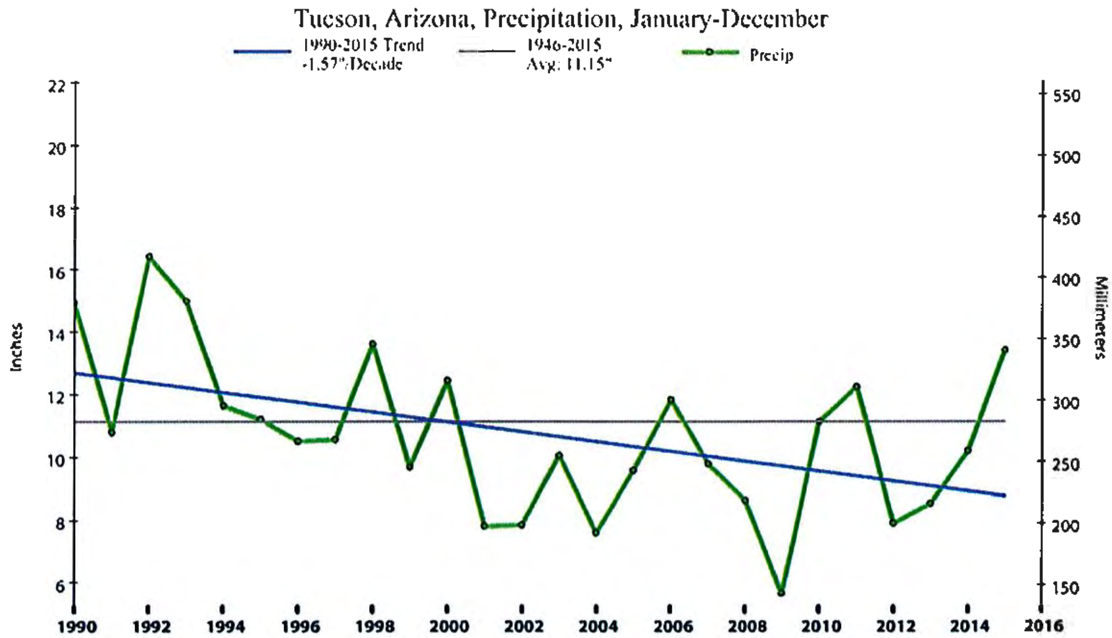

Figure 4-1: Tucson average precipitation variances based on 1990-2015 trend

Probability and Magnitude

There is no commonly accepted return period or non-exceedance probability for defining the risk from drought (such as the 100-year or 1% annual chance of flood). The magnitude of drought is usually measured in time and the severity of the hydrologic deficit. There are several resources available to evaluate drought status and even project expected conditions for the very near future.

The National Integrated Drought Information System (NIDIS) Act of 2006 (Public Law 109-430) prescribes an interagency approach for drought monitoring, forecasting, and early warning[1]. The NIDIS maintains the U.S. Drought Portal[2], which is a centralized, web-based access point to several drought related resources including the U.S. Drought Monitor (USDM) and the U.S. Seasonal Drought Outlook (USSDO). The USDM, shown in Figure 4-2, is a weekly map depicting the status of drought and is developed and maintained by the National Drought Mitigation Center. The USSDO, shown in Figure 4-3, is a six-month projection of potential drought conditions developed by the National Weather Service's Climate Prediction Center. The primary indicators for these maps for the Western U.S. are the Palmer Hydrologic Drought Index and the 60-month Palmer Z-index. The Palmer Drought Severity Index (PSDI) is a commonly used index that measures the severity of drought for agriculture and water resource management. It is calculated from observed temperature and precipitation values and estimates soil moisture. However, the Palmer Index is not considered consistent enough to characterize the risk of drought on a nationwide basis[3] and neither of the Palmer indices are well suited to the dry, mountainous western United States.

Due to climate variability, there is a likelihood of continuously higher temperatures and below normal precipitation, all aiding in drought conditions. The local vulnerability depends on duration, intensity, geographic extent, and regional water supply demands by humans and vegetation.

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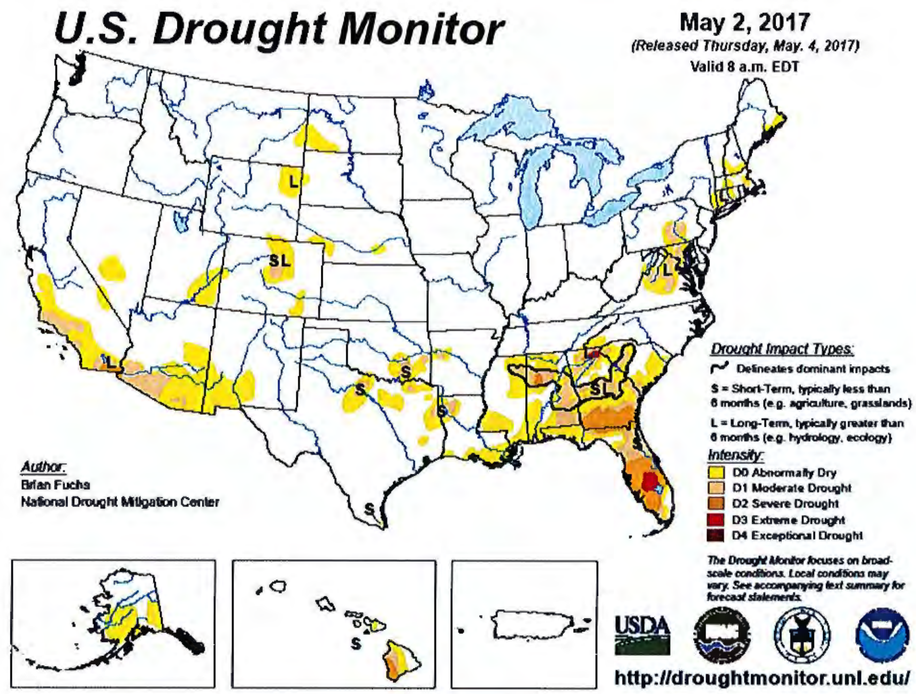
[1] National Integrated Drought Information System, 2007. *National Integrated Drought Information System Implementation Plan*, NOAA.

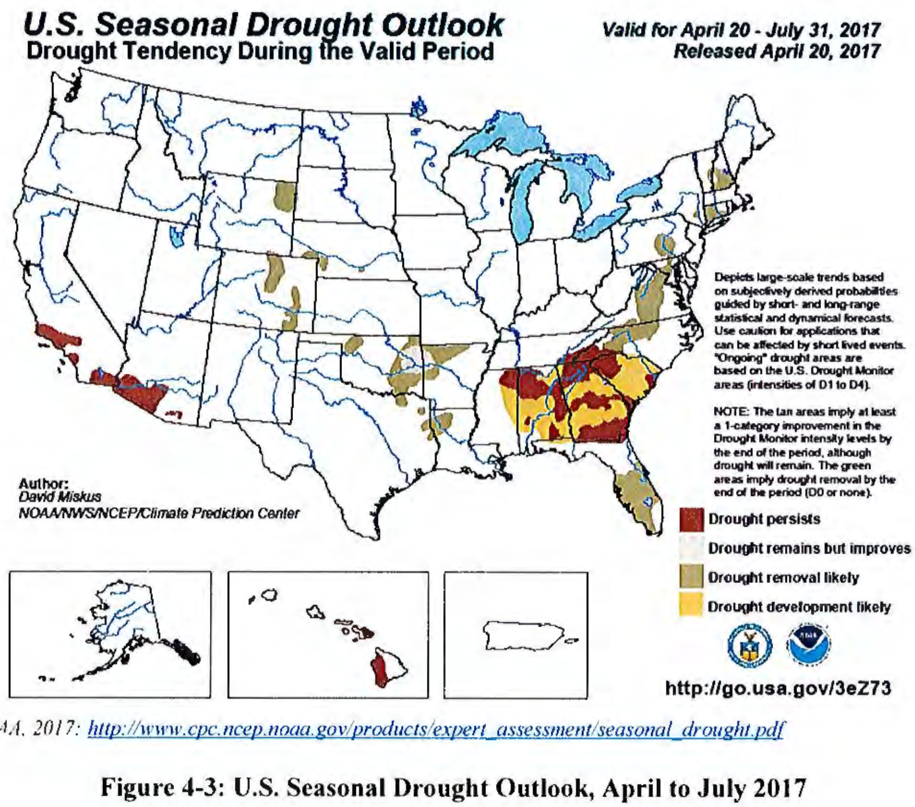
[2] NIDIS U.S. Drought Portal website is located at: https://www.drought.gov/drought/home

[3] Federal Emergency Management Agency, 1997. *Multi-Hazard Identification and Risk Assessment A Cornerstone of the National Mitigation Strategy*.



Source: United States Drought Monitor, 2017: http://droughtmonitor.unl.edu/

Figure 4-2: U.S. Drought Monitor for May 2017



Source: Source NOAA, 2017: http://www.cpc.ncep.noaa.gov/products/expert_assessment/seasonal_drought.pdf

Figure 4-3: U.S. Seasonal Drought Outlook, April to July 2017

In 2003, Governor Janet Napolitano created the Arizona Drought Task Force (ADTF), led by ADWR, which developed a statewide drought plan. The plan includes criteria for determining both short and long-term drought status for each of the 15 major watersheds in the state using assessments that are based on precipitation and stream flow. The plan also provides the framework for an interagency group which reports to the governor on drought status, in addition to local drought impact groups in each county and the State Drought Monitoring Technical Committee. Twice a year this interagency group reports to the governor on the drought status and the potential need for drought declarations. The counties use the monthly drought status reports to implement drought actions within their drought plans. The State Drought Monitoring Technical Committee defers to the USDM for the short-term drought status and uses a combination of the Standardized Precipitation Index (SPI), evaporation and streamflow for the long-term drought status. Figures 4-4 and 4-5, present the most current short and long-term maps available for Arizona as of the writing of this plan.

The current drought maps are in general agreement that Pima County is currently experiencing an abnormally dry to extreme drought condition for the short term and in a moderate drought condition for the long term. The consensus of the Monitoring Technical Committee is that several years of above normal precipitation would be needed before the drought status is removed[1]. Figure 4-2 indicates that the drought conditions are projected to persist or intensify for Pima County over the next few months.

Vulnerability

Table 4-5: CPRI Results for Drought for 2017

Participating Jurisdiction	Probability	Magnitude/ Severity	Warning Time	Duration	CPRI Score
Marana	Likely	Catastrophic	12-24 hours	<24 hours	2.50
Oro Valley	**Highly likely**	**Critical**	**>24 hours**	**>1 week**	**3.25**
Pascua Yaqui Tribe	Likely	Limited	>24 hours	>1 week	2.50
Sahuarita	**Highly likely**	**Critical**	**>24 hours**	**>1 week**	**3.25**
Tucson	**Highly likely**	**Negligible**	**>24 hours**	**>1 week**	**2.65**
Unincorporated Pima County	**Highly likely**	**Limited**	**>24 hours**	**> 1week**	**2.95**
				County-wide average CPRI =	**2.85**

*Jurisdictions in **bold** chose the hazard for mitigation in 2017 plan.*

The Town of Oro Valley is vulnerable to drought. As a result, the Oro Valley Water Utility continuously plans for current or projected drought conditions through water supply, drought, water conservation plans, and public outreach activities. The Water Utility collaborates with other local municipalities on regional drought preparedness and planning. The Oro Valley Water Utility Drought Preparedness Plan monitors climate and environmental indicators or triggers to gauge conditions that would affect natural recharge[2]. Fluctuations of these triggers above and below specified limits will identify the state or severity of current drought conditions and the corresponding actions that will be required of water users to help mitigate the effects upon potable water resources. Any two of these triggers will indicate the stage of the drought and the actions to be taken by the Utility and its customers. Additionally, the Water Utility has a water conservation ordinance in place relating to reduced water production capabilities and water outages.[3]

[1] AZ Department of Water Resources, 2007
http://www.azwater.gov/azdwr/StatewidePlanning/Drought/documents/THafferICG102507.pdf

[2] Oro Valley Drought Preparedness Plan

[3] Oro Valley Town Code Article 15-18

At this time, the Town of Sahuarita does not own or operate a water company. Within the Town of Sahuarita limits, there currently are six independent privately owned water companies and smaller areas served by on-site wells. The list of providers includes:

- Community Water of Green Valley
- Farmers Water
- Las Quintas Serenas Water
- Quail Creek Water
- Sahuarita Village Water
- Sahuarita Water

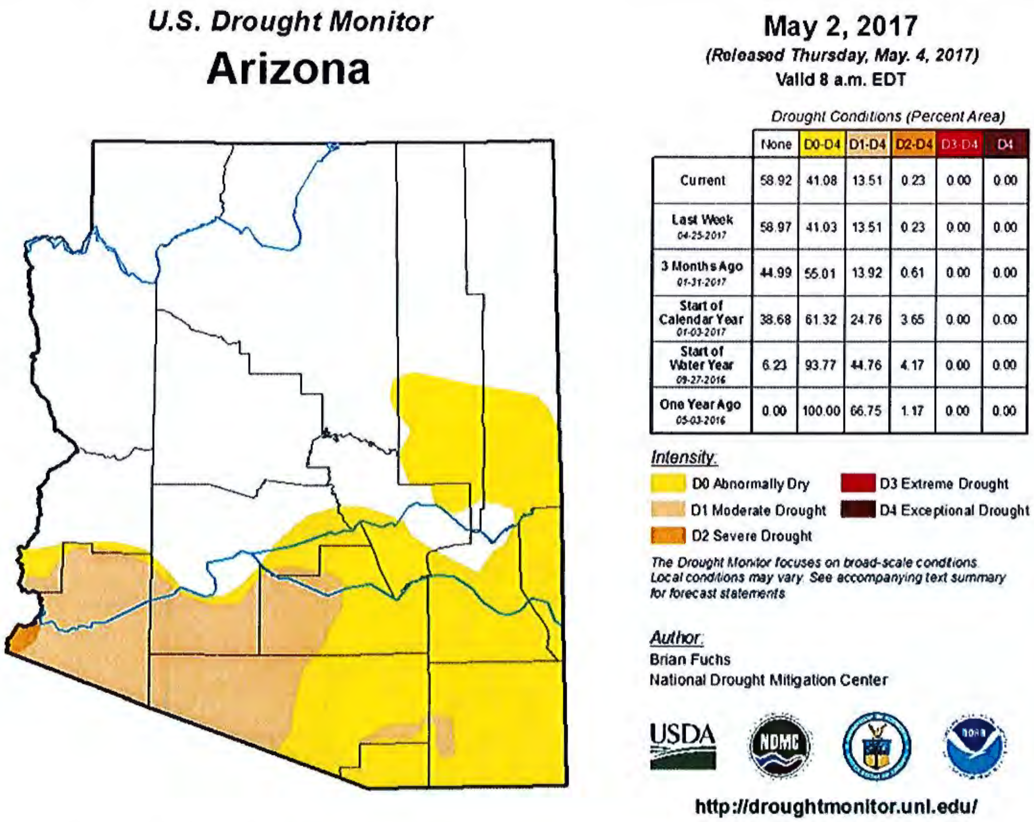
Recognizing that all water companies are vulnerable to drought, the water companies have worked with each other and the Town to develop an area wide drought plan. The drought plan takes into account Arizona Department of Water Resources goal of safe-yield. Including obtaining an assured water supply certificate for many of the master plan communities.

