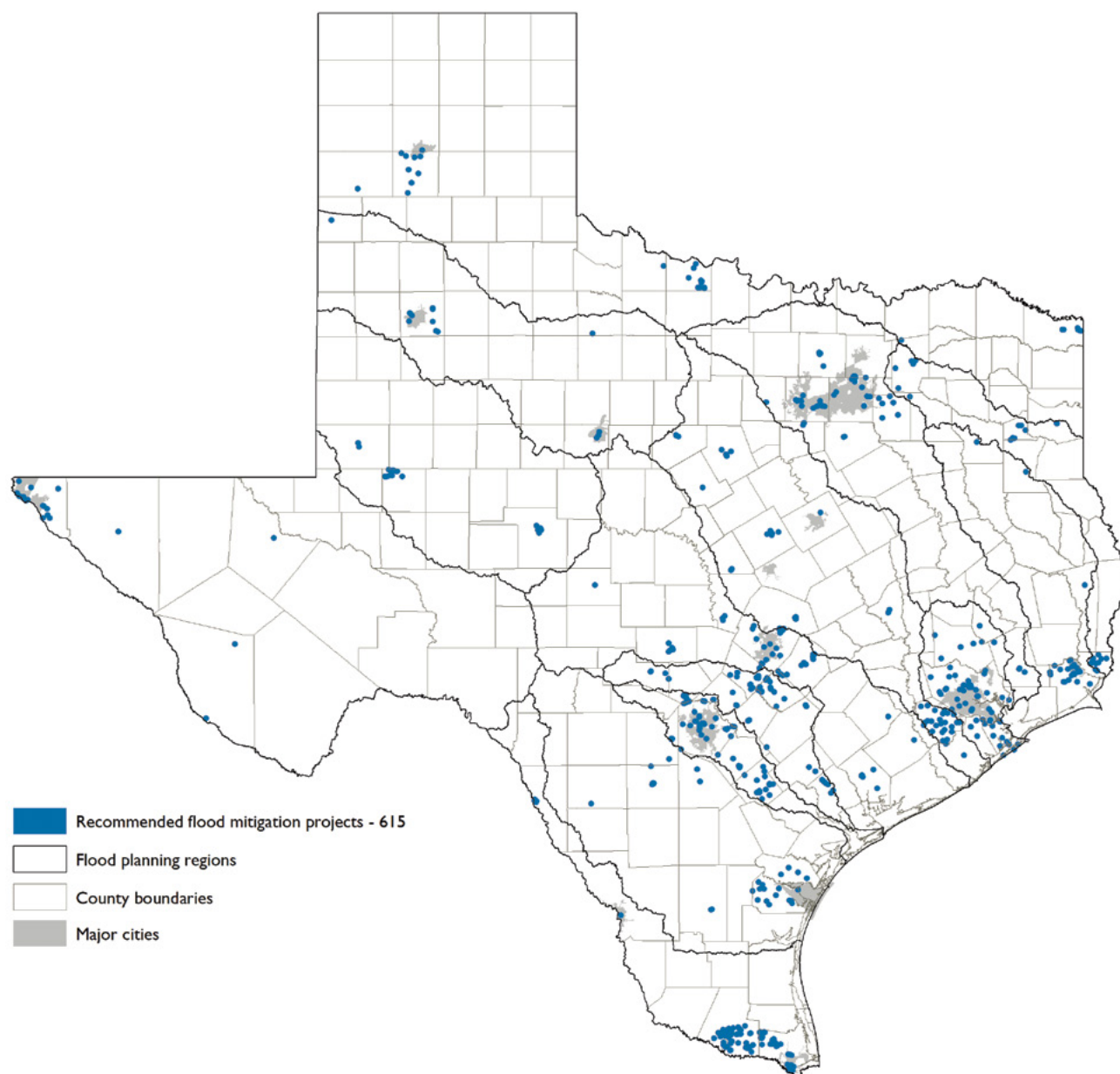
The no negative impact defined here is for the purpose of flood planning and does not have any regulatory impact related to FEMA or local or other regulatory requirements due to the approximate nature of planning. Determinations of no negative impact for each recommended flood mitigation project were submitted to the TWDB as signed and sealed statements by a professional engineer, either from the original engineer that modeled/studied the proposed project or from

the technical consultants at the time of regional flood plan development. None of the recommended flood mitigation projects were reported as causing a negative impact to neighboring areas if implemented.

Water supply

Statute requires the TWDB to determine that each regional flood plan adequately provides for the development of water supply sources, where applicable, before the TWDB may approve a regional plan. Regional flood plans must include region-wide summaries and a list of the flood management strategies and flood mitigation projects that would contribute to, negatively impact, or measurably reduce water supply. Of the 615 recommended flood mitigation projects, 37 were reported to provide at least some water supply benefit if implemented. These projects include

