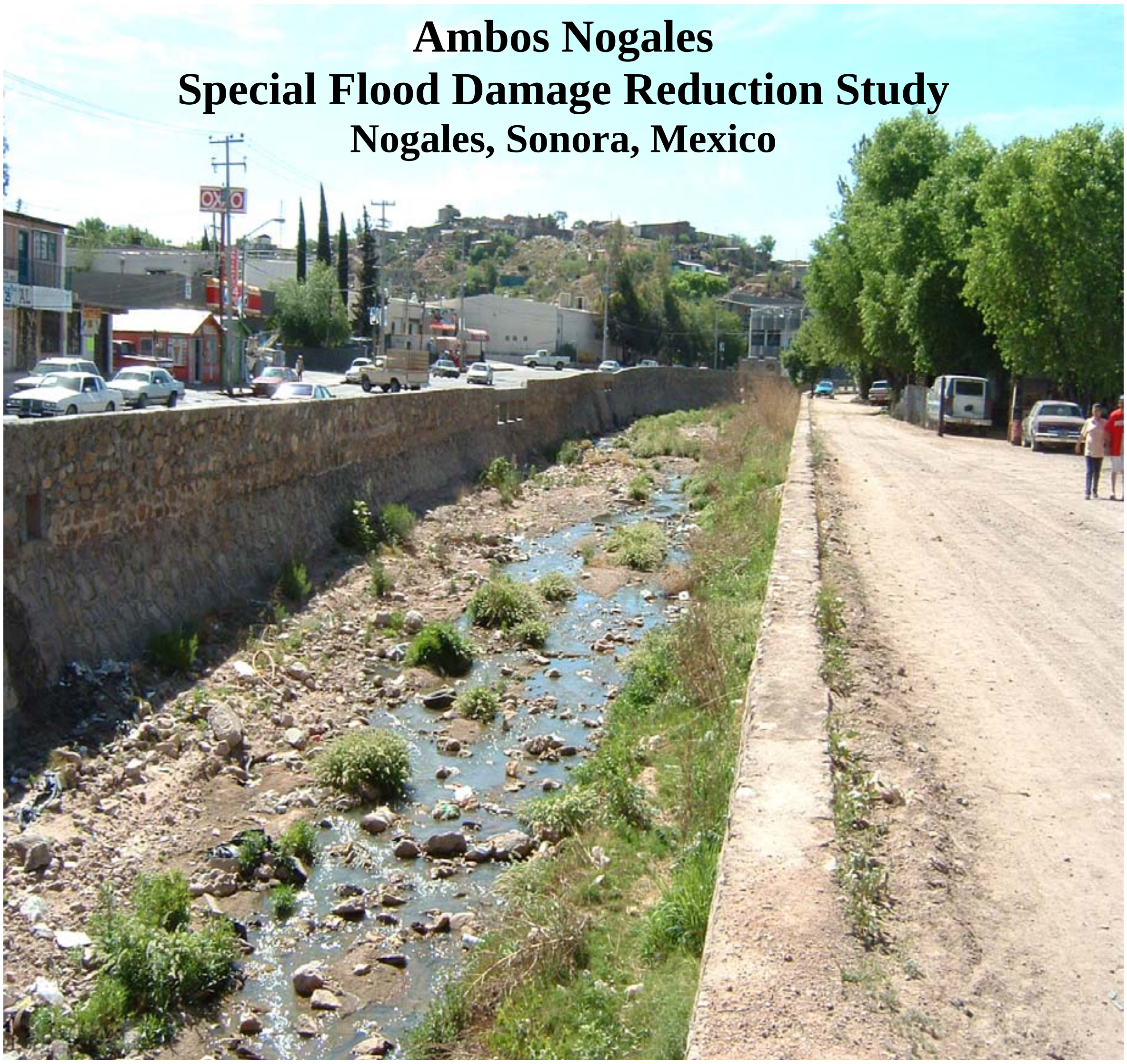
U.S. Army Corps of Engineers
Los Angeles District

International Boundary and Water Commission

Ambos Nogales
Special Flood Damage Reduction Study
Nogales, Sonora, Mexico



Prepared for:
The International Boundary and Water Commission
By:
The U.S. Army Corps of Engineers, Los Angeles District
Arizona Area Office

In association with:

TETRA TECH, INC.