The Tucson Water Department utilized the area's ground water resources to supply water to its customers (citizens and businesses) within the City via a large system of wells for decades. Over a decade of drought, leading to lack of replenishment of the ground water table, has stressed the water supply and lead to measurable subsidence (drop in elevation) in areas of the City as ground water tables are drained.

While the Tucson Water Department has begun to use its allotment of Colorado River Water to replenish water tables, and while they continue to undertake many water conservation programs for residents and business owners, continued periods of drought place stress on the water system leading to increased vulnerability for water shortages in the future.

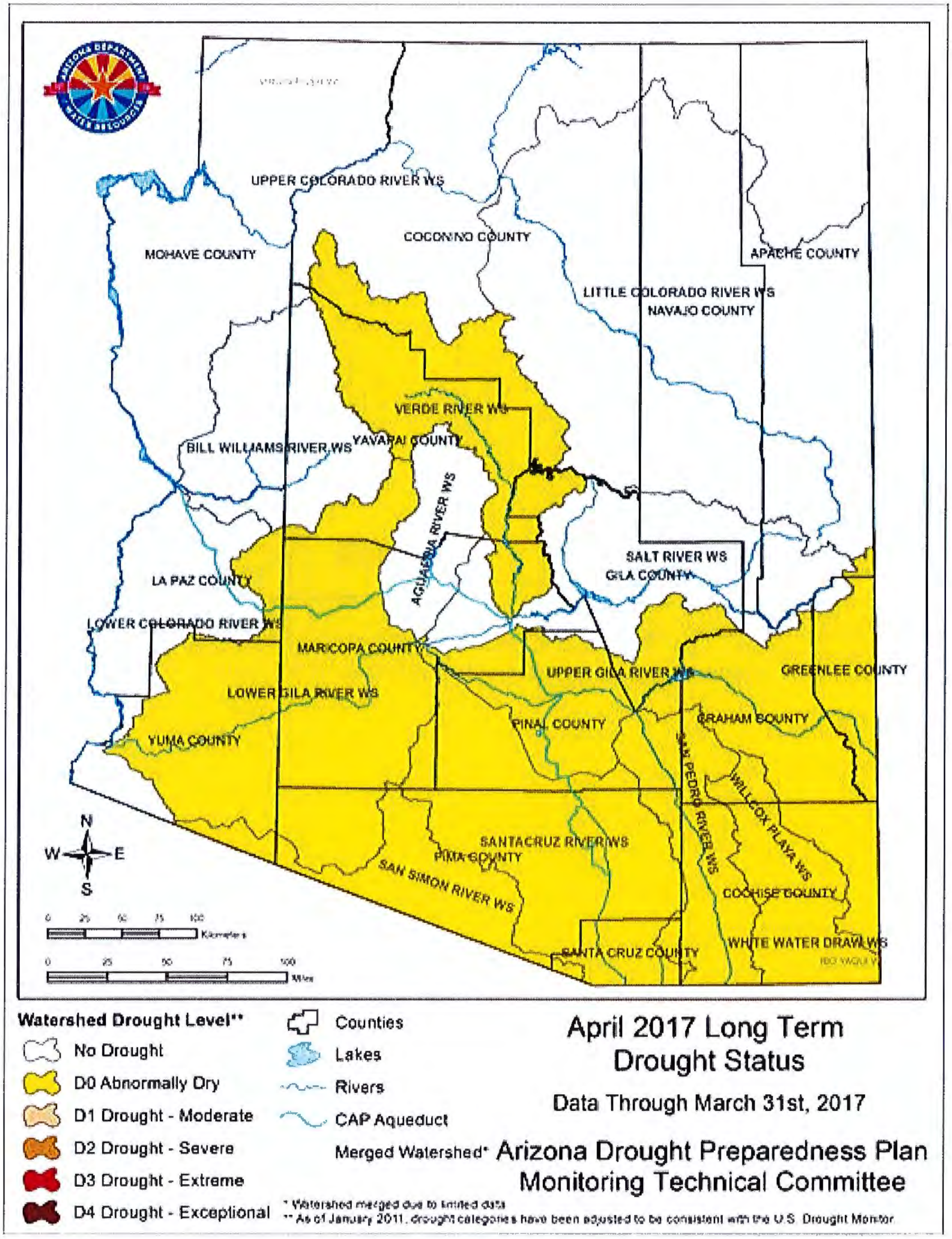
Unincorporated Pima County is vulnerable to drought for the same reasons as the other jurisdictions. Pima County has a Drought Response Plan that is based on "the varying conditions related to water resource supply and distribution system capabilities."[1] Actions within the plan will provide for maximum beneficial use of water resources for the interest of the public health, safety and welfare. The plan is broken up into different stages based on the severity of the drought stage.

[1] Pima County Drought Management, 2016: https://webcms.pima.gov/government/drought_management/



Source: Unites States Drought Monitor, 2017: http://droughtmonitor.unl.edu/data/pngs/current/current_az_trd.png

Figure 4-4: Arizona Short Term Drought Status for May 2017



Source: Arizona Department of Water Resources, 2017: http://www.azwater.gov/azdwr/StatewidePlanning/Drought/DroughtStatus2.htm

Figure 4-5: Arizona Long Term Drought Status for April 2017

Loss Estimations

No standardized methodology exists for estimating losses due to drought and drought does not generally have a direct impact on critical and non-critical facilities and building stock, except perhaps water supply systems. A direct correlation to loss of human life due to drought is improbable for Pima County. Instead, drought vulnerability is primarily measured by its potential impact to certain sectors of the County economy and natural resources including:

- Crop and livestock agriculture
- Municipal and industrial water supply
- Recreation/tourism
- Wildlife and wildlife habitat

Sustained drought conditions will also have secondary impacts to other hazards such as fissures, flooding, subsidence and wildfire. Extended drought may weaken and dry the grasses, shrubs, and trees of wildfire areas, making them more susceptible to ignition. Drought also tends to reduce the vegetative cover in watersheds, and hence decrease the interception of rainfall and increase the flooding hazard. Subsidence and fissure conditions are aggravated when lean surface water supplies force the pumping of more groundwater to supply the demand without the benefit of recharge from normal rainfall.

According to the 2015 annual report of the Pima County Local Drought Impact Group, the following drought impacts were noted:

- Decrease in ephemeral stream flows
- At Cienega Creek, groundwater levels in three wells have dropped since the drought began. Stream reaches are also shorter and the surface water volume is lower.
- Despite the warm, wetter summer weather patterns in eastern Pima County, water utilities continue to see a change in the peak high demand day. Usually occurring in mid- to late-June, the peak high water use day occurred in August and the peak was lower than in previous years.

From 1995 to 2014, Pima County farmers and ranchers received $5.7 million in disaster related assistance funding from the U.S Department of Agriculture (USDA) for crop and livestock damages. Over $2.25 million of those funds were received in 2014, following three consecutive dry winters and a severe period of the current drought cycle for Pima County.

Other direct costs such as increased pumping costs due to lowering of groundwater levels and costs to expand water infrastructure to compensate for reduced yields or to develop alternative water sources, are a significant factor but very difficult to estimate due to a lack of documentation. There are also the intangible costs associated with lost tourism revenues, and impacts to wildlife habitat and animals. Typically, these impacts are translated into the general economy in the form of higher food and agricultural goods prices and increased utility costs.

Development Trends

With anticipated population growth, Pima County's water providers will require additional water resources to meet the demands of a projected population of 1.45 million by 2041. Significant growth in the ranching and farming sectors is unlikely given the current constraints on water rights, grazing rights, and available rangeland.

The Pima County Local Drought Impact Group (LDIG), which is comprised of water providers and local, state, and federal agencies and serves as the local component of the Arizona Drought Preparedness Plan, is tasked with identifying local drought conditions and impacts, assessing severity and scope of impacts, ascertaining response and mitigation options and recommending drought staging to County Administration. LDIG submits annual drought reports to the state's Drought Monitoring Technical Committee. Pima County has also developed a Drought Response Plan and Water Wasting Ordinance that is administered and enforced through the Pima County Health Department for unincorporated areas of the county.

Drought planning should be a critical component of any domestic water system expansions or land development planning. Arizona Department of Water Resources ensures local water providers reduce their vulnerability to drought and prepare response plans in the event of a water shortage through the development of System Water Plans that are comprised of three components:

- Water Supply Plan – describes the service area, transmission facilities, monthly system production data, historic demand for the past five years, and projected demands for the next five, 10 and 20 years.
- Drought Preparedness Plan – includes drought and emergency response strategies, a plan of action to respond to water shortage conditions, and provisions to educate and inform the public.
- Water Conservation Plan – addresses measures to control lost and unaccounted for water, considers water rate structures that encourage efficient use of water, and plans for public information and education programs on water conservation.

The following are the major water providers that operate within Pima County and have developed System Water Plans with specific recommendations and requirements during times of drought:

- Tucson Water
- Marana
- Metro Water
- Flowing Wells Irrigation District
- Oro Valley
- Community Water Company of Green Valley

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4.4.2 Earthquake

Description

An earthquake is a sudden motion or trembling caused by an abrupt release of accumulated strain along faults that can be found near or far from the Earth's tectonic plates. These rigid tectonic plates move slowly and continuously over the Earth's interior, where they move away, past or under each other at rates varying from less than a fraction of an inch up to five inches per year. While this sounds small, at a rate of two inches per year, a distance of 30 miles would be covered in approximately one million years[1]. The tectonic plates continually bump, slide, catch, and hold as they move past each other which causes stress that accumulates along faults. When this stress exceeds the strength of the rocks, an earthquake occurs, immediately causing sudden ground motion and shaking. Secondary hazards may also occur, such as surface fault ruptures, ground failure, landslides, liquefaction, and tsunamis. While the majority of earthquakes occur near the edges of the tectonic plates, many damaging earthquakes also occur in the interior of plates.

Ground motion is the vibration or shaking of the ground during an earthquake caused by the radiation of seismic waves. The severity of vibration generally increases with the amount of energy released and decreases with distance from the causative fault or epicenter of the earthquake. Additional factors, such as soft soils or the presence of topographic ridges can further amplify ground motions. Ground motion causes waves in the earth's interior, also known as seismic waves, and along the earth's surface, known as surface waves. Seismic waves include P (primary) waves and S (secondary) waves. P waves are longitudinal or compressional waves similar in character to sound waves that cause back-and-forth oscillation along the direction of travel (vertical motion), with particle motion in the same direction as wave travel. They move through the earth at approximately 15,000 mph. S (secondary) waves, also known as shear waves, are slower than P waves and cause structures to vibrate from side-to-side (horizontal motion) due to particle motion at right-angles to the direction of wave travel. Unreinforced buildings are more easily damaged by S waves. Surface waves include Raleigh waves and Love waves. These waves travel more slowly and typically are significantly less damaging than seismic waves.

Seismic activity is commonly described in terms of magnitude and intensity. Magnitude (M) describes the total energy released and intensity (I) subjectively describes the effects at a particular location. Although an earthquake has only one magnitude, its intensity varies by location. Magnitude is the measure of the amplitude of the seismic wave and is expressed by a logarithmic scale that represents the amount of energy released from the movement of the fault. An increase in the Magnitude scale by one whole number represents a tenfold increase in measured amplitude of the earthquake. The Modified Mercalli Intensity (MMI) scale is a measure of how strong the shock is felt and the type of damage that it caused by the tremor at a particular location.

Another way of expressing an earthquake's severity is to compare its acceleration to the normal acceleration due to gravity. If an object is dropped while standing on the surface of the earth (ignoring wind resistance), it will fall towards earth and accelerate faster and faster until reaching terminal velocity. The acceleration due to gravity is often called "g" and is equal to 9.8 meters per second squared (980 cm/sec/sec). This means that every second something falls towards earth, its velocity increases by 9.8 meters per second, per second. Peak ground acceleration (PGA) measures the rate of change of motion relative to the rate of acceleration due to gravity. For example, acceleration of the ground surface of 244 cm/sec/sec equals a PGA of 25.0%. PGA is commonly estimated for an area and applied to building and infrastructure design. PGA, and similar calculations, are important input factors in determining the amount of shear stresses a structure can withstand.

One of the secondary hazards from earthquakes is surface faulting, the differential movement of two sides of a fault at the earth's surface. Linear structures built across active surface faults, such as railways, highways, pipelines, and tunnels, are at high risk to damage from earthquakes. Displacement along faults, both in terms of length and width, varies but can be significant (e.g., up to 20 feet), as can the length of the surface rupture (e.g., up to 200 miles).

Earthquake-related ground failure, due to liquefaction, is also a secondary hazard. Liquefaction occurs when seismic waves pass through saturated granular soil, distorting its granular structure, and causing some of the empty spaces between granules to collapse. Pore-water pressure may also increase sufficiently to cause the soil to behave like a fluid (rather than a soil) for a brief period, causing deformations. Liquefaction causes lateral spreads (horizontal movement

[1]Federal Emergency Management Agency, 1997, *Multi-Hazard Identification and Risk Assessment – A Cornerstone of the National Mitigation Strategy.*

commonly 10-15 feet, but up to 100 feet), flow failures (massive flows of soil, typically hundreds of feet, but up to 12 miles), and loss of bearing strength (soil deformations causing structures to settle or tip).