Figure 7-9. Locations of recommended flood mitigation projects



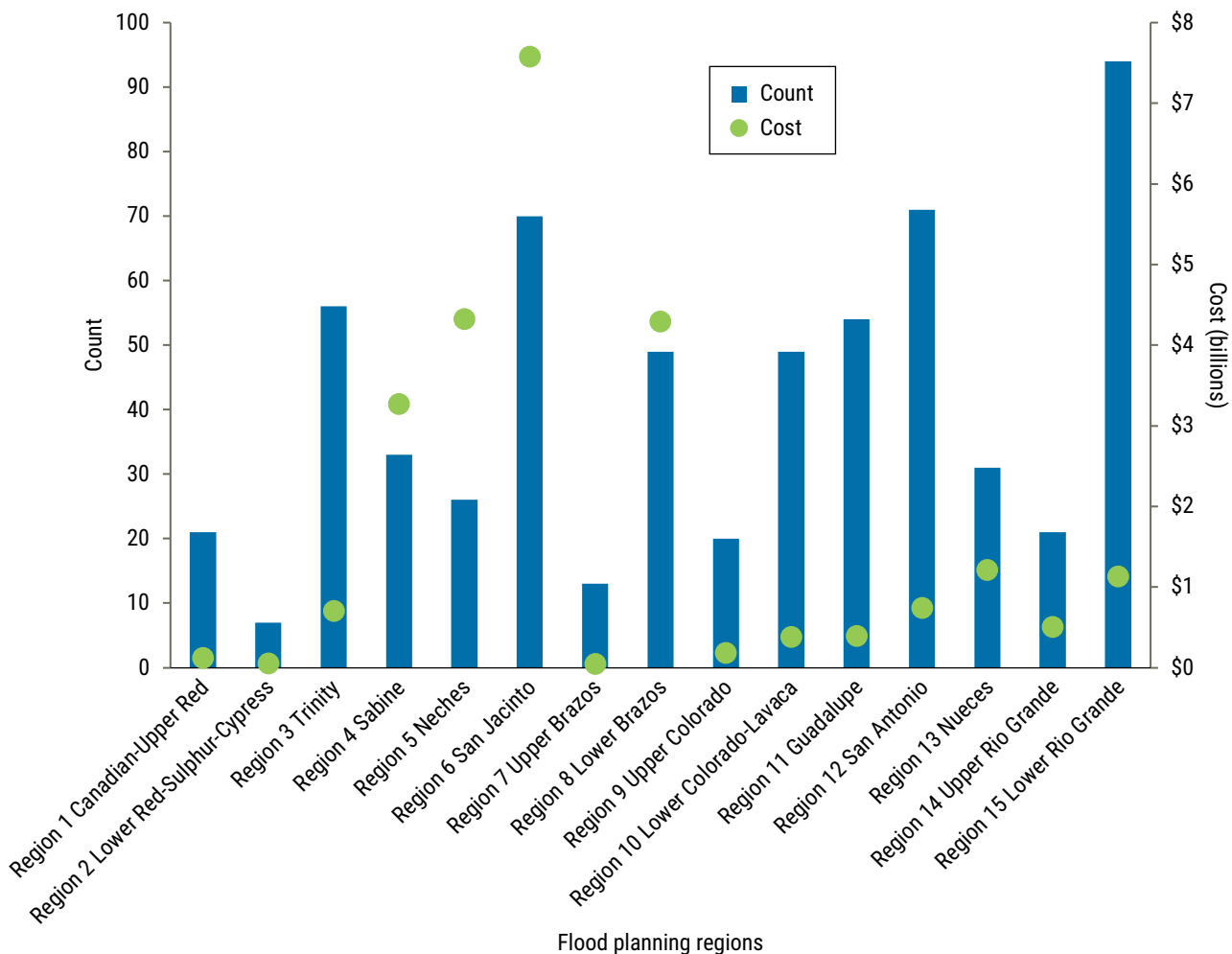
detention ponds, aquifer recharge, and natural area conservation easements, wherein the source of water supply benefits range from contributions to natural aquifer recharge to additional surface water inflows directed to reservoirs. These were recommended by Region 11 Guadalupe, Region 12 San Antonio, and Region 15 Lower Rio Grande. A discussion of the contributions to and impacts on water supply development, overall flood risk benefits, and other impacts of recommended

flood risk reduction solutions is provided in Chapter 8.

7.4.1 Recommended structural flood mitigation projects

Of the 615 flood mitigation projects recommended by the planning groups, 542 were classified as structural (Table 7-6, Table 7-7, Figure 7-11). A discussion of implementing all

Figure 7-10. Count and estimated cost of recommended flood mitigation projects by flood planning region*



* Figure 7-10 does not include Region 6 San Jacinto project ID 063000127, "Galveston Bay Surge Protection Coastal Storm Risk Management project," with a cost of approximately \$24 billion (49 percent of the total cost of recommended flood mitigation projects).

recommended flood risk solutions is provided in Chapter 8.

7.4.2 Recommended non-structural flood mitigation projects

Of all the projects recommended by the regional flood planning groups, 73 were classified as non-structural (Table 7-8, Figure 7-12). Non-structural flood mitigation projects reduce the impact of flooding without relying solely on physical infrastructure solutions.

Preparedness studies

There were 53 non-structural flood mitigation projects recommended under this category with

a total estimated cost of approximately \$11.2 million. The variety of projects include

- adopting or updating regulations and ordinances for enhanced hazard mitigation strategies;
- improving local databases to better track properties with repetitive loss; and
- installing sensors, gages, and early detection systems to provide early warning before imminent road flooding.

Property or easement acquisition

There were 13 non-structural flood mitigation projects recommended under this category with

Table 7-6. Summary of recommended structural flood mitigation projects by flood planning region

Region	Coastal	Flood walls and levees	Dams	Nature-based solutions	Storm drains
1	0	0	0	0	6
2	0	0	0	0	0
3	0	0	2	0	11
4	0	1	0	0	1
5	0	0	0	0	0
6	1	0	0	0	0
7	0	0	1	2	0
8	0	0	0	0	4
9	0	0	0	0	1
10	0	3	1	0	1
11	0	0	1	5	2
12	0	0	0	1	14
13	0	0	0	0	2
14	0	0	0	0	1
15	0	0	0	0	4
Total	1	4	5	8	47

Table 7-6 (continued). Summary of recommended structural flood mitigation projects by flood planning region

Region	Detention ponds	Channels	Regional projects	Low water crossings	Infrastructure	Grand total
1	0	0	1	8	5	20
2	2	2	0	1	1	6
3	4	0	0	1	33	51
4	12	6	0	8	0	28
5	4	6	16	0	0	26
6	14	3	25	0	7	50
7	0	2	0	2	4	11
8	1	25	8	10	0	48
9	2	15	0	0	1	19
10	1	5	0	15	0	26
11	6	4	11	12	5	46
12	5	5	3	34	5	67
13	4	3		3	19	31
14	14	1	3	0		19
15	4	2	16	0	68	94
Total	73	79	83	94	148	542

Table 7-7. Count and approximate total cost of structural flood mitigation projects by project type