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Executive Summary

This report was prepared in response to a request from the International Boundary and Water Commission, U.S. Section. The purpose of the study is to identify the nature of the current flood problem in the City of Nogales, Sonora, Mexico, to develop measures that might potentially reduce the threat of flooding, and to analyze and compare alternatives created to reduce potential flood damage. This report presents and discusses the results of the study process, contains details on the potential for various measures created for flood damage reduction, and makes recommendations regarding the suitability of various measures for implementation.

The study includes the identification of problems, opportunities and constraints. It then examines potential measures to meet study goals and objectives, analyzes the potential of each of those measures, develops preliminary alternatives, and provides discussion on the potential of a reduced array of alternatives for reduction of flood damage within the identified floodplain. The recommendations included in this study are based primarily on the effectiveness of the measures examined, although several measures were dismissed from further consideration due to obvious impacts they would cause to existing development, transportation, or perceived economic impacts.

The City of Nogales, Sonora has historically suffered from frequent and destructive flooding. The watershed surrounding the city is steep, and is developing at a rapid rate. The floodplain is narrow, highly developed, and occupied by many structures that are marginally above the surface of the floodplain. Much of the development in the floodplain was constructed in an era before flood damage evaluation methodologies were available, or before floodplain management was required.

A major flood in 1930 resulted in channelization of Nogales Wash in the mid-1930s. Since construction of this project, there have been some improvements performed on tributaries to Nogales Wash, and the installation of numerous storm drains and inlet structures. However, ongoing development of the watershed has considerably outpaced that of improvements to drainage facilities, with an associated decline in the level of protection offered by the drainage system. The combination of higher flows and reduced conveyance has resulted in increased flood risk to residents and visitors to the City. Some areas of the city are subject to significant flooding from events of as little as 2-year duration.

This study evaluated numerous means of providing structural and non-structural flood damage reduction to the currently-developed portions of the watershed. Non-structural measures examined include flood-proofing, relocation, flood warning, and floodplain regulation. Structural measures included channel improvement, inlet improvements, and detention of floodwaters; and formulated alternatives to reduce flooding from 5-, 10-, and 25-year flood events. The extent and pace of development, particularly at many of the sites appropriate for flood damage reduction measures, have created a system in which alternatives for flood control are severely constrained.

A channel improvement alternative for the underground portion of Nogales Wash in Nogales, Sonora would only provide a partial solution. It would not address tributary areas, and it would have to be continued 1300 meters north through Nogales, Arizona to reach a safe point of disposal. An inlet improvement alternative is the least costly to implement and would provide immediate relief to nuisance flooding from frequent events, and for small to moderate events that only affect a few of the tributaries. However, because of the limited capacity of the main underground channel, inlet improvements will not have a significant effect on flooding in basin-wide events.

Detention can potentially reduce peak discharges to the point where they can be conveyed by the existing underground channel, and appears to be the most effective element in a comprehensive solution to downstream flooding. Large scale regional detention basins that control a majority of the watershed would be most efficient. However, the only areas in the watershed that would be topographically suitable are already occupied by residences, businesses, and regional transportation facilities; and any attempt to implement would severely disrupt commerce and tourism. As a result, the detention alternative was formulated using many smaller basins located in relatively undeveloped areas on major tributaries. Each basin can provide a significant reduction in flooding for intervening areas, but even as a group, they only provide a partial solution to larger flooding in the mainstem channel.

In summary, evaluation of potential alternatives for channel improvement scenarios, inlet improvements, and detention options indicate that there is no single approach that provides a complete solution to the flooding problem in Nogales, Sonora.

Recommendations

Implementation of a program of inlet improvement may provide the most cost-effective and immediate method of flood damage reduction and improved public safety due to the reduction in nuisance flooding. However, floodwater detention would be the most effective element in a comprehensive solution. The proposed basins can provide significant reduction in flooding for intervening areas, and provide a measure of flood damage reduction in the mainstem channel.