History

Seismic activity occurs on a regular basis throughout the State of Arizona, although most go undetected. Although rare, damaging earthquakes affecting Pima County have been recorded in the past as follows:

- The earliest recorded earthquake affecting Arizona, and possibly the largest, occurred in 1830. With an estimated Modified Mercalli Intensity (MMI) of IX recorded at San Pedro, AZ, approximately 25 miles west of Tucson, the earthquake would have caused massive damage to built structures[1].
- In 1887, the Sonoran earthquake caused significant destruction in southern Arizona towns, including Tucson, and was one of the largest earthquakes in North American history. The earthquake was caused by the reactivation of a basin and range normal fault that is similar to other faults in Arizona[2]. The epicenter was located approximately 100 miles south of Douglas, Arizona, along the Pitaycachi fault in Mexico, and caused great destruction at its epicenter. The earthquake was so large that it was felt from Guaymas, Mexico to Albuquerque, New Mexico. It is estimated variously to have been an intensity VIII and M7.6 earthquake. In Arizona, water in tanks spilled over, buildings cracked, chimneys toppled, and railroad cars were set in motion. An observer at Tombstone, near the Mexican border, reported sounds ``like prolonged artillery fire''[3]. With the increase in development, if such an earthquake occurred today it would cause extensive damage in southeastern Arizona[4].

The main faults of concern in Pima County are as follows and shown in Figure 4-6. The three main Quaternary faults are the Pitaycachi, Santa Rita and the Huachuca faults. There have been not earthquake events of significance since the 2012 revision.

Probability/Magnitude

Probabilistic ground motion maps are typically used to assess the magnitude and frequency of seismic events. These maps estimate the probability of exceeding a certain ground motion, expressed as peak ground acceleration (PGA), over a specified period of years. For example, Figure 4-7 displays the probability of exceeding a certain ground motion, expressed as PGA, in 50 years in the Western United States. This is a common earthquake measurement that shows three things including the geographic area affected (colored areas on map below), the probability of an earthquake of each level of severity (e.g., 2% chance in 50 years), and the severity (PGA) as indicated by color.

Note that Figure 4-7 expresses a 2% probability of exceedance and, therefore, there is a 98% chance that the peak ground acceleration displayed will not be exceeded during 50 years. The 50-year return period use is based on statistical significance and does not imply that the structures are thought to have a useful life of only 50 years. Similar maps exist for other measures of acceleration, probabilities, and time periods.

It is useful to note that according to the USGS, a PGA of approximately 10% gravity (0.10 g) is the approximate threshold of damage to older (pre-1965) dwellings or dwellings not made resistant to earthquakes. The 0.10 g measure was chosen because, on average, it corresponds to the MMI VI to VII levels of threshold damage in California within 25 km of an earthquake epicenter.

Figure 4-8 provides a more detailed view of the 2%, 50-year PGA map for Pima County. As demonstrated by this map, the central portion of Pima County has a PGA that ranges between 0.06g and 0.10g. The eastern third of the county is within the 0.10g to 0.12g range. The western portion of the county ranges from 0.08g to 0.16g with the

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[1] Arizona Division of Emergency Management, *State of Arizona Multi-Hazard Mitigation Plan*

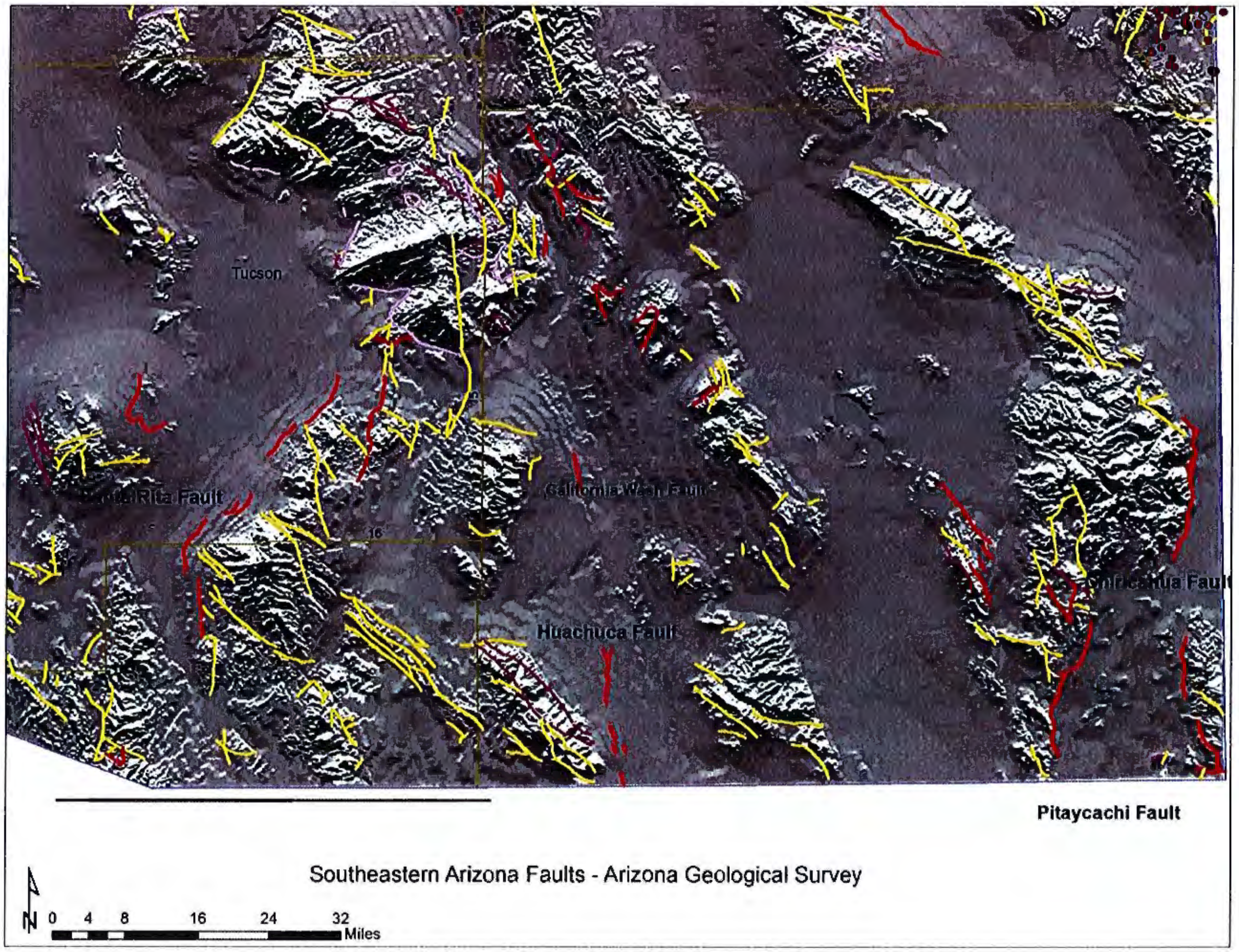
[2] DuBois, S.M., and Smith, A.W., 1980, *The 1887 earthquake in San Bernardino Valley, Sonora, historic accounts and intensity patterns in Arizona*: Arizona Bureau of Geology and Mineral Technology Special Paper no. 3, 112 p.

[3] Arizona Division of Emergency Management, *State of Arizona Multi-Hazard Mitigation Plan*; Bausch, Douglas B. and David S. Brumbaugh, May 23, 1994. Seismic Hazards in Arizona –Arizona Ground Shaking Intensity & 100 yr Acceleration Contour Maps. http://www4.nau.edu/geology/aeic/staterep.txt; D.B. Bausch and D.S. Brumbaugh, 1994, *Seismic hazards in Arizona*: Flagstaff, AZ Earthquake Information Center, 49 p., 2 sheets, scale 1:1,000,000.; US Geological Survey (USGS): September 12, 2003, "Earthquake History of Arizona." http://wwwneic.cr.usgs.gov/neis/states/arizona/arizona_history.html

[4] Jenny, J.P. and S.J. Reynolds, 1989. "Geologic Evolution of Arizona" in Arizona Geological Society Digest, No. 17.

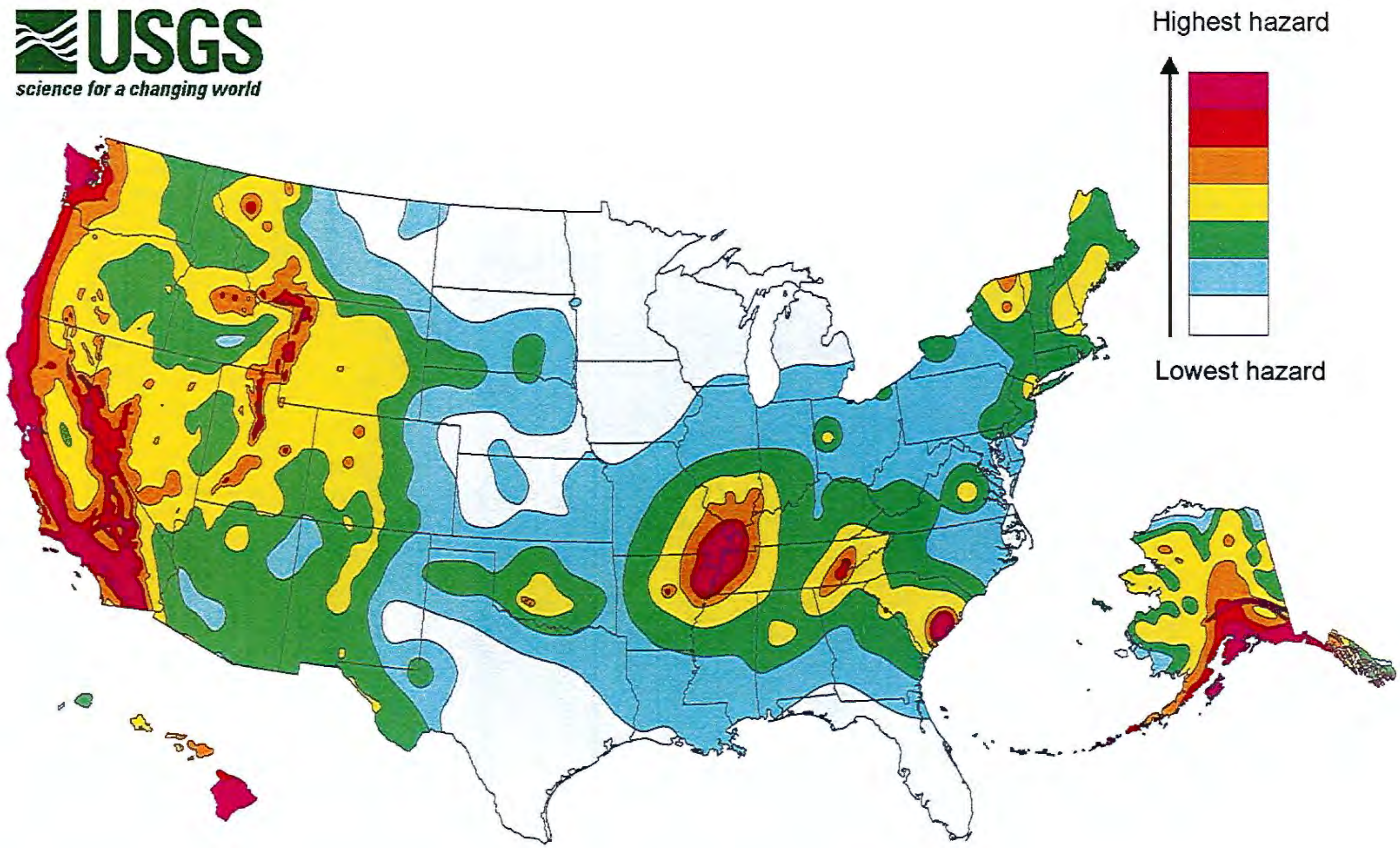
highest PGA values occurring along the Yuma County and Mexico border. Overall, PGA values for Pima County are low in comparison with other counties within the State, and especially in areas of high population.

The possible effects of climate variability on earthquake probability should be low since earthquakes are non-climatic in nature.



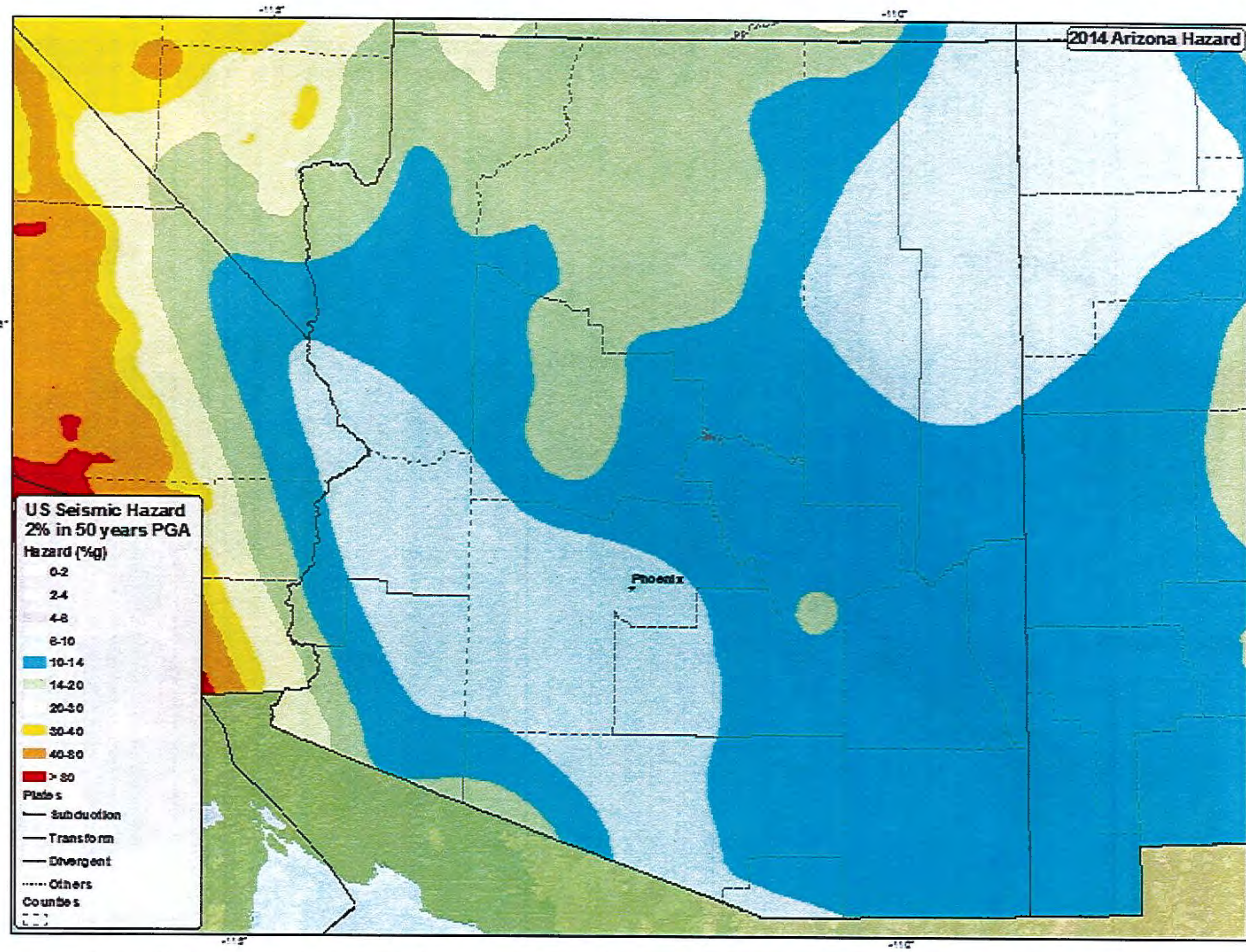
Source: Arizona Geological Society, 2017

Figure 4-6 Southeastern Arizona Earthquake Fault Systems



Source: United States Geological Survey Simplified 2014 hazard Map (PGA, 2% in 50 years), 2016:
https://earthquake.usgs.gov/hazards/hazmaps/conterminous/2014/images/HazardMap2014_lg.jpg

Figure 4-7: USGS Simplified 2014 Earthquake Hazard Map



Source: United States Geological Survey 2014 Seismic Hazard Map: https://earthquake.usgs.gov/earthquakes/byregion/arizona-haz.php

Figure 4-8: PGA for a 2% Chance in 50 Years' Recurrence

In general, the risk of seismic hazard in the urbanized portions of Pima County are relatively low; however, denser populations, existence of high rise buildings, existence of unreinforced masonry buildings, and the lack of earthquake awareness among its population elevate the risks associated with seismic activity.