FMP type	Recommended FMP count	Total FMP cost*	Notes
Low water crossings or bridge improvements	94	\$475 million	These structural flood mitigation projects included projects to improve low water crossings or bridges at risk of flooding. Unsurprisingly, most of the recommended improvements for low water crossings are in regions with the highest proportion of low water crossings across the state: Region 8 Lower Brazos, Region 10 Lower Colorado-Lavaca, Region 11 Guadalupe, and Region 12 San Antonio—all regions within Flash Flood Alley.
Infrastructure	148	\$2.8 billion	These projects varied across regions and included improvements to storm sewers and roadside ditch systems as well as the construction of detention basins, bridge elevation, channel grading, and street reconstruction.
Regional detention ponds	73	\$3.7 billion	Regional detention ponds are designed for the temporary or permanent retention of storm runoff. The areas of these recommended flood mitigation projects vary in size from approximately 9,319 square feet to more than 408 square miles.
Regional channel improvements	79	\$5.5 billion	These projects generally aim to restore, maintain, and/or enhance stormwater flow capacity to mitigate flooding in adjacent drainage areas or detention basins.
Storm drain improvements	47	\$443 million	These flood mitigation projects largely consist of installing, repairing, and upgrading stormwater drainage systems.
Dam improvements, maintenance, and repair	5	\$68.5 million	These projects help address aging dam infrastructure through repair and maintenance actions.
Flood walls and levees	4	\$2.4 billion	These projects focus on constructing or improving flood walls and levees—embankments to prevent overflow from the adjacent water body.
Coastal protections	1	\$24 billion	Coastal protection flood mitigation projects include sea wall improvements, ecosystem restoration, bayou gates, and other structural and non-structural measures to increase flood protection along Texas' coastline.
Nature-based solutions	8	\$6.9 million	These projects include playa improvements, conservation easement acquisition, and detention facilities enhanced with natural features.
Comprehensive regional projects	83	\$9.2 billion	This category includes projects intended to work together to achieve flood risk reduction, such as plans to construct levees, floodwalls, pump stations, drainage structures, detention ponds, or other flood mitigation infrastructure.

* Costs are approximate.

FMP = Flood mitigation project

a combined estimated cost of approximately \$162 million. These projects generally focused on buyouts, the purchase of private residential properties at risk for recurring flood damage and/or loss of life.

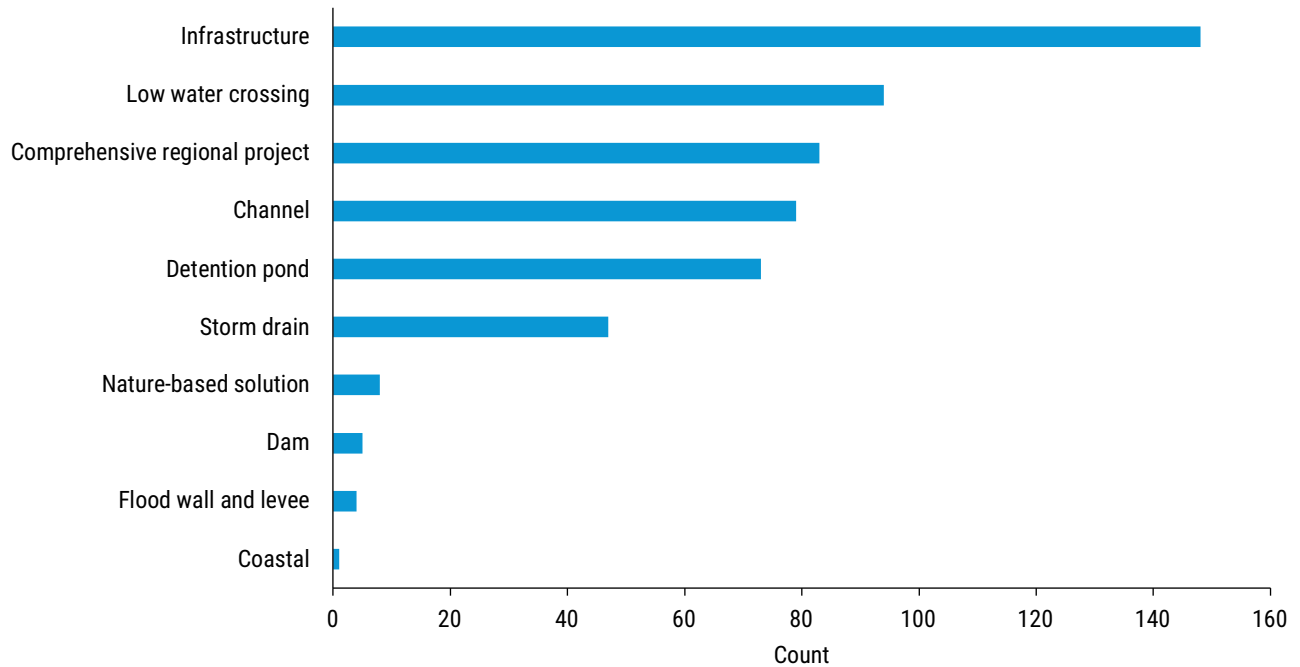
Elevation of individual structures

There were four non-structural flood mitigation projects recommended under this category with a combined estimated cost of approximately \$20.6 million. Elevating a structure involves physically raising it above the base flood elevation. Accord-

ing to FEMA, this method of flood risk reduction may be achieved through a variety of methods, including “elevating on continuous foundation walls; elevating on open foundations, such as piles, piers, posts, or columns; and elevating on fill” (FEMA, n.d.).

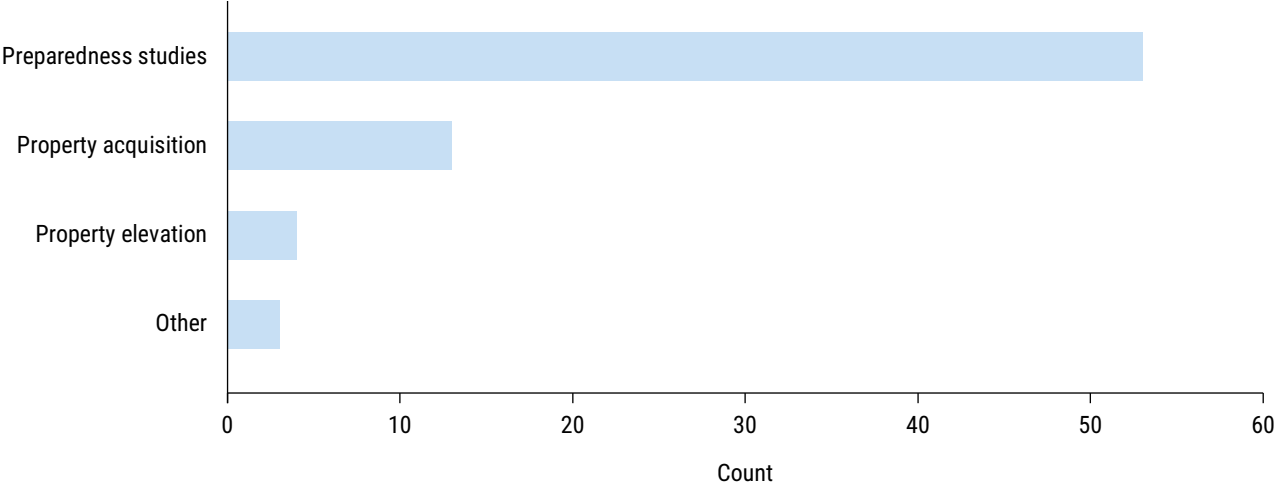
Other non-structural projects

There were three non-structural flood mitigation projects recommended under this category with a total cost of approximately \$911,000. These projects include efforts to disperse National Flood