It is recommended that the results of this study be discussed with City officials and representatives from the agencies responsible for its potential implementation. Should this combination of measures be determined to be politically supportable, and a decision is made to pursue floodwater detention, an optimization study of detention basin options would logically follow the pursuit of inlet improvements on tributaries. This effort would include consideration of dam safety requirements, land ownership, utilities, environmental and social impacts, and cultural resource issues.

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Chapter 1 – Introduction

Purpose of Study

The purpose of this study is to: (1) identify the nature of the current flood problem in the City of Nogales, Sonora, Mexico; (2) to develop measures that might potentially reduce the threat of flooding, and; (3) to analyze and compare alternatives created to reduce potential flood damage. This report presents and discusses the results of the study process, contains details on the potential for various measures created for flood damage reduction, and makes recommendations regarding the suitability of various measures for implementation.

Scope of Study

This study examines the hydrology and hydraulic characteristics of the watershed of Nogales Wash upstream of the boundary between the United States and Mexico. This watershed covers an area of approximately 72.47 square kilometers (28 square miles). It does not examine flood issues north of that boundary, although consideration of the potential effects of developed measures on that area is taken into consideration. The scope of technical study ranged from analysis of simple administrative measures, to that of potential detention and channel improvement options.

Study Process

This study follows the general format of the initial phases of the broadly-utilized Federal planning process. It includes the identification of problems, opportunities and constraints. It then examines potential measures to meet study goals and objectives, analyzes the potential of each of those measures, develops preliminary alternatives, and provides discussion on the potential of a reduced array of alternatives for reduction of flood damage within the identified floodplain.

The recommendations included in this study are based primarily on the technical effectiveness and perceived impacts of the measures examined. Several measures were dismissed from further consideration due to obvious impacts they would cause to existing development, transportation, or perceived economic impacts. Others were screened from further consideration due to their inability to effectively address the identified problems. While the study does not include a formal analysis of cultural, environmental, or economic impacts, these issues were considered during plan formulation.

History of Study on Nogales Area

Nogales Wash has been the subject of study on flooding issues since the early part of the 20th Century. While not all conducted in detail, these fundamental studies resulted in the installation of storm drains and flood control culverts within the City of Nogales, Sonora. Work on channels has proceeded sporadically throughout the remainder of the century.

- On January 7, 1932, Senate Document No. 44, "Flood Control at Nogales, Arizona – Mexico", was submitted to Senator Carl Hayden of Arizona. This document transmitted a report prepared by the International Boundary Commission (IBC), which evolved into the International Boundary and Water Commission (IBWC) in 1944, concluding that the flood situation was serious, and demanded an immediate solution. The report recommended that the governments of the United States and Mexico complete final studies, plans, and cost estimates for a flood control project in those two nations. This report lead to construction of a flood control channel system, constructed by the IBC in the 1930's and 1940's. This system was located partially within Mexico, and is still functioning within the City of Nogales, Sonora, today.

- A Corps of Engineers investigation for flood control in the Nogales, Arizona area was initiated in December 1977 after the IBWC turned down a request by the Santa Cruz County Flood Control District for a 5.5 mile extension of the existing channel through Nogales, Arizona. The IBWC could not support an extension of that nature due to its location entirely within the United States. Initial study by the Corps in February 1978 indicated that much of the erosion evident was on private property, and that the Corps' authority to address erosion problems is limited to protection of public facilities. The District Engineer recommended floodplain management measures for the U.S. side of the border. No apparent study of flooding within Mexico was conducted, although preliminary analysis of discharges issuing from the watershed upstream of the border was obtained.

- The September 1978 report entitled "6-10 October 1977, Flood Damage Report on Storms and Floods on Santa Cruz, Gila, and San Pedro Rivers, Arizona", contains hydrologic and economic data on the Nogales Wash area. None of this data covers economic damages within the City of Nogales, Sonora.