The rate of seismicity in Pima County has historically been low, with the area's most recent quakes originating in San Luis in 1976 (M 6) and Baja, Mexico in 2010 (M 7.2). The largest impact of an earthquake on the metropolitan area would be the economic impact from a catastrophic southern California earthquake, which would disrupt approximately 60% of Arizona's fuel and 90% of Arizona's food goods. The Tucson metropolitan area could also be significantly affected by a major quake in the Yuma or Northern Arizona Seismic Belt (NASB). A repeat of the 1887 earthquake would result in significant damage to Arizona's population centers, particularly where development is located on alluvial plains and steep slopes. It should also be noted that although the small earthquakes occurring in Pima County are of low seismic risk to buildings, the repeated shaking could eventually cause structural damage. In unstable areas, small earthquakes may also trigger landslides and boulders rolling off mountain slopes[1].

Vulnerability

Table 4-6: CPRI Results for Earthquake for 2017

Participating Jurisdiction	Probability	Magnitude/ Severity	Warning Time	Duration	CPRI Score
Marana	Possible	Critical	12-24 hours	> 1 week	2.50
Oro Valley	Possible	Critical	< 6 hours	< 6 hours	2.50
Pascua Yaqui Tribe	Possible	Limited	< 6 hours	< 6 hours	2.20
Sahuarita	Possible	Limited	< 6 hours	> 1 week	2.50
Tucson	**Possible**	**Critical**	**< 6 hours**	**<6 hours**	**2.50**
Unincorporated Pima County	Possible	Limited	< 6 hours	> 1 week	2.50
				County-wide average CPRI =	**2.45**

*Jurisdictions in **bold** chose the hazard for mitigation in 2017 plan.*

Only the City of Tucson chose Earthquake as a hazard to mitigate. Other jurisdictions gave it the same rating as 2.50, but it was not a priority for mitigation for those Local Planning Teams. The rating of 2.50 by several others was purely coincidental.

While earthquakes are not a regular occurrence in and around the City of Tucson - none have occurred within the last planning cycle and the last documented earthquake occurring more than a century ago - there is nonetheless a recognized and documented history of large earthquakes in the vicinity that have caused damage within the City. The lack of earthquake awareness and preparedness over the last century as Tucson has built up and out, and without specific building codes to protect buildings from seismic damage; the City is in a vulnerable position. Due to the dramatic development over the past century, it is understood that an earthquake many years ago may have only tipped over water towers and startled horses would today be likely to cause widespread damage and injury within the City.

The earthquake risk assessment performed for Pima County did not explore the potential for collateral hazards such as liquefaction or landslide. However, losses associated with these ground failures would have been negligible given the level of shaking expected for Pima County (i.e., not enough strong shaking to trigger significant ground failure). However, Landslide has been added to this Plan as a hazard for unincorporated Pima County.

The annualized loss estimates developed represent the average of all eight of the HAZUS modeled return periods (100-year through 2,500-year events). The largest potential annualized losses to jurisdictions in Pima County include the City of Tucson and the unincorporated portions of Pima County. Tucson accounts for an estimated $1.6 million in residential losses and $212,000 in commercial losses equating to over 80% of the total losses countywide. These estimations have been adjusted to reflect current damage loss.

[1] Jenny, J.P. and S.J. Reynolds, 1989. "Geologic Evolution of Arizona" in Arizona Geological Society Digest, No. 17.

Development Trends

The major faults within Pima County are generally located within the mountain ranges where development is limited due to state and local land ownership. The earthquake risk in the identified growth areas of the Pima County jurisdictions is at the borderline of the 10% g PGA, which as previously stated, is the approximate threshold of damage for older (pre-1965) dwellings or dwellings not made resistant to earthquakes. Throughout the County, new development is typically regulated to comply with current building codes that will provide for more stable seismic designs of new construction.

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4.4.3 Extreme Cold

Description

Tucson's desert climate is generally prone to mild winters. The average overnight low temperature in the coldest months, December and January, hovers just above the 39°F mark. During the rest of the cooler parts of the year, in late fall and early spring, low temperatures tend to hover in the 40-50°F range.

This tendency for mild winters has led to infrastructure design that is not resistant to, nor built with the capacity for, extended cold periods. Additionally, the tendency for mild winters means that the people, residences, pets, as well as plants and wildlife in the Tucson area are not prepared for cold weather. It is for this reason that temperatures that would be considered typical in other parts of the country where cold winters are the norm are instead considered extreme cold in Tucson.

While on average winters in Tucson are mild, it is not unusual to see brief periods where overnight lows drop below freezing or even reach Hard Freeze warning levels as described by the National Weather Service. While rare in Tucson, very cold temperatures (colder than 20°F) can also occur during the winter months. The coldest temperatures often occur after winter storms move past the region, precipitation ends, and skies clear allowing for rapid cooling at night.

Since many water lines and inlets to residences and businesses are above ground and exposed to the elements, and since the populace of Tucson is not well aware of the need to protect these pipes with proper insulation, these extreme cold temperatures can result in frozen and burst pipes. This can cause extensive water damage to homes, business, and government buildings.

Additionally, during extreme cold in Tucson the populace seeks to keep warm by heating their home. However, due to the typically mild winters, natural gas distribution systems to and within the City of Tucson have not been built to handle peaks loads during extreme cold events. This has led to instances of large scale heating fuel outages during spells of extreme cold, putting at risk residents of Tucson, especially those vulnerable populations with access and functional needs.

Finally, the culture in Tucson is to expect mild winters and therefore the populace is under-informed regarding the potential for and possible impacts of extreme cold. This has and can lead to damage to homes, crops, and injuries or deaths to people or their pets.

History

While extreme cold is not the norm in Tucson, events have occurred with some regularity over the last decade. A few examples follow[1]:

- In January of 2007, extreme cold hit Tucson for several days in a row, with the low temperature at the Tucson International Airport hitting 17°F on January 15. The prolonged extreme cold weather led to substantial damage in the community due to damaged water pipes.

- In February 2011, record cold temperatures dropped into the mid to upper teens across the Tucson area for several nights in a row, with minimal daytime heating, and high winds which combined resulting in two fatalities. A woman in her late 30's was found dead in an alley near East Speedway and North Campbell Ave. A second woman was also found dead near the intersection of East Grant and North Craycroft. Another person was also found lying out in the cold nearly frozen and was taken to the hospital with non-life threatening injuries. The cold also lead to numerous burst water pipes. A water pipe at a main Metro Water location froze, leaving almost 30 residences and businesses without water on the northwest side. More than 200 customers in Tucson reported frozen or burst water pipes. At least 2000 residents and businesses were without water at some point for a day. AAA saw a 20% increase in local calls, mostly about dead car batteries. Davis-Monthan Air Force Base had several buildings damaged by flooding due to frozen fire sprinkler pipes, which resulted in the buildings being closed for safety reasons. The intersection of Grant Road and Stone Ave. was also closed due to a burst water main that was causing slick road conditions. Reid Park Zoo was also closed due to numerous broken water pipes. Due to cold temperatures along the natural gas route from El Paso to Tucson, Southwest Gas could not meet natural gas demand,

[1] [1] National Centers for Environmental Information (NCEI), 2016, https://www.ncdc.noaa.gov/stormevents/

which resulted in about 14,000 Tucson customers being without heat. Pima County and the City of Tucson collaborated to open a warming shelter for residents without heat. Untold numbers of plants, trees, and shrubs were also killed by the record cold, including many saguaro cacti.

- In January 2013, cold low temperatures persisted across much of southeast Arizona for several nights. Most of the damage consisted of broken water pipes. Low temperatures in the teens or lower 20s for several nights caused numerous pipes to burst in the Tucson metropolitan area. The Tucson International Airport dropped to 15 degrees on the morning of January 15. Most of the frozen pipes exposed to the cold were on the roofs or sides of homes. In addition, citrus fruits were damaged by the hard freeze, which meant that local food banks could not glean unpicked fruit to supplement their food donations. Total damage was estimated at $100,000. Additionally, two house fires were indirectly related to the cold weather. A mobile home caught fire when the owner attempted to thaw frozen pipes with a propane torch. Another home caught fire after residents placed a heat lamp and blankets on a patio overnight to keep pets warm. No one was injured in either fire.

Probability and Magnitude

Despite the generally mild winters in Tucson, over the last decade the National Weather Service averages two published hard freeze warnings in Tucson each year. One the extreme end of the spectrum during the 2010/2011 winter season seven hard freeze warnings were published. Thus, the probability of extreme cold weather is actually highly likely on an annual basis. While any of these hard freeze events have the potential to cause infrastructure damage, damage to the environment, and, most importantly loss of life, the most extreme cold events noted above impact Tucson with a high magnitude due to the nature of the typical building techniques, the design of utility infrastructure in the region, as well as the culture in Tucson where the residents expect mild winters and are mostly unprepared for extreme cold[2].

Vulnerability

Table 4-7: CPRI Results for Extreme Cold 2017

Participating Jurisdiction	Probability	Magnitude/ Severity	Warning Time	Duration	CPRI Score
Marana	Possibly	Limited	6-12 hours	<24 hours	2.15
Oro Valley	Possibly	Limited	< 6 hours	<1 week	2.25
Pascua Yaqui Tribe					
Sahuarita	Possibly	Limited	12-24 hours	<1 week	2.10
Tucson	**Highly Likely**	**Critical**	**>24 hours**	**>1 week**	**3.25**
Unincorporated Pima County	Likely	Limited	12-24 hours	< 1 week	2.55
				County-wide average CPRI =	**3.27**

*Jurisdictions in **bold** chose the hazard for mitigation in 2017 plan.*

Although extreme cold could affect the entire County, the City of Tucson chose it as a primary hazard to address due to its costly response costs particular to their jurisdiction.

Loss Estimations

There is no standardized method for estimating losses associated with extreme cold events and none is made for this Plan. From a historical perspective, both human and infrastructure losses could be expected with any significant extreme cold event especially regarding loss of human life for those exposed to the cold weather for long periods, and damage to water supply infrastructure. This is especially true in Pima County non-mountainous areas, such as the City of Tucson, since extreme cold events are rare and the general population is not likely to be prepared for such an event.

[2] [2] National Centers for Environmental Information (NCEI), 2016, https://www.ncdc.noaa.gov/stormevents/

Development Trend Analysis

While extreme cold is a yearly threat, it is unlikely to affect future development. Enforcement and implementation of modern building codes to regulate new developments, in particular the proper installation and protection of water supply lines, in conjunction with public education on how to respond to hazardous cold conditions is probably the best way to mitigate against such losses.

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4.4.4 Extreme Heat

Description

Extreme temperatures can occur within any area and can often have adverse impacts on the health and welfare of a community or region. These extreme temperatures can affect people, pets, plants and infrastructure throughout the area. Extreme heat is considered a risk to Pima County residents.

Extreme heat is either high temperature above the 95th percentile for the date or the combination of very high temperatures and exceptionally humid conditions that exceed regionally based indices for perceived risk. According to the National Weather Service, heat is one of the leading weather-related killers in the United States. Heat is responsible for hundreds of fatalities and even more heat-related illnesses[1]. The major human risks associated with extreme heat are as follows:

- Heat Cramps: May occur in people unaccustomed to exercising in the heat and generally ceases to be a problem after acclimatization.
- Heat Syncope: This refers to sudden loss of consciousness and is typically associated with people exercising who are not acclimated to warm temperatures. Causes little or no harm to the individual.
- Heat Exhaustion: While much less serious than heatstroke, heat exhaustion victims may complain of dizziness, weakness, or fatigue. Body temperatures may be normal to moderately elevated. The prognosis is usually good with fluid treatment.
- Heatstroke: Considered a medical emergency, heatstroke is often fatal. It occurs when the body's responses to heat stress are insufficient to prevent a substantial rise in the body's core temperature. While no standard diagnosis exists, a medical heatstroke condition is usually diagnosed when the body's temperature exceeds 105°F due to environmental temperatures. Rapid cooling is necessary to prevent death, with an average fatality rate of 15% even with treatment.

Extreme heat affects individuals who work outdoors, as well as the homeless who have no access to shade or cooling, particularly at night. In Arizona, the average cost for the hospital treatment of a heat related illness in 2008 was $7,500 per person, thus totaling $11,000,000 in treatment costs only[2]. Hikers and others involved in outdoor recreation frequently succumb to extreme heat when they run out of water. Extreme heat can stress the elderly and people with compromised immune systems or other health issues, leading to heart attacks and respiratory distress. Many of the elderly and those in poverty either have no air conditioning or have insufficient resources to use air conditioning during a heat wave. In the southwest deserts, air conditioning in the summer is exactly as critical as home heating in the winter is for those in the northern tier of states. Other vulnerable populations during a heat wave include infants, young children, and those with functional or access needs.