Figure 7-11. Count of recommended structural flood mitigation projects by project type**Table 7-8. Summary of recommended non-structural flood mitigation projects by flood planning region**

Region	Preparedness studies	Property acquisition	Property elevation	Other	Total
1	1	0	0	0	1
2	1	0	0	0	1
3	2	3	0	0	5
4	0	3	1	0	4
5	0	0	0	0	0
6	20	0	0	1	21
7	1	1	0	0	2
8	0	1	0	0	1
9	0	0	0	1	1
10	19	1	3	0	23
11	7	1	0	0	8
12	1	3	0	0	4
13	0	0	0	0	0
14	1	0	0	1	2
15	0	0	0	0	0
Total	53	13	4	3	73

Figure 7-12. Summary of recommended non-structural flood mitigation projects by project type



Insurance Program materials, developing floodplain ordinances at the county level, and playa improvements.

7.5 Recommended flood management strategies

The planning groups were required to demonstrate that each recommended flood management strategy meets the following criteria, as applicable:

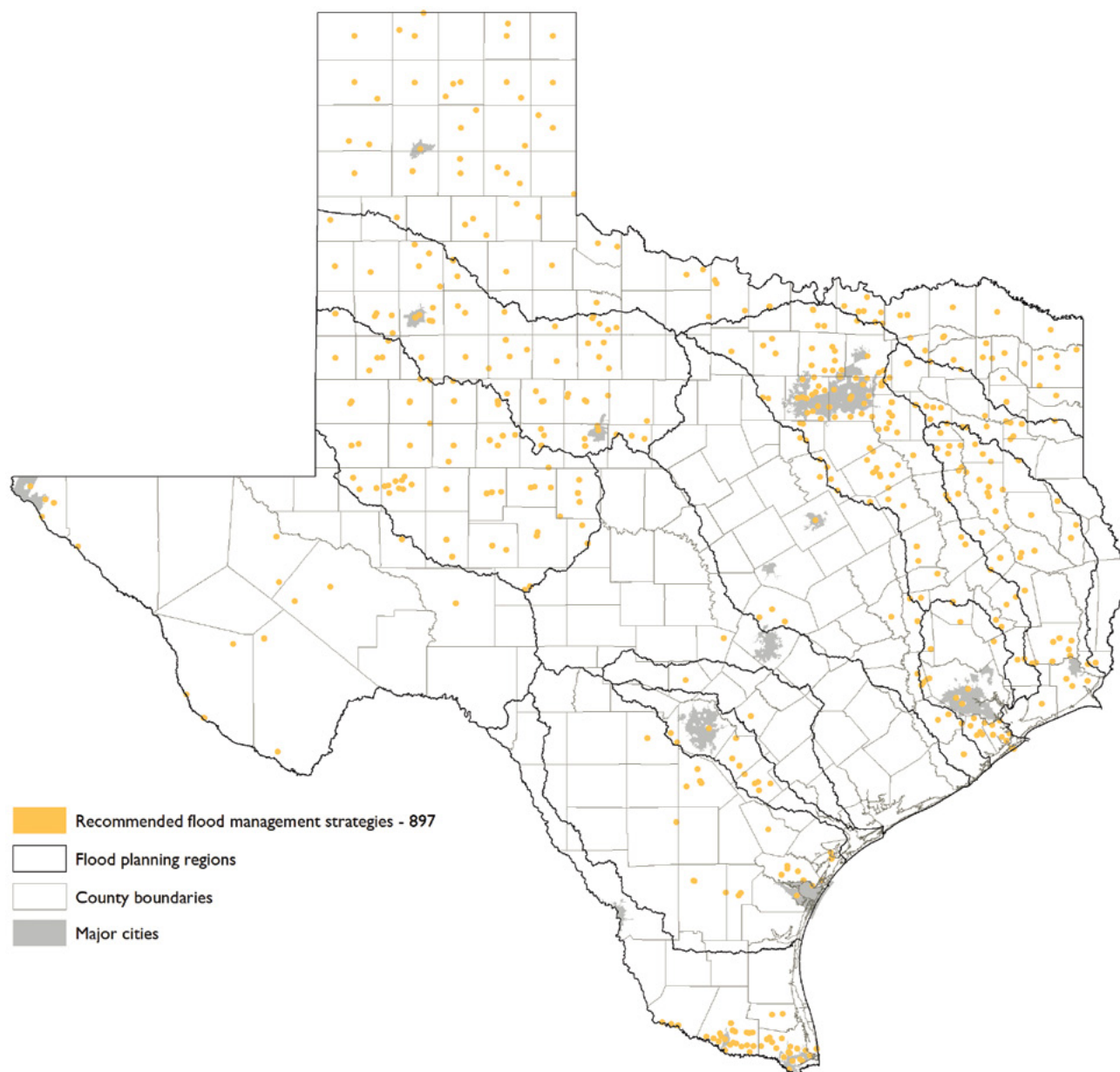
- Reduces the potential impacts of flooding.
- Mitigates for flood events associated with a 1 percent (100-year) annual chance storm event; if mitigating for 1 percent (100-year) annual chance storm events is not feasible, the planning groups may recommend, with an explanation, flood management strategies that mitigate more frequent events.
- Includes measurable reductions in flood impacts in support of the region’s specific flood mitigation and/or floodplain management goals.
- If contributing to water supply, the strategy must not result in an overallocation of a water source based on the water availability alloca-

tions in the most recently adopted state water plan.