- The Federal Emergency Management Agency of the United States government completed a Flood Insurance Study for the City of Nogales, Arizona during October 1980. It contains no information on floodplain or damages within the City of Nogales, Sonora, although discharges and floodplain information on the area immediately upstream of the border would have been developed for accurate study.

- In June, 1982, a formal re-study of flooding issues within the Nogales Wash watershed was initiated by the U.S. Army Corps of Engineers and Santa Cruz County Flood Control District. Although authority for implementation existed only within the U.S., study of the hydrology of the watershed within Mexico was conducted. The report was completed in March 1988. This feasibility study was conducted under current Federal planning guidelines, and included a full environmental impacts analysis, public involvement process, and resulting Federal feasibility study report. The report was accompanied by technical documentation consisting of hydrology, hydraulics, geotechnical studies, design, real estate, economics, recreation and aesthetic treatments, demographics, non-structural analyses, and sensitivity analysis. The study indicated a lack of economical feasibility of many examined alternatives, but recommended a flood warning system and channel modifications along the International Boundary and in the community of Chula Vista, Arizona. Revision of the report resulted in a revised final report in June 1988. This report is the basis for much information used in this special study.

- The Arizona Department of Water Resources prepared a "Preliminary Project Evaluation" of Potrero Creek, in Santa Cruz, County, Arizona, in July 1983. This report addressed potential solutions to flooding in the Chula Vista and Pete Kitchen area of Nogales, Arizona. Although some hydrologic analysis of discharges issuing from Mexico was performed, no detailed study of Nogales, Sonora was performed.

- An undated report entitled, "Estudio Hidrologico Para El Encauzamiento Y Embovedamiento del Arroyo "Los Nogales" en Nogales, Sonora" was prepared. This report describes flooding conditions in Nogales, Sonora, and provides recommendations for structural improvement of Nogales Wash. The report contained monthly rainfall records from 1914 through 1982, rainfall frequency analyses, and runoff analyses.

- In 1990, a study entitled, "Estudio Hidraulico Para La Demarcacion de la Zona Federal del Arroyo "Los Nogales" was prepared by the Secretaria de Agricultura Y Recursos Hidraulicos, Comision Nacional del Agua, Gerencia Estatal del Agua, Subgerencia de Administracion del Agua. This study described hydraulic analysis of Nogales Wash, and provided regulatory floodplain boundaries. It included 11 large-scale maps showing flood boundaries in the open channel portion of Nogales Wash.

- In 1994, an updated hydrologic analysis was issued in "Nogales Wash and Tributaries, Nogales, Arizona, Appendix 1 – Hydrology", by the U.S. Army Corps of Engineers, Los Angeles District. This report addressed future development in the Nogales Wash watershed. These results were further updated in an internal memorandum of April 2002, addressing peak discharges at the international boundary.

- In 1997, a map was prepared for planning of preventative measures in the event of a natural disaster such as a tropical storm. This map was provided in an internal letter among staff at the IBWC, dated December 1998.

- In 1999, preliminary sketches of potential debris trap alternatives were prepared for the inlets to the covered channel segments of Nogales Wash. The sketches were provided in an internal letter among staff at the IBWC.

- In March 2003, a web-based document was issued entitled, "Critical US-Mexico Borderland Watershed Analysis, Twin Cities Area of Nogales, Sonora and Nogales, Arizona." This document focuses on water quality issues, and was prepared by the USGS and Arizona Department of Environmental Quality.

Study Participants

This current special study was initiated by the U.S. Section of the International Boundary and Water Commission (USIBWC) , and prepared by the U.S. Army Corps of Engineers, Los Angeles District, Arizona Area Office (USACE). U.S. agencies and entities participating in data collection, site analysis, or review included the USIBWC, USACE, City of Nogales, Arizona, Santa Cruz County, and the National Weather Service. Participating Mexican agencies and entities included Comision Internacional de Limites y Aguas, Seccion Mexicana (Mexican Section of the IBWC), Comision Nacional del Agua, Comision de Agua Potable y Alcantarillado del Estado de Sonora, and ciudad de Nogales, Sonora.