In addition to the loss of life, extreme heat can affect infrastructure. Power lines are de-rated based on the ambient air temperature, which provides cooling. High temperatures and calm conditions can lead to overheating of power lines as well as power transformers, resulting in widespread power outages. Transportation systems also suffer from extreme heat or cold. Rail lines can buckle in extreme heat as the metal expands. Thermal expansion and contraction causes pavements to crack, leading to moisture penetration and pavement breakdown. Extreme heat also threatens pavement markings and signage, shortening their life and requiring more frequent replacement.

History

Extreme temperature events occur in Pima County on a regular basis, but the damaging events typically occur during the summer months. The following are heat-related statistics:

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[1] National Weather Service, 2016: http://www.nws.noaa.gov/os/heat/index.shtml

[2] Arizona Department of Health Services, 2010: http://azdhs.gov/documents/director/public-information-office/news-releases/2010/100519%20Heat%20death%20report%20(2).pdf

- According to the Arizona Department of Health Services, a total of 737 heat-related deaths have occurred in Pima County over the period of 2001-2013. The highest total was 116 in 2005 when an extended heat wave occurred in central Arizona[3].
- Deaths of illegal immigrants in the desert areas along the Arizona-Mexico border are also attributed to extreme heat. In 2001 and 2002, 79% of the 125 heat fatalities among illegal AZ immigrants took place in Pima County[4].
- August 14-16, 2015 extreme heat caused 36 heat related illnesses, including 12 in metropolitan Tucson, 12 in western Pima County and 12 on the Tohono O'odham Nation. Temperatures reached 115 between August 14 and 16 in south central and southwestern Arizona. Record high temperatures were set at Tucson, Ajo, Organ Pipe National Monument, and Picacho Peak State Park. High electricity demand caused power outages in the Tucson area[5].
- In June 2016, National Weather Service issued widespread excessive heat warnings due to "rare, dangerous, and deadly" temperatures expected[6]. Temperatures were at record-breaking highs and tied the mark as the third highest temperature recorded in Tucson at 115 degrees. The heat wave was responsible for several death across the region[4].

Probability and Magnitude

There are no recurrence or non-exceedance probabilities developed for extreme temperature events in Arizona or Pima County. Table 2.1 *Climate Statistics for Stations in Pima County* provides example normal and extreme temperature ranges for various weather stations within the county. In general, extreme temperatures vary from normal by 10 to over 30°, with highs that exceed 110° and the trend (though not linear) is toward increased number of days with high temperatures at or above 105°F and 110°F.

One indicator of the degree of danger associated with extreme heat is the Heat Index (HI) or the "Apparent Temperature." According the NWS, the HI is an accurate measure of how hot it really feels when the Relative Humidity (RH) is added to the actual air temperature. Figure 4-9 is a quick reference chart published by the NWS that shows the HI based on current temperature and relative humidity, and levels of danger for HI values. It should be noted that the HI values were devised for shady, light wind conditions and that exposure to full sunshine can increase HI values by up to 15°F. In addition, strong winds, particularly with very hot, dry air, can be extremely hazardous.

Climate variability may have a strong impact on extreme temperatures and extreme heat in particular. The Centers for Disease Control says that rare extreme heat events that may occur once every 20 years could start occurring every two to four years in certain parts of the country including Arizona[7]. Events could become more severe and last longer as well as being more common.

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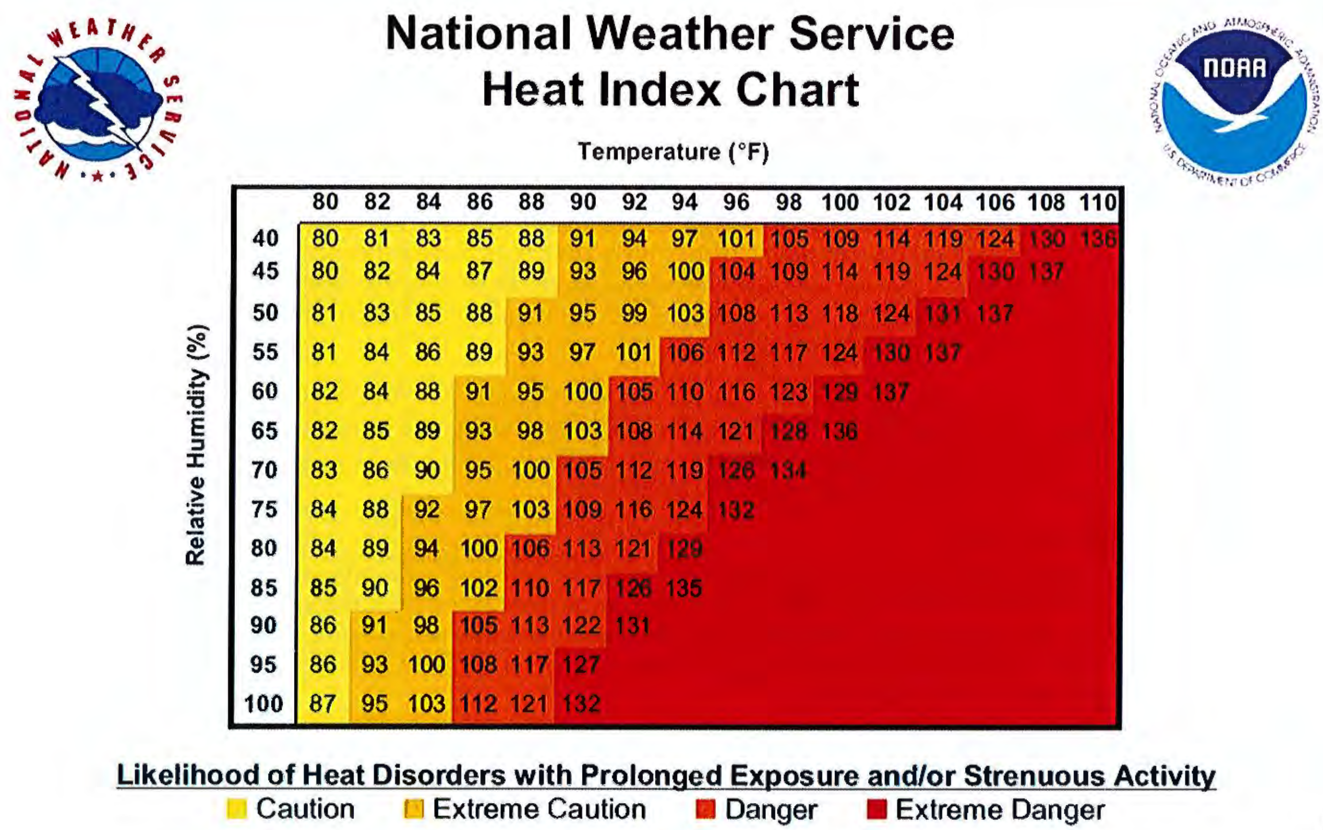
[3] Arizona Department of Health Services, 2015: http://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/pubs/heat-related-deaths-updated-may-2015.pdf

[4] Heat Fatalities in Pima County, Arizona, http://climateknowledge.org/heat_waves/Doc7003_Keim_Heat_Pima_Health%26Place_2007.pdf

[5] National Centers for Environmental Information (NCEI), 2016

[6] National Weather Service, 2016.

[7] Centers for Disease Control, Climate Change and Extreme Heat Events, retrieved 2017: https://www.cdc.gov/climateandhealth/pubs/ClimateChangeandExtremeHeatEvents.pdf



Source: NWS, 2016 http://www.weather.gov/media/unr/heatindex.pdf

Figure 4-9: National Weather Service Heat Index Chart

Vulnerability

Table 4-8: CPRI Results for Extreme Heat for 2017

Participating Jurisdiction	Probability	Magnitude/ Severity	Warning Time	Duration	CPRI Score
Marana	Likely	Limited	> 24 hours	> 1 week	2.50
Oro Valley	**Likely**	**Critical**	**> 24 hours**	**> 1 week**	**2.80**
Pascua Yaqui Tribe	**Highly Likely**	**Limited**	**> 24 hours**	**< 1 week**	**2.85**
Sahuarita	**Highly Likely**	**Critical**	**> 24 hours**	**< 1 week**	**3.15**
Tucson	**Highly Likely**	**Critical**	**> 24 hours**	**< 1 week**	**3.15**
Unincorporated Pima County	**Highly Likely**	**Critical**	**12-24 hours**	**< 1 week**	**3.30**
				County-wide average CPRI =	**2.96**

*Jurisdictions in **bold** chose the hazard for mitigation in 2017 plan.*

The Town of Oro Valley is vulnerable to extreme heat. Extreme heat events occur on a regular basis, typically in the summer months resulting in threats to public health and safety. In recent years, temperatures in the summer months have been the warmest on record. Fluctuation in temperatures may also lead to higher uses of electricity, gas, or water that can lead to outages or interruptions in service. Oro Valley has susceptible populations in children and the elderly. Tourism brings people from areas not familiar to the desert climate that can leave them vulnerable to extreme heat.

The Pascua Yaqui Tribe's vulnerability to extreme temperature is mainly heat related. The Tribe operates two casinos and one golf course that receive numerous heat-related emergency calls annually. As with other jurisdictions, the elderly and young are also vulnerable to the temperature extremes.

Sahuarita, like other neighboring communities, is vulnerable to heat and heat related emergencies. Sahuarita is home to golf courses and pre-planned communities where outdoor activities are emphasized. Sahuarita has many senior communities and elder care facilities as well as areas for young families. As the elderly and young are more vulnerable to heat, the Town chose extreme temperature as one of its hazards.

As a high-desert climate, Tucson is a place of extremes. The City sees very high summer temperatures annually, and just months later will experience sub-freezing winter temperatures. While this is the norm, over the last decade the range of extremes has grown with recent summer temperatures breaking multiple records in one month and winter temperatures dropping to a point that the community, and infrastructure owners, are not prepared for.

During the summertime, extreme heat is generally handled well by the community – however, is widely understood that this is dependent on the reliable delivery of electric power so that residents and businesses can cool their homes and buildings. The potential for electrical system failure during the summer due to storms, wildfires, or overuse/stress on the system are realities that Tucson as a City is beginning to address more thoroughly in our planning processes as it is recognized that a long-term power outage during an extreme heat wave would leave a large portion of the City vulnerable.

During the wintertime, on the other hand, extreme cold temperatures are something the City is less accustomed to and prepared for. Local building practices and codes do not take in to account the protection of water pipes from extremely cold weather, and local natural gas supply infrastructure was not built to take into account the demand for heating fuels when temperatures drop well below freezing during periods of record breaking cold. This type of cold weather has, and can again, lead to wide spread failure to deliver heating fuel and failure of water delivery systems, again leaving large populations within the City vulnerable.

Unincorporated Pima County residents and visitors are vulnerable to extreme heat like the jurisdictions. Full-time citizens of Pima County are generally prepared for the hot climate; however, the homeless and visitors can be overcome due to exposure and lack of awareness. The Pima County Health Department maintains a "Beat the Heat" campaign and various other departments get involved during heat emergencies. Like others, unincorporated Pima County is vulnerable to electrical outages that moves the emergency from individuals outdoors to those indoors as well including the vulnerable elderly and young.

Loss Estimations

Losses due to extreme heat primarily occur in the form of death and illness for people and animals as mentioned at the beginning of this section. Arizona Department of Health Services tracks data and monitors trends and other factors to determine if a statistical significance exists. History would indicate that multiple deaths due to extreme heat are highly likely, especially for illegal immigrants that attempt to cross the Arizona deserts during the summer months. Homeless, low income, elderly, young and access and functional needs populations are particularly vulnerable to extreme heat due to the increased exposure to the natural elements and decreased ability to compensate in the form of cooling apparatus.

Development Trends

Growth in Pima County has significantly increased the population and infrastructure exposed to extreme heat. There is also an increased demand on resources for electric power during the summer months. The primary intersect of extreme high temperature hazards and future development of the county is in the general increase in population and commensurate infrastructure development required.

Over the decades as the metropolitan area has dramatically grown in size, the "urban heat island" effect has developed. This has caused temperatures in the center of metropolitan areas to become much warmer than those in rural areas have. The concrete and asphalt of urban areas retains the heat of the day, and releases it slowly as compared to the surrounding desert terrain, which cools much quicker at night. As development continues to occur within Tucson and its surrounding area, heat conditions will continue to increase.

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4.4.5 *Flood*

Description

For the purpose of this Plan, the hazard of flooding addressed in this section will pertain to floods that result from precipitation/runoff related events. Other flooding due to dam or levee failures is addressed separately. The three seasonal atmospheric events that tend to trigger floods in Pima County are:

- *Tropical Storm Remnants*: Some of the worst flooding tends to occur when the remnants of a hurricane that has been downgraded to a tropical storm or tropical depression enter the State. These events occur infrequently and mostly in the early autumn and usually bring heavy and intense precipitation over large regions causing severe flooding.
- *Winter Rains*: Winter brings the threat of low intensity; but long duration rains covering large areas that cause extensive flooding and erosion, particularly when combined with snowmelt.
- *Summer Monsoons*: A third atmospheric condition that brings flooding to Arizona is the annual summer monsoon. In mid to late summer, the monsoon winds bring humid subtropical air into the State. Solar heating triggers afternoon and evening thunderstorms that can produce extremely intense, short duration bursts of rainfall. The thunderstorm rains are mostly translated into runoff and in some instances, the accumulation of runoff occurs very quickly resulting in a rapidly moving flood wave referred to as a flash flood. Flash floods tend to be localized and cause significant flooding in local watercourses.

Damaging floods in the County include riverine, sheet, alluvial fan, and local area flooding. Riverine flooding occurs along established watercourses when the banks full capacity of a watercourse is exceeded by storm runoff or snowmelt and the overbank areas become inundated. Sheet flooding occurs in regionally low areas with little topographic relief that generate floodplains over a mile wide, Alluvial fan flooding is generally located on piedmont areas near the base of the local mountains, such as the Tortolita Fan, that are characterized by multiple, highly unstable flow paths that can rapidly change during flooding events. Local area flooding is often the result of poorly designed or planned development wherein natural flow paths are altered, blocked or obliterated, and localized ponding and conveyance problems result. Erosion is also often associated with damages due to flooding.