Of the 1,097 flood management strategies initially identified and evaluated by the regional flood planning groups, 897 were ultimately recommended for inclusion in the 2023 regional flood plans with a total estimated cost of approximately \$2.8 billion (Figure 7-13, Figure 7-14). There were 771 recommended flood management strategies with non-recurring, non-capital costs totaling over \$313 million.

While most of the planning groups chose to approach flood management strategies community by community, several regions chose to recommend broad, regional strategies and initiatives. Of these, the most notable are Region 10 Lower Colorado-Lavaca and Region 11 Guadalupe, each of which recommended five region-wide strategies. The reasoning was to make each strategy inclusive of all communities within the region and encourage collaboration between sponsors, particularly neighboring communities. Table 7-9 summarizes the recommended flood management strategies by category across each planning region. Figure 7-15 summarizes all recommended flood management strategies by category.

Figure 7-13. Locations of all recommended flood management strategies



None of the recommended flood management strategies are anticipated to have a negative impact on neighboring areas, and one recommended strategy reported a water supply benefit, if implemented.

Some regions chose to categorize potential construction projects as flood management strategies versus flood mitigation projects if they were unable to meet the technical evaluation

threshold of a flood mitigation project, such as the benefit-cost analysis.

7.6 Ranking recommended flood risk reduction solutions

Texas Water Code § 16.061 requires the state flood plan to include a ranked list of all recommended flood risk reduction solutions. Ranking

Figure 7-14. Count and estimated cost of all recommended flood management strategies by flood planning region

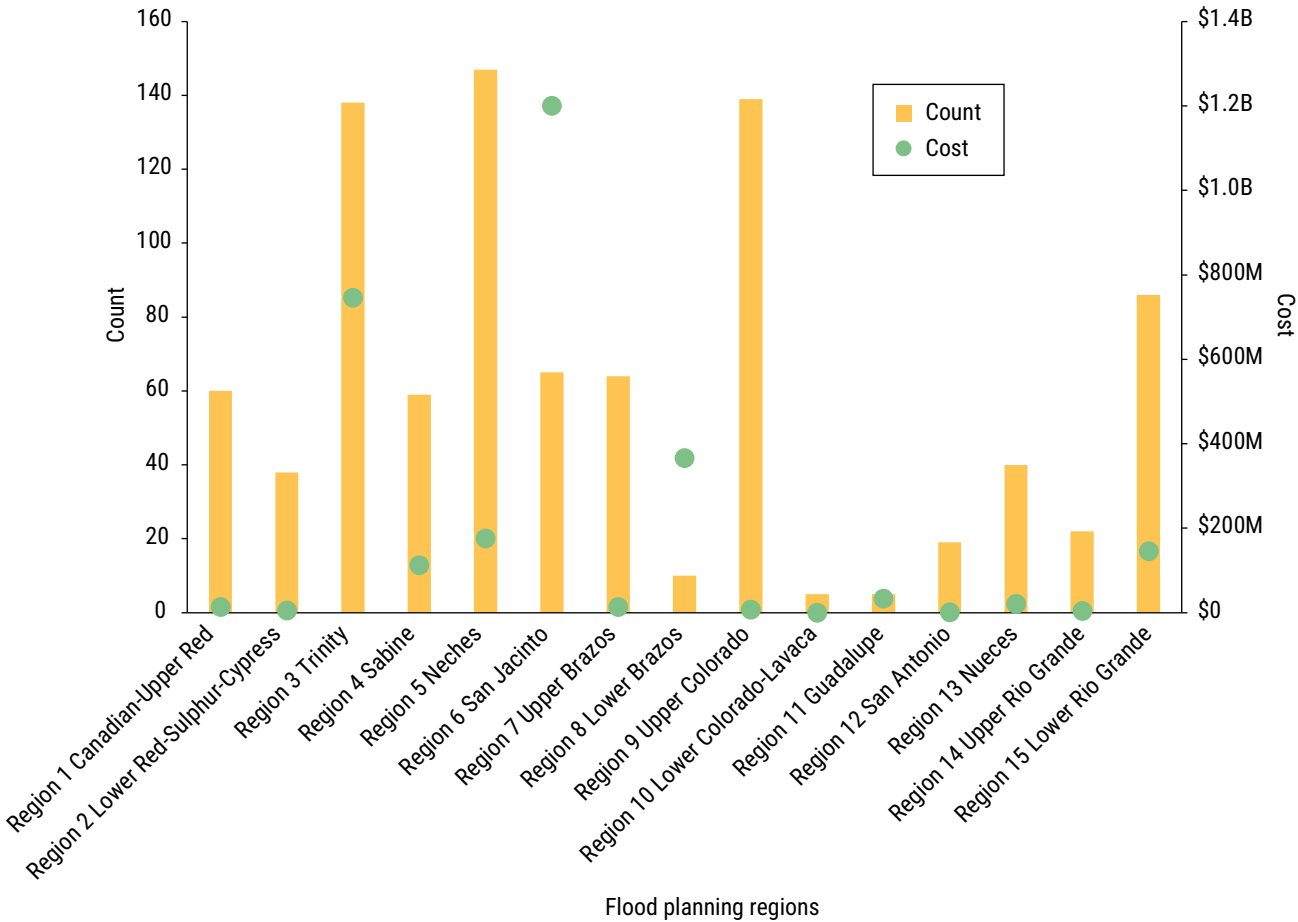
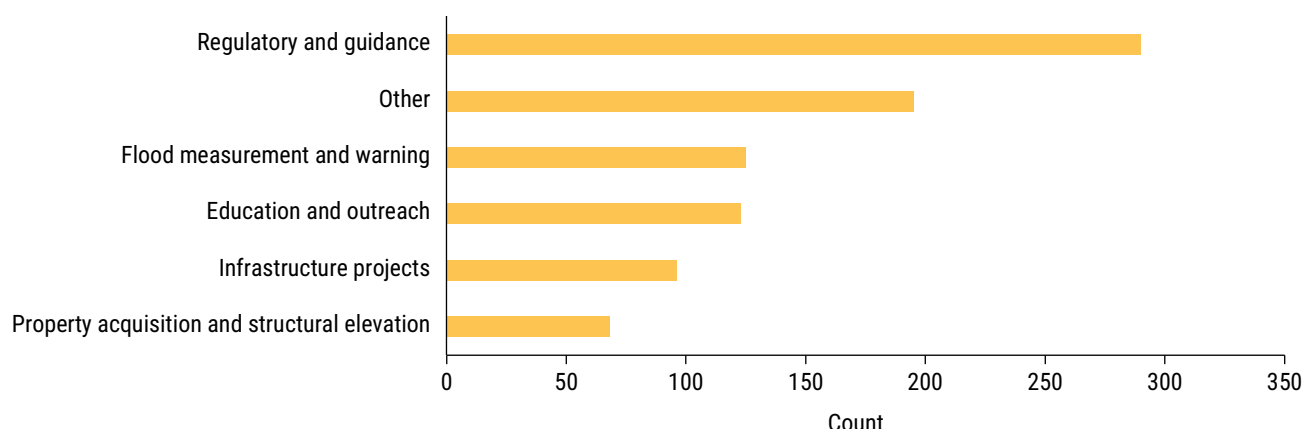