Water Resource Projects

As mentioned above, the IBWC constructed approximately five kilometers of covered channel, and 2.1 kilometers of open channel, for flood control purposes, within the cities of Nogales, Arizona, and Nogales, Sonora, Mexico (together referred to as “Ambos Nogales”). These channels were constructed in the 1930’s and 1940’s.

In approximately 1931, a recreation reservoir was created on Chimeneas Arroyo approximately 6.1 kilometers south of the international border. The drainage area upstream of this feature is approximately 10.07 square kilometers. The dam has little effect on large flood events.

In 1951, the IBWC constructed an International Waste Water Treatment Plant approximately 2.4 kilometers north of the border. By the mid-1960’s, this plant was no longer adequate, and a new facility was constructed in 1972 at the confluence of Potrero Creek and the Santa Cruz River, 14 kilometers north of the border..

Santa Cruz County constructed approximately 140 meters of soil cement and gabion bank protection on the west bank of Nogales Wash adjacent to Chula Vista in 1985.

The Natural Resources Conservation Service (former Soil Conservation Service) placed approximately 100 meters of Kellner Jacks on the west bank of Nogales Wash adjacent to the Firestone Gardens community in 1985. In 1987, the NRCS constructed an additional 190 meters of jacks on the opposite side of the channel.

Much of the floodplain area of the City of Nogales, Sonora possesses a storm drain system. Because of the age of the downtown area, and the sporadic nature of development, this storm drain system varies widely in both capacity and method of conveyance. Some areas are drained by lined and unlined open channels, others by covered channels. Transition from one channel type to another is common. Storm drain inlets exist along many tributaries, which feed into covered channels that subsequently confluence with the main channel of Nogales Wash. The existing channel system is covered in greater detail in Chapter 2.

Chapter 2 – The Study Area

Location

The study area is located entirely within the nation of Mexico and involved study of the entire watershed of Nogales Wash and tributaries upstream of its crossing into the United States. The focus of the study was on flood damage reduction for the City of Nogales, Sonora, although the City of Nogales, Arizona was always a primary consideration in regards to the viability of flood damage reduction measures. These two cities are known together as "Ambos Nogales". The City of Nogales, Sonora is located immediately south of the international boundary, approximately 98 kilometers south of the City of Tucson, Arizona. While the study effort modeled the entire watershed of Nogales Wash upstream of the international boundary, it is largely focused on the area subject to most damaging flooding within Mexico. This area extends from approximately the San Ramon Industrial District in the south, to the crossing of Nogales Wash into the City of Nogales, Arizona.

The study area watershed is a wedge-shaped feature, with its widest dimension in the foothills above the City of Nogales. The drainage area of the watershed is approximately 72.47 square kilometers. Figure 1 shows the Nogales Wash watershed and its relation to the City of Nogales.

General Description and Topography

The study area is located within the Mexican Highlands area of northern Sonora, Mexico. This region is characterized by numerous low, but rugged mountain ranges separated by deep, narrow, alluvial valleys. Nogales Wash occupies one sub-watershed of the larger Santa Cruz River Basin, which extends into the United States, and eventually flows into the Colorado River System, which makes its way back into Mexico above the Gulf of California. Elevations within the Nogales Wash watershed range from 1,660 meters above MSL in the headwaters to 1,180 meters at the international boundary. Nogales Wash extends approximately 11 kilometers south into Mexico.

Nogales Wash occupies a narrow, alluvium-filled valley, flowing generally south to north in its path. Nogales Wash drains the majority of the watershed (66.11 square kilometers), and incorporates tributary inflows from Arroyo Chimeneas (La Granja River), Arroyo 5 de Febrero (Canada El Muerto), Canada Celeya, Calle Heroes, and Calle Buenos Aires. Cemetery Wash drains a 6.36 square kilometer area in the northwest quadrant of the watershed, to a separate confluence with Nogales Wash downstream of the international boundary. Numerous smaller tributaries join the main channel along its length. The valley floor averages approximately ¾ kilometers in width. The channel varies from less than ½ meter deep in the headwaters areas, to as much as 6 meters deep in its most incised reaches. Figure 1 illustrates the topography of the watershed, key features, and major tributaries to Nogales Wash.