Another major flood hazard comes as a secondary impact of wildfires in the form of dramatically increased runoff from ordinary rainfall events that occur on newly burned watersheds. Denuding of the vegetative canopy and forest floor vegetation, and development of hydrophobic soils are the primary factors that contribute to the increased runoff. Canopy and floor level brushes and grasses intercept and store a significant volume of rainfall during a storm event. They also add to the overall watershed roughness that generally attenuates the ultimate peak discharges. Soils in a wildfire burn area can be rendered hydrophobic. Hydrophobic soils, in combination with a denuded watershed, will significantly increase the runoff potential, turning a routine annual rainfall event into a raging flood with drastically increased potential for soil erosion and mud and debris flows.

History

Flooding is clearly a major hazard in Pima County. Pima County has been part of 13 disaster declarations for flooding, with none of those declarations occurring in the past five years. There have been numerous other non-declared events of flooding incidents occurring in the last five years. The following incidents represent examples of major flooding that has affected the County:

- During August and September of 1983, nearly seven inches of rain fell, saturating the soil around the Tucson metropolitan area. These conditions were exacerbated when a surge of moisture from Tropical Storm Octave, which was located off the central Baja California coast, moved northeast across the area. The result over a four-day period were torrential rains ranging from five to nine inches, causing flooding in Tucson and southeast Arizona. Bridges in the area, including all spanning the Santa Cruz River except one, were damaged or partially washed away. Additional damage occurred along the other watercourses throughout thc area. Several buildings fell into Rillito Creek due to bank erosion and extensive damage occurred to agriculture in Marana. Cost estimates (using 1984 dollars) to repair and mitigate flood damage were estimated at $105.7 million. Four deaths in Eastern Pima County were attributed to the flood.
- In late December 1992 - early January 1993, a series of winter storms produced record-breaking precipitation amounts and severe weather across much of Arizona. Heavy rains combined with melting snowpack caused heavy flooding of both local washes and regional rivers within Pima County. Nearly every community and

city within the county was impacted by the storms at some level. Most of the heavy damage was associated with the Gila, San Pedro, and Santa Cruz Rivers. According to the USACE Flood Damages Report, the total public and private damages from the 1993 floods were estimated to exceed $12 million in Pima County alone. The flooding prompted a federal disaster declaration (FEMA-977-DR-AZ) for almost the entire state[1].

- On August 14, 2005 and August 23, 2005, intense heavy rains caused significant damage to public infrastructure throughout Pima County. The severe runoff resulted in damages to numerous roads, traffic lights, water well fields, berms, crossings, and police vehicles. After over an inch of rain fell across a large portion of the Tucson Metro Area, some locations with more than two inches, several roads became flooded, closed, and impassable. In addition to all the flooded roadways, several trailer homes located in the southern portion of the Tucson Metro Area, were flooded and surrounded by rising water. Rescue teams evacuated several people from these homes. Brawley wash was out of its banks and flooding roadways causing them to be impassable. Over $260,000 in damages were estimated[2].
- In late July and early August 2006, several areas of the state were struck by severe storms and flooding during the period of July 25 to August 4, 2006. Tropical moisture poured into Southeast Arizona, saturating the ground at most locations. As rainfall continued, additional runoff quickly filled rivers and washes, exceeding bank full capacities and flooding homes and businesses as well as nearby roads. Some roadways were washed away due to the strong floodwaters. Lots of flash flooding occurred throughout the Tucson Metro Area due to saturated grounds and extremely heavy rainfall. Numerous roads were closed due to flooding throughout the entire Metro Area for many hours. A USGS stream gage was destroyed by floodwaters in Rincon Creek. Additionally, there were numerous swift water rescues and car stranded in flooded roadways. It was estimated that nearly 100 vehicles were flooded. Several rivers running through the Tucson Metro Area flooded on July 31, 2006. The Rillito River flooded with water over the cement banks near Dodge Boulevard. Additionally, the Rillito River was over bank full just east of the Swan Road Bridge. River Road near La Cholla Road was flooding from the Rillito River. Sabino Creek was out of its banks and houses were flooded near Sabino Canyon and Bear Canyon. Below is a listing of some of the damage, but not all, caused by the flooding and an estimate for the cost of repairs:

  - Sabino Canyon Recreation area road and facility damaged, $100,000
  - Forty homes and businesses flooded, $1,200,000
  - One home destroyed due to flooding, $150,000
  - Water main broke near the Mt. Lemmon highway, $20,000
  - Catalina Highway road washed away, $50,000
  - Agricultural irrigation system damaged, $500,000
  - Cement plant flooded, $400,000
  - Gravel pit flooded, $30,000
  - General infrastructure damage, $500,000.

  The flooding prompted a federal disaster declaration (FEMA-1660-DR-AZ) for Gila, Graham, Greenlee, Pima, and Pinal Counties. Total disaster expenditures exceeded $13.6 million (ADEMA, 2010; PCRFCD, 2011).[3]
- On February 19, 2008, a state of emergency was declared for Pima County for flooding and damages due to 8.5 inches of precipitation that fell in and around Mt. Lemmon within Pima County in less than a 24-hour period. Damages to roads left residents stranded in their homes, limited access to food and medical assistance and damaged potable water supply lines, which affected transmission and distribution of potable water to homes. The rainfall and snowmelt created conditions that threatened the health and safety of residents and exceeded the capabilities of Pima County. Several people in Tucson needed to be rescued from flowing washes. Damages were estimated to exceed $770,000[4].

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[1] US Army Corps of Engineers, Los Angeles District, 1994, *Flood Damage Report – State of Arizona – Floods of 1993*

[2] National Centers for Environmental Information (NCEI), 2010

[3] Arizona Division of Emergency Management, Pima County Regional Flood Control District

[4] National Centers for Environmental Information (NCEI), 2010

- On January 21, 2010, sixteen hikers were trapped on Sabino Canyon Trail at approximately 11 AM after the stream rose above its banks, covering low water crossings. The San Simon and Vamori Washes in the Tohono O'odham Nation rose 1-2 feet out of their banks during the evening of January 21. Several other washes flowed out of their banks, resulting in barricaded roadways near Saguaro National Park East and West, including East Tucson and Avra Valley. A motorist was trapped in the Canada del Oro Wash near Rancho del Lago at approximately 7 AM on January 22 requiring a swift water rescue. Storm-wide damages were estimated at $300,000 (NCDC, 2011). A presidential disaster was declared (FEMA-1888-DR-AZ) for several counties and Indian tribes in the state including Pima County.
- In July 2010, torrential rainfall across portions of eastern Pima County resulted in numerous reports of flash flooding in the Tucson metro area. Flash flooding was observed on Tanque Verde Creek with a peak depth of 11.69 feet at Tanque Verde Guest Ranch. Approximately 30 homes on Barbary Coast Road, Gold Dust Road, and Kitt Carson were flooded. Numerous swift water rescues were performed in the Tucson metro area, near the county fairgrounds, in the Recon Valley area, and on the Old Spanish Trail in the Hilton Head Ranch area. Damages were estimated to exceed $500,000[5].
- Between 2011 and April 2016 there were 39 flash flooding events with two deaths and damage amounting to $2.366 million dollars. September 15, 2011 the 5h highest rainfall total on record occurred at Tucson International Airport with 2.84", and up to 3.00" at nearby locations. Over 3 feet of water covered the roads near the airport causing over 30 roads to be closed and two flights had to be diverted to Phoenix. Six swift water rescues were performed and six people were rescued from their homes as rivers exceeded their banks. In Sahuarita, a wash overflowed into a community flooding 15 homes. A homeless man was swept away by the Santa Cruz River. Damage was estimated at $1 million in Tucson and $500K at Sahuarita[6].
- On September 8, 2014, moisture associated with Tropical Depression Norbert caused extensive street flooding on the east side of Tucson requiring numerous swift water rescues. One woman drove into Alamo Wash and drowned when her vehicle was swept downstream under a bridge[3].
- Heavy rain in the Corona de Tucson area of Vail on July 7, 2014 caused widespread flash flooding, closed roads, and caused property damage. According to the Pima County Regional Flood Control District's (PCRFD) ALERT system precipitation gauges, the area experienced storms with total rainfall ranging from 1.5 to over 2 inches, with rainfall intensities of up to two inches in less than an hour reported in portions of the watershed. The high intensity of the storm over a relatively short duration caused the floodwaters to rise and fall quickly, catching many by surprise[7].
- On July 9, 2014 an intense, localized storm with rainfall intensities of 2 inches per hour or greater affected Why, Arizona. Several Structures were damaged during the event[6]. Historic and real-time rainfall and streamflow data, along with descriptions of floods are available on the Pima County Regional Flood Control website at: http://webcms.pima.gov/government/flood_control/

Probability and Magnitude

For the purposes of this Plan, the probability and magnitude of flood hazards in Pima County jurisdictions are based on the 1% probability floodplains (also known as the 100-year flood, as the flood has a 1% chance of being equaled or exceeded in any single year) delineated on FEMA Flood Insurance Rate Maps (FIRMs)[8]. FEMA completed a map modification program to update the FIRMs for the County into a digital FIRM (DFIRM) format. The Pima County Regional Flood Control District (PCRFCD) is responsible for keeping these up-to-date as revisions are made. Floodplain GIS base files were obtained from the PCRFCD and are the basis for the flood hazard depictions in this Plan.

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[5] National Centers for Environmental Information (NCEI), 2011

[6] National Centers for Environmental Information (NCEI), 2016

[7] Pima County Regional Flood Control District, 2016

[8] FEMA 100 Year Flood Zones, http://www.arcgis.com/home/item.html?id=e9aa2179f31b4b9cbe5c7f8b1b91cea3, 2016

Vulnerability

Table 4-9: CPRI Results for Flood 2017					
Participating Jurisdiction	**Probability**	**Magnitude/ Severity**	**Warning Time**	**Duration**	**CPRI Score**
Marana	**Likely**	**Catastrophic**	**12-24 hours**	**< 24 hours**	**3.05**
Oro Valley	**Likely**	**Catastrophic**	**< 6 hours**	**< 24 hours**	**3.35**
Pascua Yaqui Tribe	**Likely**	**Limited**	**< 6 hours**	**< 24 hours**	**2.75**
Sahuarita	**Highly Likely**	**Catastrophic**	**12-24 hours**	**> 1 week**	**3.70**
Tucson	**Highly Likely**	**Critical**	**6-12 hours**	**< 6 hours**	**3.25**
Unincorporated Pima County	**Highly Likely**	**Critical**	**< 6 hours**	**< 24 hours**	**3.50**
			County-wide average CPRI =		**3.27**

*Jurisdictions in **bold** chose the hazard for mitigation in 2017 plan.*

The different types of weather in Pima County described above produces distinctively different types of floods. Flood producing storms in Pima County typically fall into one of two types: summer monsoon thunderstorms and winter mesoscale storms.

Summer monsoon storms are highly convective systems that produce intense rainfall over relatively small areas. Monsoon storms are more likely to trigger flood events on smaller watercourses, particularly later in the monsoon season when antecedent soil moisture is higher. Monsoon storm flooding is short-lived and may affect an area suddenly as a flash flood. These floods tend to be of shorter duration. Furthermore, monsoon rainfall may affect just one watershed. In most years, the annual peak flow will occur on different days at different gauging stations. However, the July 31, 2006 event, which produced debris flows in the Santa Catalina Mountains significant flooding on the Santa Cruz downstream of the Rillito occurred after several days of rainfall in the Santa Catalina Mountains.

Flash floods are generally associated with summer monsoon thunderstorms. Several factors make flash floods a challenging hazard to mitigate.

1) Real-time precipitation gages may miss storm cells that are small enough in aerial extent although large enough in volume to cause flash flooding.
2) Extreme rainfall intensities can generate runoff that reaches peak flow in periods measured in minutes, providing little or no ability to provide the public with a warning about any specific event.
3) The leading edge of the flood may extend miles below the storm event that created it, flooding an area that may have received no rainfall and may not have even been cloudy, thus catching individuals completely unaware of the threat.

Winter mesoscale storms generally originate in the Pacific Ocean and produce bands of precipitation over a period of days. Though characterized by low rainfall intensity, these long duration storms yield the high volumes of water necessary to produce significant flow events on the major watercourses. Precipitation characteristics create floods that build slowly and may last for days. These include Tropical Storms. In general, the largest floods on the Santa Cruz River have occurred because of tropical storms that come up from the Sea of Cortez in the fall, but do not produce significant flooding in most years. In October 1983, tropical storm Octave produced the flood of record on the Santa Cruz River. Between 6 ½ to 7 ½ inches of rain fell across the area in five days. The flooding stretched to Clifton/Morenci, Wilcox, Safford and Nogales. More than a dozen people died. While high rainfall depths and extended duration certainly produce conditions conducive for flooding, saturated soils that have limited capacity to absorb rainfall also play a role. They may also include frontal systems that can provide more sustained flow durations, even as flood peaks tend to remain low. In rare occasions winter frontal systems have produced rain on snow in January to March.

In addition to flash flood largely associated with mountain front drainage, sheet flow flooding is a phenomenon unique to watersheds with low topographic relief and a severe lack of adequate flow conveyance through channels. The lack of defined drainage channels often deceives the public into thinking that there are no flood hazards in the area. Sheet flow flooding may develop quickly but where slopes are particularly shallow, the duration of sheet flow flooding may extend more than 24 hours. Private roadways not designed for all weather access are common in these areas of the County. As a result and in combination with the widespread nature of sheet flow flooding, during times of flooding residents and emergency services ability to gain safe or reliable access to and from the affected area may be limited.

Alluvial fans create a special type of floodplain that has characteristics that are similar to sheet flow floodplains. Alluvial fans occur below mountain fronts and consist of an accumulation of sediment carried out of the mountains via riverine flow. At the margin of the mountain front, flow containment is lost and floodwaters spread out across the alluvial fan. Alluvial fans may have better defined channels or flow corridors but they are not large enough to convey large storm events and, due to their location below the break in slope, channels often aggrade and lose capacity. Since alluvial fans often consist of poorly consolidated alluvium, the loss of channel capacity in existing channels leads to the creation of new channels or the reestablishment of old channels. This characteristic of alluvial fans leads to significant uncertainty with respect to the location and severity of flood flows. The combination of severe, directed flow at uncertain locations, unconsolidated soils and the likelihood of flash floods in this environment results in potentially extreme flood and erosion hazards.

Historically, flood events of limited aerial extent occur at least every few years in Pima County. These floods may not affect many people but the effects of these floods may be severe for those affected. Floods on the major watercourses occur approximately once every ten years. Historically, these floods had a significant impact on the community; however, flood and erosion hazard improvements within the urban core have largely limited the hazards to the public from large flood events on the major watercourses. In addition, improved regulation of development through elevating structures above the base flood, protecting structures from erosion hazards and protection of natural floodplains has ensured that new development is more flood resilient than was previously the case in unincorporated Pima County.