Table 7-9. Recommended flood management strategy categories by flood planning region

Region	Education and outreach	Flood measurement and warning	Infrastructure projects	Property acquisition and structural elevation	Regulatory and guidance	Other	Total
1	2	3	1	1	52	1	60
2	3	3	0	1	31	0	38
3	19	20	5	20	59	15	138
4	16	9	1	4	19	10	59
5	25	17	54	18	31	2	147
6	15	6	8	17	10	9	65
7	10	5	11	0	37	1	64
8	0	2	2	2	1	3	10
9	0	1	0	0	0	138	139
10	2	1	1	1	0	0	5
11	1	1	1	1	1	0	5
12	11	1	0	0	7	0	19
13	9	4	2	3	17	5	40
14	2	7	3	0	6	4	22
15	8	45	7	0	19	7	86
Total	123	125	96	68	290	195	897

Figure 7-15. Summary of all recommended flood management strategies by category**Table 7-10. Summary of recommended flood risk reduction solutions and associated eligible costs included as ranked lists in Appendix B**

Flood risk reduction solution	Count	Cost
Flood management evaluations	3,097	\$2,626,511,560
Flood mitigation projects	615	\$49,055,365,644
Flood management strategies*	771	\$2,825,000,885
Total	4,483	\$54,506,878,089

* With non-recurring, non-capital costs.

flood risk reduction solutions for this purpose primarily focused on flood risk and flood risk reduction to life and property. Per TWDB rules, the state flood plan includes three ranked lists of flood risk reduction solutions for evaluations, projects, and strategies with non-recurring, non-capital costs⁴⁰ (Table 7-10).

7.6.1 Background

The overarching goal of the regional and state flood plans is to protect against the loss of life and property by (1) identifying and reducing the risk and impact to life and property that already exists, and (2) avoiding increasing or creating new flood risks by addressing future development within areas known to have existing or future flood risks.

The ranking criteria and methodology are generally intended to

- identify areas with the worst existing risk of flooding in the 1 percent (100-year) annual chance floodplain;
- identify flood risk reduction solutions that may result in greater overall reduction in flood risk; and
- primarily focus on projects with the greater potential to mitigate the risk to life and property.

In spring 2023, the TWDB developed a proposed methodology for ranking flood management evaluations, flood mitigation projects, and flood management strategies in separate lists and solicited stakeholder feedback. The TWDB provided to stakeholders an explanation of the methodology and considerations, the ranking Excel workbooks,

⁴⁰ 31 TAC § 362.4 (c)(5))

and other supporting documents for review. The TWDB considered the valuable stakeholder feedback and made several changes, including adjusting criteria weights and normalizing scores using an inverse hyperbolic sine function,⁴¹ which resulted in a score spread that better served smaller communities.

Although a significant factor used in prioritizing Flood Infrastructure Fund financial assistance for the state fiscal year 2024–2025 cycle, the methodology was not developed directly for the purpose of allocating state funding. Agency funding decisions occur through a separate TWDB process as funds are appropriated by the Texas Legislature. How the state flood plan project ranking may be considered in any future Flood Infrastructure Fund project funding prioritization and allocation remains to be determined, although the TWDB anticipates it may play a role.

The draft proposed state flood plan ranking was utilized for the draft intended use plan for the state fiscal year 2024–2025 Flood Infrastructure Fund cycle. In January 2024, as part of the public comment period for the draft intended use plan for the state fiscal year 2024–2025 Flood Infrastructure Fund cycle, the TWDB received additional stakeholder feedback on the modified version of the ranking methodology that would play a significant role in the funding prioritization scoring. The comments received were helpful in informing the ranking, but they did not result in any further changes to the ranking criteria or methodology used in the final intended use plan prioritization.

⁴¹ The inverse hyperbolic functions are inverses of the hyperbolic functions, such that $\operatorname{arcsinh}(z) = \log(z + \sqrt{1 + z^2})$. For the purpose of the state flood plan ranking, inverse hyperbolic sine normalization distributed the number ranges in a manner similar to the logarithmic scale where it prevents the largest projects from receiving very high scores while the vast majority of remaining projects receive very few points and cluster together at the low end of the ranking scale.

7.6.2 Ranking methodology

The TWDB's ranking methodology for state flood plan flood risk reduction solutions is intended to provide a consistent approach for use across Texas to systematically address flood hazard with the population, properties, and critical facilities most at risk during a 1 percent (100-year) annual chance storm event. The ranking process aims to focus on severity of flood risk and reducing flood risk and impact to life and property as described by the legislature.

The basic approach was to ensure that by the end of the first regional flood planning cycle the TWDB would collect enough comparable data from all 15 regions to provide an adequate basis for developing a meaningful ranking method that could be applied consistently to all recommended flood solutions.

In keeping with the bottom-up approach of regional flood planning, the state flood plan ranking only utilizes data provided by planning groups in their regional flood plans. However, there is one ranking factor that was calculated by the TWDB using data reported by the regional flood planning groups: percent of structures removed from the 1 percent (100-year) annual chance floodplain.

The ranking criteria generally focused on flood risk and flood risk reduction to people, structures, critical facilities, low water crossings, farm and ranch land, and several other relevant and/or statutory factors, including water supply benefits, nature-based solutions, mobility, and environmental benefits, amongst others (Figure 7-16). During review, the TWDB noted some significant data inconsistencies across several regions in the planning group-reported datasets; therefore, certain data categories were not used in the state flood plan ranking.