Geology and Soils

The study area lies within a terrain underlain by Tertiary sedimentary and Mesozoic intrusive rocks. In general, the Tertiary sediments overlie the Mesozoic rocks; however, due to uplift along various Tertiary normal faults, several vertical contacts occur. Canyons and valleys are filled with older and recent alluvium. Older alluvium mantles bedrock along the margins of the canyons. Both units may be over 100 meters thick.

Numerous faults in the area are of Tertiary age, but none are known to be active. The nearest known active fault is in the Patagonia Mountains, 7 kilometers northeast of Nogales, Arizona. The greatest earthquake within the historic record was a 7.2 Richter magnitude quake centered approximately 70 kilometers southeast of Nogales, in 1887. In 1916, an earthquake occurred in the immediate area of Nogales, with an estimated epicentral intensity of approximately VI.

There are three general soil associations within the Nogales area. These areas: Comoro-Pima, Caralampi-White-House-Hathaway, and Lampshire-Chirachua, Graham. Soils are primarily shallow and rocky, with rocks of andesite and rhyolite-tuffs, granites, and small areas of clay shales. Steeper slopes exhibit numerous rock outcroppings and shallow loamy soils. Shallow loamy soils with thin clay sub-soils are located on gentler slopes.

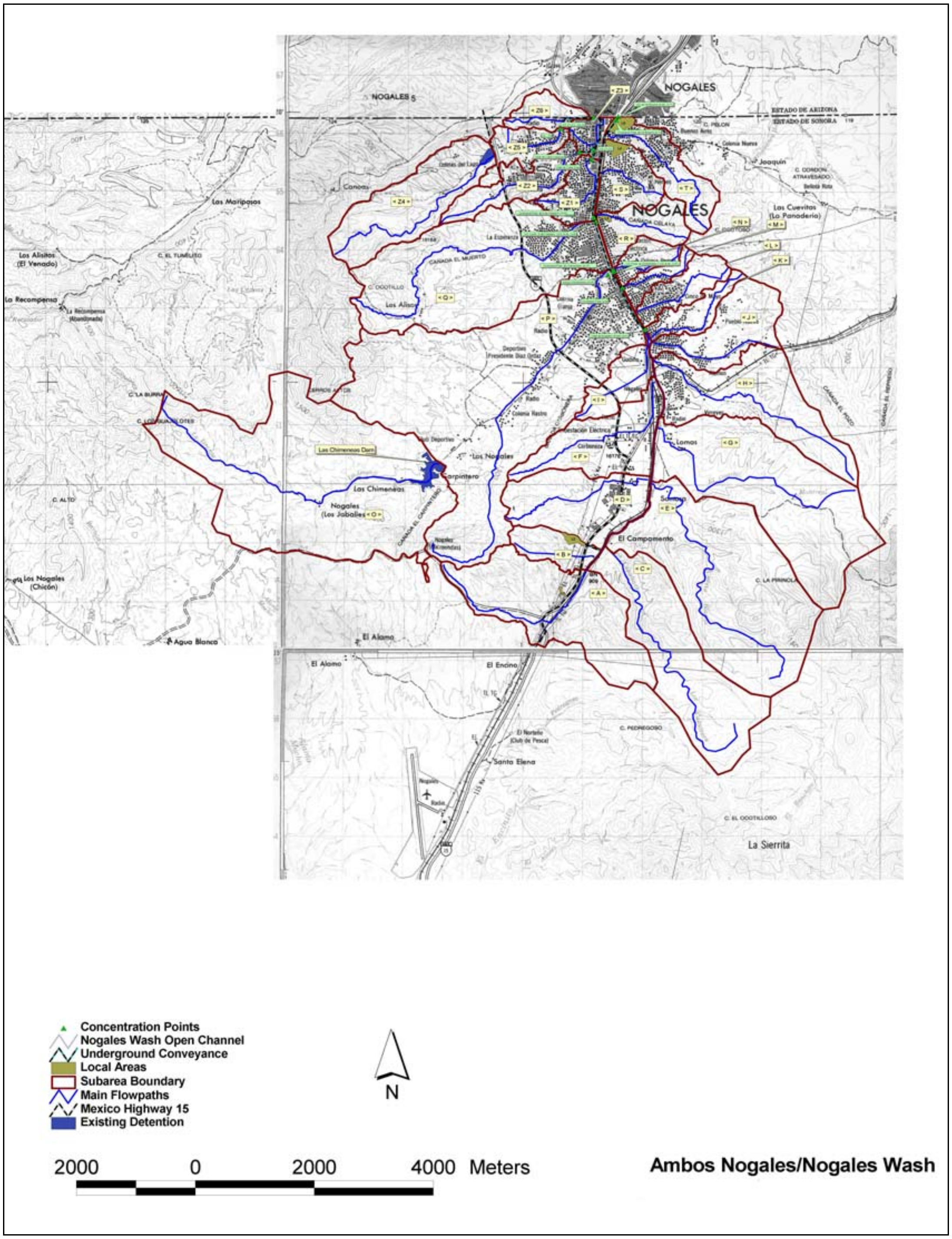
Climate

The climate of the study area is considered semi-arid high desert. The mean maximum and minimum temperatures for January are approximately 18 and -3 degrees Celsius, respectively. The mean maximum and minimum temperatures for July are approximately 34 and 18 degrees Celsius, respectively. Extreme highs and lows range from approximately 41 degrees Celsius to -19 degrees Celsius.