This section contains a map and data table for unincorporated areas known to flood frequently and where warning is required per the NFIP (see Figure 4-10 and 4-11). Figure 4-12 and 4-13 are Special Studies Floodplains map showing locally mapped floodplains. These are mapped either by a developer or by unincorporated Pima County. Table 4-11 contains data for these Special Studies Floodplains areas including exposure estimates. The PCRFCD works closely with the PCOEM to add locally identified special studies flood-prone areas.

While bank protection installed by the PCRFCD along major watercourse has reduced erosion and overbank flooding in much of the urbanized incorporated areas of the County some development pre-exists floodplain regulation and infrastructure is at risk. This area includes:

- The Forty Niner's Country Club Subdivision on Tanque Verde Creek geologic floodplain,
- The alluvial fan areas of Lee Moore, Franco and Flato washes particularly in the Summit neighborhood south of Sahaurita Road,
- The broad floodplains of Avra Valley and the Black Wash, as well as
- Numerous canyon washes impacted by fires within National Forests in the upper watershed and encroachment in the foothills residential areas.

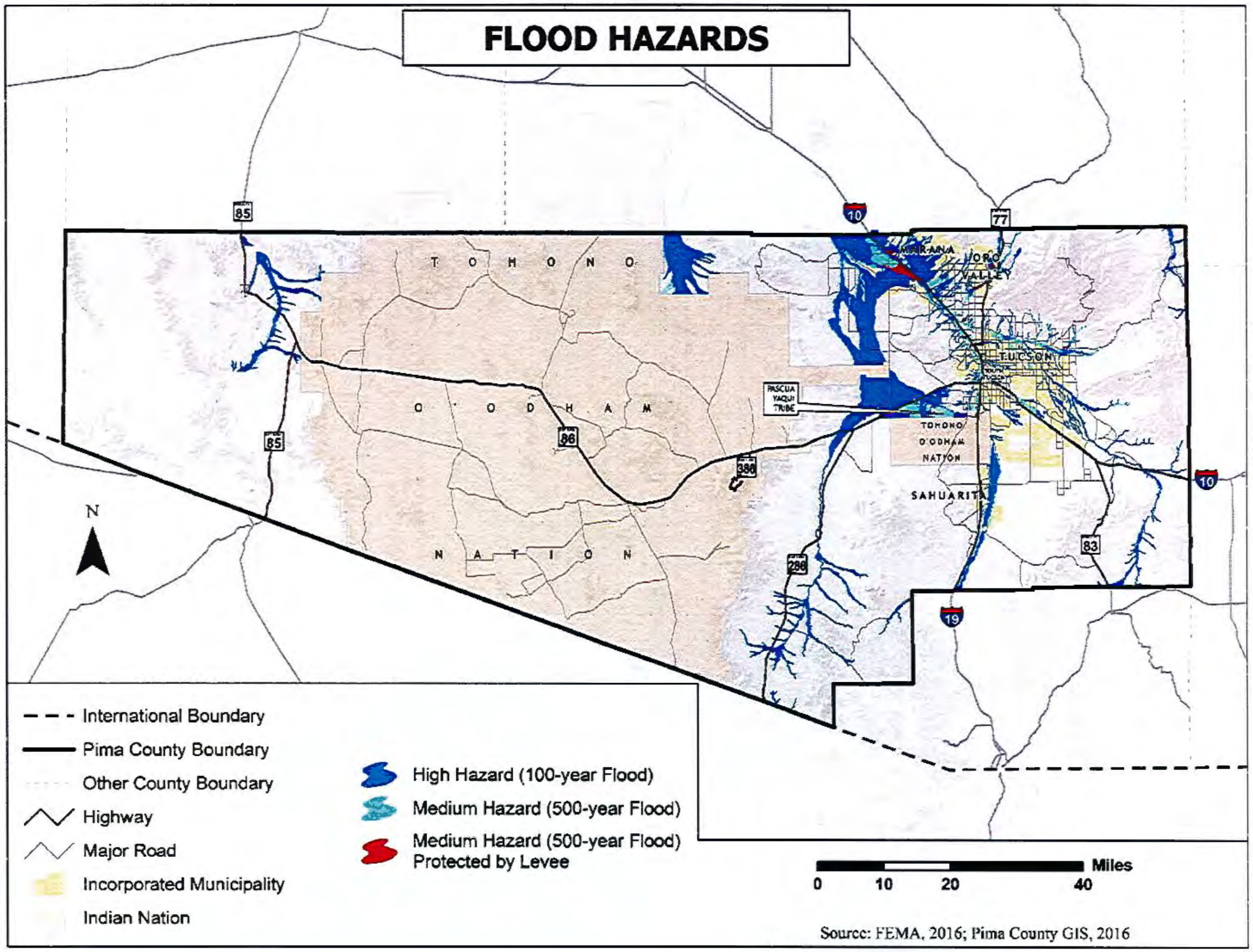

Figure 4-10: Pima County Flood Hazards

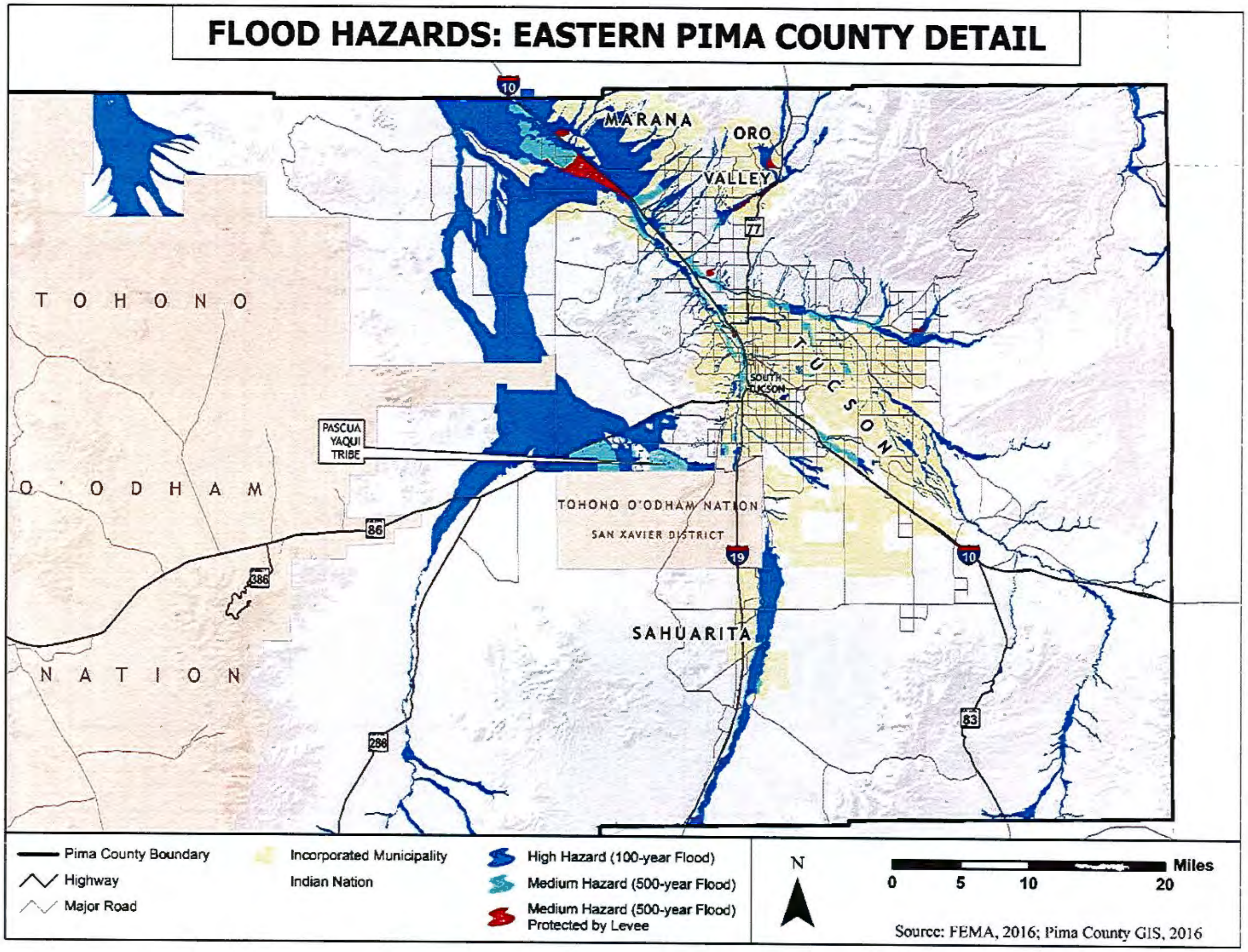

Figure 4-11: Eastern Pima County Flood Hazards Detail

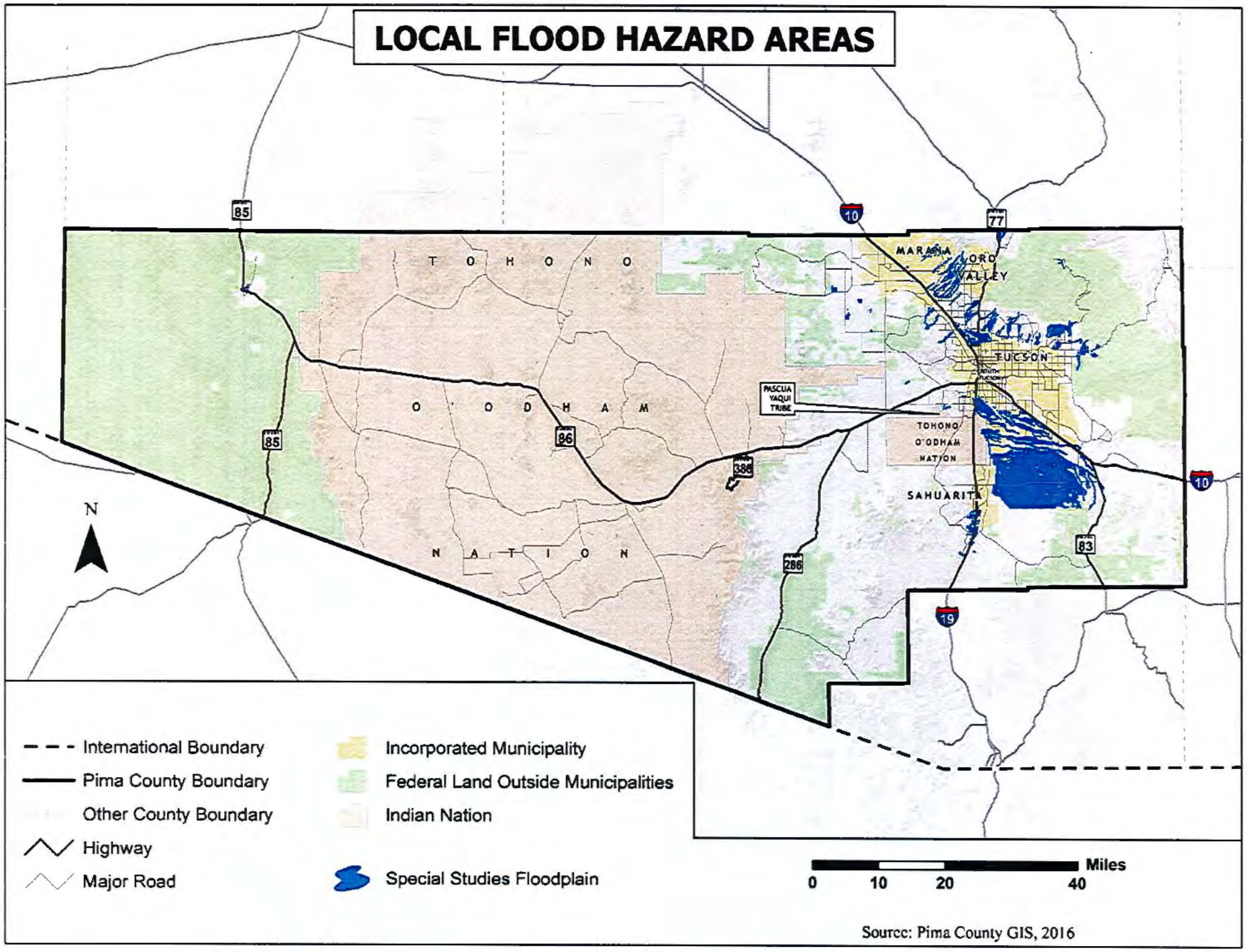

Figure 4-12: Local Flood Hazard Areas Pima County

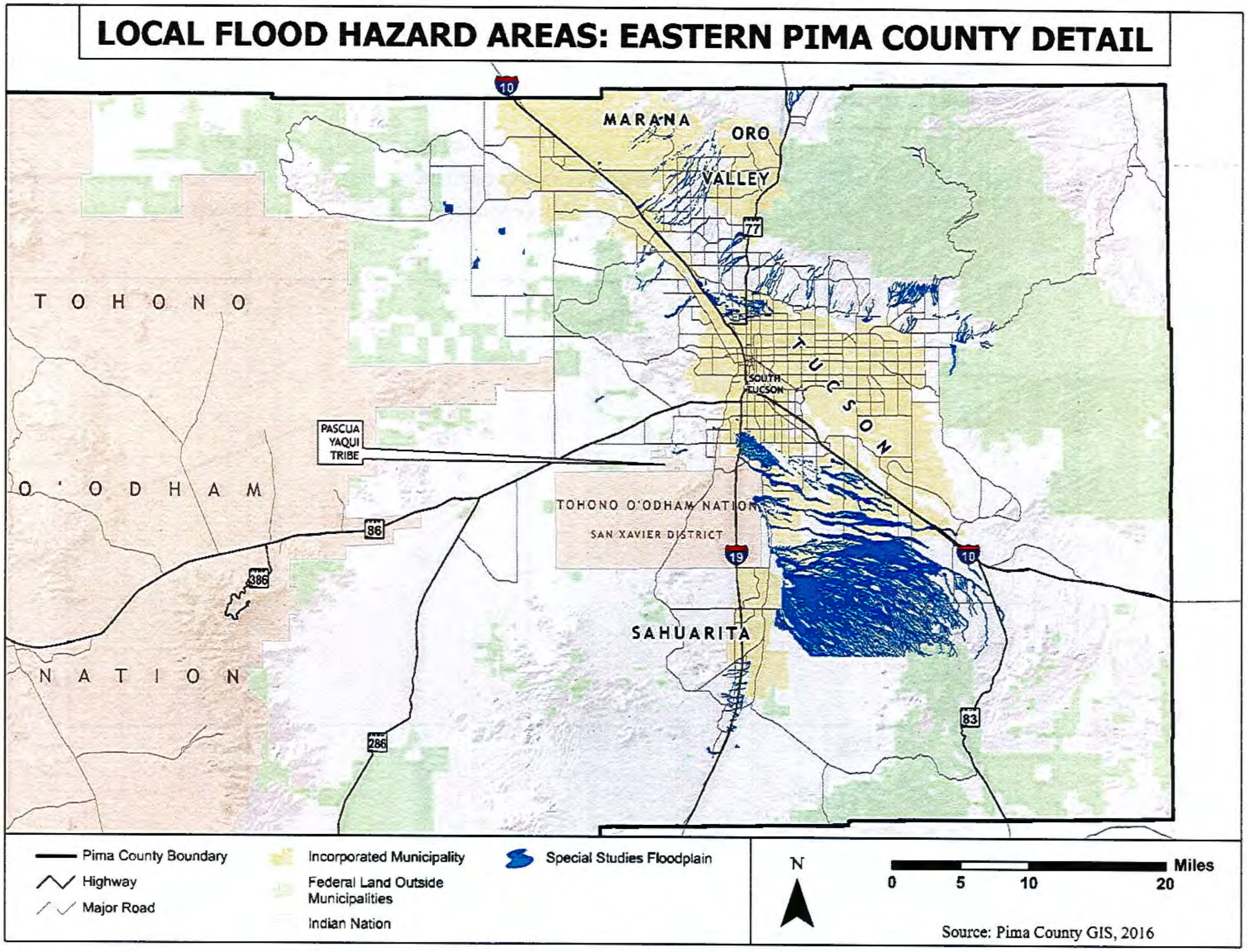

Figure 4-13: Local Flood Hazard Areas Eastern Pima County Detail

The Town of Marana has significant concerns regarding flooding. There are several flooding sources within Marana that can cause hazards to property or roadways. They include runoff from the Tortolita Mountains, runoff from the Tucson Mountains, and overbank flow from the Santa Cruz River. Two additional flooding sources include the Rillito River and the Canada del Oro Wash, are contained within their banks during the base flood (commonly known as the "100 year flood") but are susceptible to hazardous erosive failures. Areas include:

- Santa Cruz River: Major regional storm events, such as significant rainfall in the Catalina Mountain watershed, can send enough Stormwater runoff into the Canada del Oro or Rillito River systems that will direct floodwaters to the Santa Cruz River potentially causing the closure of the Ina Road bridge for structural precautions, the closure of the Sanders Road bridge due to overtopping, the capturing of the El Rio Open Space preserve, and evacuation due to overbank flows of the Berry Acres subdivision in far north Marana. Major storm systems south of Tucson, potentially all the way from Mexico, within the Santa Cruz watershed can also cause these issues. Some areas of Continental Ranch adjacent to the Santa Cruz River and the Town's airport could be impacted by Santa Cruz flood events above the base flood.

- Tortolita Mountain Alluvial Fan: The Tortolita Mountain watershed consists of several major washes that leave the mountain system whose floodplains overlap in a broad alluvial floodplain. Higher on the alluvial fan and closer to the mountains, the washes are well defined and the floodplains are more certain. The lower you travel on the floodplain the more the floodplain broadens out into overlapping sheet flow areas. Tangerine Road in its current condition is susceptible to flooding and road closures due to at-grade dip crossings. At the end of the alluvial fan lies the Central Arizona Project Canal system that has a protective berm on its upstream side and over chute pipe outlets to carry floodwaters across the canal at various locations. This berm/over chute system interrupts the sheet flow characteristics of the lower alluvial fan and reconcentrates the floodwaters at the pipe outlet locations. Localized flooding and road closures occur downstream of the over chutes. A similar situation occurs where the Tortolita Fan runoff is intercepted by the Union Pacific Railroad and Interstate 10. These facilities are raised higher than the adjacent ground, impounding water on their upstream sides and create focused flooding issues where culverts or interchange openings allow focused floodwaters through. There are also some areas of the interstate and railroad that can be outright overtopped. Should there be a rainfall event significant enough to cause runoff by the sandy soils of the Tortolita Fan; the water will go through the series of impoundments and discharges noted above through the Central Arizona Project Canal, Union Pacific Railroad, and Interstate 10 to arrive at northwest Marana. These floodwaters then either sheet flow or are carried in the bar ditch and irrigation canal system in a northwesterly pattern throughout northwest Marana. Property damage and road closures occur until the flood waters recede.

- Tucson Mountain floodplain: The Tucson Mountain watershed consists of several washes that leave the mountain system but unlike the Tortolita Fan, the washes remain well confined due to the rockier nature of the terrain and the closer proximity of the mountain range to the Santa Cruz River. The Town has not experienced major property damage from Tucson Mountain runoff but several roads both east and north of the mountain range are subject to closure during major rain events in the watershed. FEMA mapping categorizes the Town's airport as being in a sheet floodplain from the Tucson Mountains but the mapping does not appear to consider the raised Central Arizona Project canal immediately east of the airport.

- Canada del Oro wash and Rillito River: Both of these systems contain the base flood for their watersheds. However, property and roadways adjacent and crossing these systems could be susceptible to flooding from events above the base flood. A segment of the Canada del Oro wash west of Thornydale road that is not armored with bank protection. That segment could experience erosive failure. Prior to development of this area, the Town will require the bank protection to be put in place. The most hazardous aspect of these systems however is where they come together at the Santa Cruz River just west of Interstate 10. No part of this confluence is bank protected. A sand and gravel pit within the confluence area that has been mined well below the bed of the river. If the berm protecting the sand and gravel pit were to fail, the resulting pit capture could cause a headcut eastwards and erode away the adjacent portion of Interstate 10, the Union Pacific Railroad, a major Tucson Electric Power transmission line, transcontinental high-pressure gas pipeline, and a transcontinental fiber optic line.

The Town of Oro Valley is susceptible to flood hazards on a relatively frequent basis due to tropical storm remnants, winter rains, and summer monsoons. Localized events are the most common and frequent types of flooding in Oro Valley, however, there are infrequent occasions of more widespread or regional flooding events. Examples of larger flood events affecting the Town of Oro Valley include:

- July 4, 2012. Estimated hundred-year event occurred that caused flooding to the Lomos de Oro wash. There were limited damages because of a FEMA funded mitigation project (2006) to add gabions and other flood protections.
- September 8, 2014. Hurricane Norbert. Several localized areas across the Town received between 3.5-4.5 inches of rain in an hour's time. This flooded streets, overflowed normal wash channels, led to swift water rescues, and flooded homes and yards. There was significant storm recovery need to include debris and sediment clean up, repairs to impacted public infrastructure, and clean-up by individual homeowners and businesses. Additionally, short and long-term mitigation measures were identified, prioritized, and completed. The storm led to a SBA declaration for the State of Arizona.
- August 7-10, 2015. The four (4) Pima County Flood Control ALERT rain gauges located in Oro Valley measured over one (1) inch of rain, with one measuring over three (3) inches of rain in a short amount of time. These back-to-back storms produced a lot of rain, sediment, debris, and flooded dip crossings.
- August 31, 2015. This storm had limited rainfall, but caused wind damage due to microburst, power outages, and damages to public infrastructure.
- August 1-2, 2016. Significant rainfall amounts over consecutive days across the metro region, including Oro Valley. Due to saturated ground conditions, there was concern for regional impacts with any additional precipitation.
- August 17, 2016. This storm brought heavy rain, flooded roadways, high winds, microburst, lightning caused fires, and power outages due to downed power poles. This storm resulted in damages to both public and private infrastructure.