To rank flood risk reduction solutions with a focus on technical merit, the TWDB only considered data submitted by the planning groups in its

Figure 7-16. Criteria and associated weights used to rank recommended flood management evaluations, flood mitigation projects, and flood management strategies^a

	Criterion	Criterion type	Criteria grouping	FME ranking criterion?	FME ranking weight	FME grouping weight	FMP ranking criterion?	FMP ranking weight	FMP grouping weight	FMS ranking criterion?	FMS ranking weight	FMS grouping weight	Max score
Reported data from FME, FMP, and FMS GIS feature classes	1 Estimated structures at 1 percent (100-year) flood risk ^a	Flood risk	Life, safety, and property	Yes	15.0%	75.0%	No	0.0%	0.0%	Yes	10.0%	40.0%	10
	2 Estimated population at 1 percent (100-year) flood risk ^a	Flood risk		Yes	15.0%		No	0.0%		Yes	10.0%		10
	3 Critical facilities at 1 percent (100-year) flood risk ^a	Flood risk		Yes	25.0%		No	0.0%		Yes	10.0%		10
	4 Low water crossings at flood risk ^a	Flood risk		Yes	20.0%		No	0.0%		Yes	10.0%		10
	5 Estimated road closures ^a	Flood risk	Mobility	Yes	5.0%	15.0%	No	0.0%	0.0%	Yes	5.0%	15.0%	10
	6 Estimated road miles at 1 percent (100-year) flood risk ^a	Flood risk		Yes	10.0%		No	0.0%		Yes	10.0%		10
	7 Estimated farm & ranch land at 1 percent (100-year) flood risk (acres) ^b	Flood risk	Agriculture	Yes	10.0%	10.0%	No	0.0%	0.0%	Yes	5.0%	5.0%	10
	8 Structures removed from 1 percent (100-year) floodplain ^a	Flood risk reduction					Yes	5.0%		Yes	10.0%		10
	9 Percent structures removed from 1 percent (100-year) floodplain (Calculated by TWDB from reported data)	Flood risk reduction	Life, safety, and property				Yes	10.0%	45.0%	No	0.0%	25.0%	10
	10 Residential structures removed from 1 percent (100-year) floodplain ^a	Flood risk reduction					Yes	2.5%		Yes	5.0%		10
	11 Estimated population removed from 1 percent (100-year) floodplain ^a	Flood risk reduction					Yes	10.0%		Yes	10.0%		10
	12 Critical facilities removed from 1 percent (100-year) floodplain ^a	Flood risk reduction					Yes	10.0%		No	0.0%		10
	13 Low water crossings removed from 1 percent (100-year) floodplain ^a	Flood risk reduction	Mobility				Yes	7.5%	5.0%	No	0.0%	0.0%	10
	14 Estimated roadway miles removed from 1 percent (100-year) floodplain ^a	Flood risk reduction					Yes	5.0%		No	0.0%		10
	15 Estimated farm & ranch land removed from 1 percent (100-year) floodplain (acres) ^b	Flood risk reduction	Agriculture				Yes	5.0%	5.0%	Yes	7.5%	0.0%	10
	16 Percent nature-based solution (by cost)	Other					Yes	2.5%					10
	17 Benefit-cost ratio	Other					Yes	2.5%					10
	18 Water supply benefit (Y/N)	Other					Yes	5.0%		Yes	5.0%		10
	FMP project type (10 points) Low water crossing (4 points) Preparedness						Yes						
	FMS project type (10 points) Flood measurement and warning (8 points) Regulatory and guidance (6 points) Education and outreach (4 points) Property acquisition and structural elevation (4 points) Infrastructure projects (2 points) Other						Yes	2.5%		No	0.0%		
	Subtotal						No	0.0%		Yes	2.5%		10
FMP project details scoring (computed by the regional flood planning groups) ^c	21 Score 1: Severity - Pre-project average depth of flooding (100-year)	Flood risk				100.0%			70.0%			100.0%	
	22 Score 2: Severity - Community need (percent population)	Flood risk					Yes	5.0%					10
	23 Score 6: Life and safety	Flood risk reduction					Yes	5.0%					10
	24 Score 8: Social vulnerability	Other					Yes	5.0%					10
	25 Score 10: Multiple benefits	Other benefits					Yes	2.5%					10
	26 Score 13: Environmental benefit	Other benefits					Yes	2.5%					10
	27 Score 15: Mobility	Other benefits					Yes	5.0%					10
	Subtotal												
	Total (must add to 100 percent)												

Note: All flood risk and risk reduction information are for 1 percent (100-year) annual chance storm. Grey cells indicate the criterion is not applicable for that flood risk reduction solution type.

^a Only recommended flood management strategies with non-recurring, non-capital costs were ranked in the 2024 State Flood Plan.

^b Indicates that select reported data were normalized on the curve (ArcSinh), scoring 0-10.

^c Project details criteria are described below. Refer to "project details scoring" for a description of all data included in project details available at www.twdb.texas.gov/flood/planning/planningdocu/2023/doc/04_Exhibit_C_TechnicalGuidelines_April2021.pdf.

Score 1: Severity - Pre-project average depth of flooding (100-year): Ranking of severity based on the baseline/pre-project average 100-year flood depth.

Score 2: Severity - Community need (percent population): Ranking of severity based on a community's need by percentage of project community affected by population.

Score 6: Life and safety: Ranking of reduced flood risk by percentage of structures removed from the 100-year floodplain in post-project condition.

Score 8: Social vulnerability: Ranking based on the Centers for Disease Control SVI data for Texas, by calculating an average project SVI by census tract and classifying the vulnerability level.