Mean monthly precipitation over the basin ranges from approximately 3 mm in May, to over 118 mm in July. About 50 percent of the mean annual precipitation falls within the monsoon months of July, August, and September. Most precipitation falls as a result of heavy summer thunderstorm activity, although tropical storms off the west coast of Mexico may produce heavy general and local precipitation. Much of the remaining precipitation falls within general winter-type storm events. The driest months of the year are May and June.

Winds within the region are generally moderate, with light breezes prevailing from the south. Gusts of up to 110 kilometers per hour have been recorded during heavy thunderstorms.

Figure 1. Nogales Wash Study Area



Surface Hydrology

Sub-basins within the Nogales Wash watershed can be classified as either desert valley or desert mountain. Stream gradients range from about 12% in headwater tributaries, to about 4% in the floodplain area of Nogales Wash.

Flow is generally ephemeral throughout much of the watershed. The vast majority of the channel system and watershed contains no natural surface water flow. Return flow of less than 0.1 cms, from a variety of introduced sources, may be found in various covered channel segments. Perennial flow in the channel may occur in the reach upstream from Calle Jesus Garcia, upstream of the main inlet near Calle Tepic, in the underground channel downstream of that point, and in the Arroyo 5 de Febrero upstream and within the covered channel segment west of Nogales Wash.