There may also be other cascading events associated with a flood such as damages to infrastructure, severe wind (microbursts), downed power poles, power outages, uprooted trees, flooded homes, and other related damages.

The Pascua Yaqui flood vulnerability is mainly related to the main body of land for the tribe that is located in the Black Wash flood plain. The Black Wash gathers waters from washes from the Tohono O'odham and Pima County, runs through the jurisdiction and then back into Pima County. The flooding affects the residences as well as the business and gaming communities by cutting off critical services from citizens. In 2015, a monsoon flood event washed out critical communications infrastructure including phone and data lines.

The Town of Sahuarita is vulnerable to flooding mainly due to its proximity to the Santa Cruz River. Several large washes run through the Town and upstream rain events can overwhelm wash channels. Sahuarita Road runs from SR83 to the east to just west of I-19 through the town. Sahuarita Road has numerous low-level wash crossings that are vulnerable to flood events and can cut off citizens from emergency services. Numerous modular housing areas have structures with increased vulnerability to flooding when washes back up as well.

Flooding in Tucson is a yearly expectation during the summer monsoon and often during the winter weather patterns as well. The community is generally fairly well prepared for these storms and their short-term flash flooding effects. Although every year damage is done to roadways and other infrastructure and people become stuck, and sometimes injured or killed, while trying to cross flooded washes that cross roadways. The flood vulnerability may come from two other sources. First, the potential for the track of tropical storm/hurricane remnants from the Pacific Ocean, usually via the Gulf of California, has led to widespread and large-scale rainfall causing severe flooding of large drainages such as the Santa Cruz River. These storms usually coincide with the tail end of the monsoon events. Second, there is a history of large scale flooding events from El Niño weather patterns occurring during Tucson's winter rainy season. These weather patterns can again greatly increase overall rainfall over a short period of the season leading to flooding. They can also create cascading events such as a heavy snowpack on the mountains that border Tucson, followed by a warm tropical rainstorm that leads to heavy snowmelt and flooding of waterways and washes within the City.

While mitigation projects throughout the city have been underway since the record flooding in 1983, caused by remnants of Tropical Storm Octave, there are still large lengths of waterways and washes that are vulnerable to erosion, bank degradation, and other flooding threats. Numerous bridges and roadways are vulnerable to substantial infrastructure damage during large-scale floods.

Loss Estimations

The estimation of potential exposure to high and medium flood hazards was accomplished by intersecting the human and facility assets with the flood hazard limits depicted on the Flood Hazard Maps (See Maps 6-1 and 6-2). Population and residential building figures are from the 2010 Census; counts at the block level were intersected with those flood hazard areas using a more complex dasymetric technique from FEMA's HAZUS-MH software. This technique uses land cover information derived from satellite imagery to remove the areas in Census blocks that are largely without population or housing (e.g. vacant land, agricultural areas, etc.).

Replacement costs for the critical facilities and infrastructure identified in this Plan were taken from work done for the 2012 Plan, with an across-the-board 7% increase applied (due to the change in the Consumer Price Index for the West Region from 2012 to 2016). Replacement costs for the residential buildings were developed using a hybrid approach: the mean residential building replacement cost per block was taken from HAZUS-MH and was then multiplied by the total building count for each block as given in the 2010 Census.

Loss estimates to all facilities located within the high and medium flood hazard areas were then calculated from the replacement costs using a simple ratio. (Most of the assets located within high hazard flood areas will be subject to three feet or less of flooding.) Using the FEMA tables, it is assumed that all structural assets located within the high hazard areas will have a loss-to-exposure ratio of 0.20 (or 20%). A loss-to-exposure ratio of 0.05 (5%) is assumed for assets located in the medium hazard areas. Locally defined floodplains are assumed to have a loss-to-exposure ratio of 0.20 (20%). Table 4-12 summarizes the critical facility, population, and residential housing unit exposure and loss estimates for the high and medium flood hazards.

Each jurisdiction is responsible for identifying their critical facilities and infrastructure. ***Critical facilities and infrastructure*** are systems, structures and infrastructure within a community whose incapacity or destruction would *have a debilitating impact on the defense or economic security of that community* and *significantly hinder a community's ability to recover following a disaster.*

The following criteria were used to define critical facilities and infrastructure for this analysis:

1. **Communications Infrastructure:** Telephone, cell phone, data services, radio towers, and internet communications, which have become essential to continuity of business, industry, government, and military operations.
2. **Electrical Power Systems:** Generation stations and transmission and distribution networks that create and supply electricity to end-users.
3. **Gas and Oil Facilities:** Production and holding facilities for natural gas, crude and refined petroleum, and petroleum-derived fuels, as well as the refining and processing facilities for these fuels.
4. **Banking and Finance Institutions:** Banks, financial service companies, payment systems, investment companies, and securities/commodities exchanges.
5. **Transportation Networks:** Highways, railroads, ports and inland waterways, pipelines, and airports and airways that facilitate the efficient movement of goods and people.
6. **Water Supply Systems:** Sources of water; reservoirs and holding facilities; aqueducts and other transport systems; filtration, cleaning, and treatment systems; pipelines; cooling systems; and other delivery mechanisms that provide for domestic and industrial applications, including systems for dealing with water runoff, wastewater, and firefighting.
7. **Government Services:** Capabilities at the federal, state, and local levels of government required to meet the needs for essential services to the public.
8. **Emergency Services:** Medical, police, fire, and rescue systems.

Other assets such as public libraries, schools, businesses, museums, parks, recreational facilities, historic buildings or sites, churches, residential and commercial subdivisions, apartment complexes, and so forth, are typically not classified as critical facilities and infrastructure unless they serve a secondary function to the community during a disaster emergency (e.g. - emergency housing or evacuation centers).

In summary, nearly $230 million in critical facility related losses are estimated for high and medium flood hazards, for all the participating jurisdictions in Pima County. An additional $1.03 billion in high and medium flood losses to 2010 Census residential housing units is estimated for all participating Pima County jurisdictions. Regarding human vulnerability, a total population of 37,951 people, or 3.9% of the total population, is potentially exposed to a high hazard flood event. A total population of 44,024 people, or 4.6% of the total population, is potentially exposed to a medium hazard flood event. This exposure is based upon FEMA floodplains. Exposure loss estimates for locally defined floodplains and levees is provided below in Table 4-11.

It is noted that the loss and exposure numbers presented above represent a comprehensive evaluation of the County as a whole. It is unlikely that a storm event would occur that would flood all of the delineated high and medium flood hazard areas at the same time. Accordingly, actual event based losses and exposure are likely to be only a fraction of those summarized above. Furthermore, any flood event that exposes assets or population to a medium hazard will also expose assets and populations to the high hazard flood zone. That is, the 100-year floodplain would be entirely inundated during a 500-year flood in the localized area of impact.