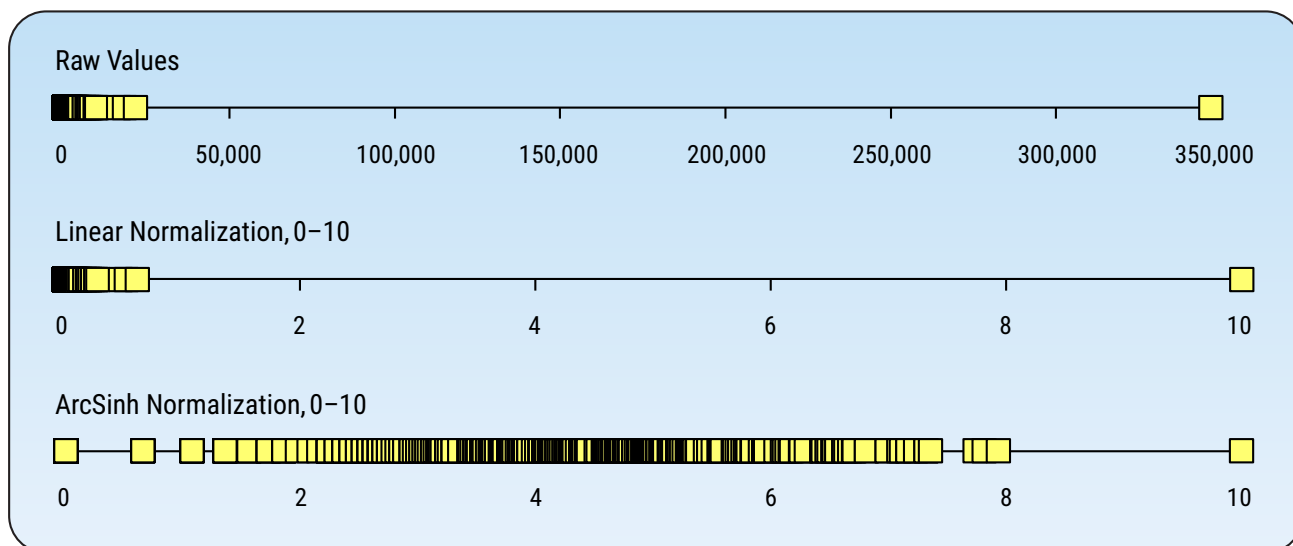
Score 10: Multiple benefits: Ranking a project based on the reporting of significant, measurable, expected benefits to: recreation, transportation, social and quality of life, local economic impacts, meeting sustainability goals, and/or project resilience goals.

Score 13: Environmental benefit: Ranking of expected level of environmental benefits to be delivered by project to water quality, cultural heritage, habitat, air quality, natural resources, and soils/erosion and sedimentation.

Score 15: Mobility: Ranking project improvement and protection of mobility during flood events, with particular emphasis on emergency service access and major access routes.

FME= flood management evaluation FMP= flood mitigation project FMS= flood management strategy

Figure 7-17. Effect of inverse hyperbolic sine normalization methods for ranking using estimated population removed from 1 percent (100-year) annual chance floodplain



adopted ranking methodology. This methodology includes considering initial feedback received from the TWDB Flood Technical Advisory Group and two rounds of flood planning stakeholder input prior to publishing the initial draft state flood plan. While some potential criteria considered for ranking were ultimately not adopted, they were still included in the stakeholder feedback materials for transparency.

Select reported data criteria was normalized using an inverse hyperbolic sine function to transform the raw data to a range of 0 to 10.⁴² This approach was used to more evenly distribute scores over the full range of potential points for each criterion and prevent the largest solutions from receiving very high scores while the vast majority of remaining solutions receive very few points and cluster together at the low end of the ranking scale (Figure 7-17).

There are three sets of prioritizations by flood risk reduction solution type:

Flood management evaluations: The ranking criteria for flood management evaluations are

limited to the identification of flood risk in the 1 percent (100-year) annual chance floodplain, which relied on reported raw data included for each of the recommended flood mitigation projects. These criteria were grouped into three major themes: (1) life, safety, and property; (2) mobility; and (3) agriculture. The associated proposed weights for these criteria show an emphasis on areas of greatest risk to life and property, including areas with low water crossings and structures.

Flood mitigation projects: These ranking criteria primarily focus on flood risk reduction in the 1 percent (100-year) annual chance floodplain in addition to several other benefit indicators, including nature-based solution, benefit-cost ratio, and water supply benefit. The ranking criteria for flood mitigation projects are split into two major categories:

- **Reported data:** Raw data included for each recommended project. Criteria in this category are grouped into three major themes: (1) life, safety, and property; (2) mobility; and (3) agriculture and comprise 70 percent of the total weight for flood mitigation projects. Only one of these criteria, “percent of structures removed from 1 percent (100-year) annual chance floodplain,”

⁴² For example, a score of 10 was assigned to all values greater than a certain higher end number for each reported criterion that was normalized.

was calculated by the TWDB using reported data. This criterion is intended to give additional weight to projects with a bigger impact on smaller communities.

- **Project details:** More complex project scores computed by planning groups using raw data. While reported data was required for all recommended flood mitigation projects, not all planning groups had pertinent information available during this planning cycle. In these events, planning groups were advised to leave fields blank, in which the criteria were scored as zero. Criteria obtained from the project details category comprises 30 percent of the total weight for flood mitigation projects. The project details template is an Excel worksheet intended to acquire detailed project data for each recommended flood mitigation project in the regional flood plan. For details on how scores were calculated, refer to Section 3.9 of TWDB Exhibit C: Technical Guidelines for Regional Flood Planning and the Project Details Workbook available on the TWDB website.⁴³

Flood management strategies: The ranking criteria for flood management strategies focus on risk identification in the 1 percent (100-year) annual chance floodplain and flood risk reduction. These criteria relied on reported raw data included for each of the recommended flood management strategies, which were grouped into three major themes: (1) life, safety, and property; (2) mobility; and (3) agriculture. While there is potential for flood management strategies to share the same flood risk reduction criteria as projects, the TWDB found a general lack of data provided to that effect as many recommended strategies are non-structural.

7.6.3 Ranking results

The results of TWDB flood risk reduction solution rankings are included in Appendix B and available to review or download via the Interactive State

Flood Plan Viewer.⁴⁴ The spreadsheets used to develop the rankings are also available on the 2024 State Flood Planning website.

References

FEMA (Federal Emergency Management Agency), n.d., Structure elevation, www.fema.gov/hmgrp-appeal-categories/structure-elevation#:~:text=Structure%20Elevation%20is%20an%20eligible,by%20FEMA%20or%20local%20ordinance

FEMA (Federal Emergency Management Agency), 2009, BCA reference guide, www.fema.gov/sites/default/files/2020-04/fema_bca_reference-guide.pdf



Blanco Riverine Flood Mitigation Project; photo courtesy of James Arceneaux

⁴³ www.twdb.texas.gov/flood/planning/planningdocu/2023/index.asp

⁴⁴ Texasstatefloodplan.org