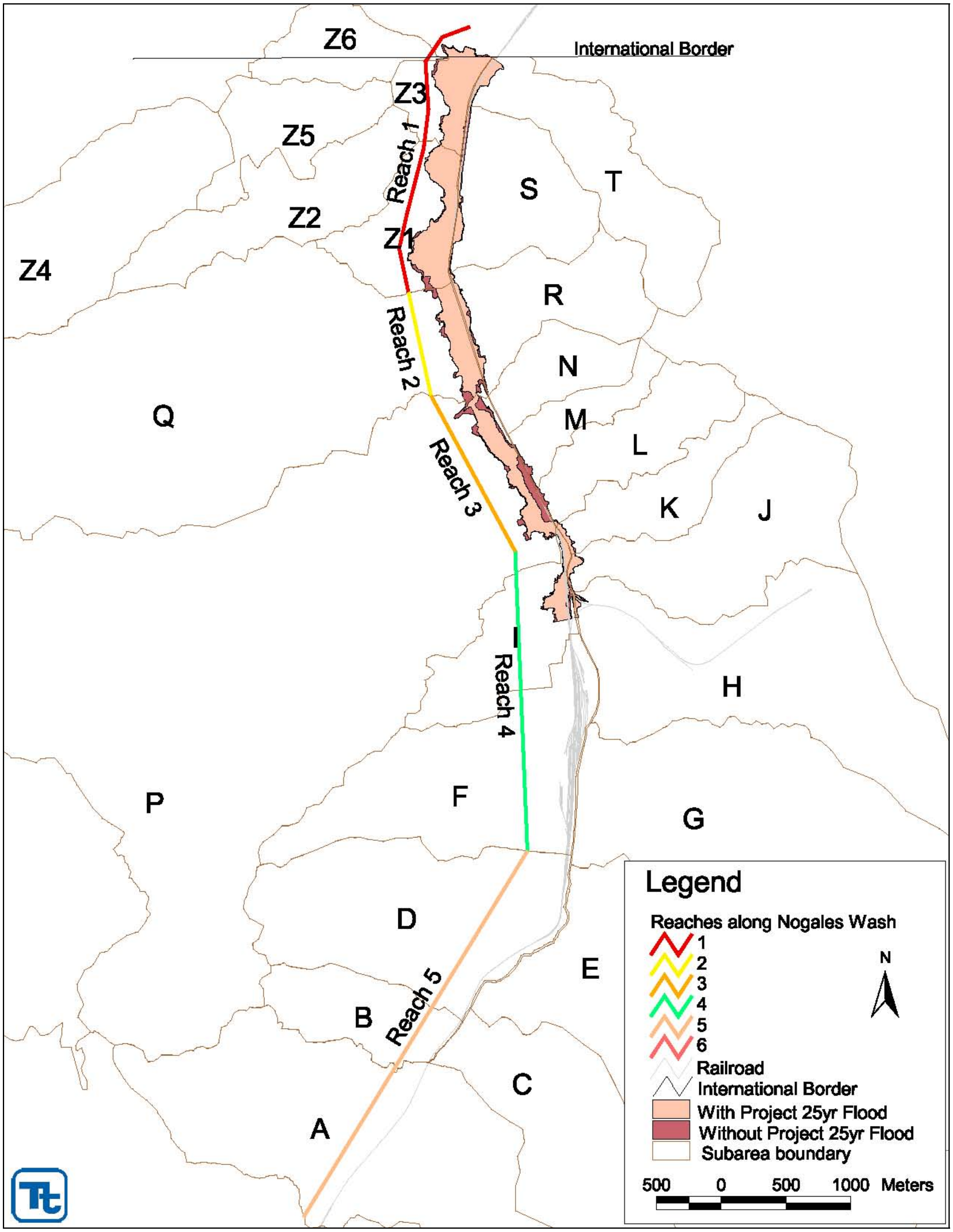
Historic accounts indicate the presence of dry weather flow in the channel system of between 0.05 and 0.5 cubic meters per second, at least into the 1980's (COE, 1988). The cause of the loss of this historic baseflow is unknown, but may be related to unregulated ground water withdrawal within the watershed.

Major tributaries to the mainstem channel include Arroyo Chimeneas (La Granja River), Arroyo 5 de Febrero (Canada El Muerto), Canada Celeya, Calle Heroes, Calle Buenos Aires, and Cemetery Wash. Streamflow in all major tributaries upstream of the developed portion of the watershed is ephemeral.

The results of a preliminary study on the hydrology and hydraulics of the Nogales Wash watershed within Mexico may be found in the report "Ambos Nogales/Nogales Wash Flood Control Study, Nogales, Sonora, Mexico", dated August 2003. That report contains information on conveyance capacities of the channel, expected discharges at various concentration points, and a preliminary look at improvement alternatives. However, this current report contains revised hydrology and more detailed analysis of preliminary alternatives for flood damage reduction. The following is a discussion of existing hydrology and watershed characteristics. A discussion of flooding problems is contained in Chapter 3.

For the purposes of hydrologic analysis, the study area was broken up into smaller subareas and reaches. These were largely based on existing features such as channel confluences and changes from one type of channel to another. As mentioned earlier, the focus of this analysis is on the reaches of the system most subject to substantial flood damage, notably the mainstem of Nogales Wash and tributaries within the City of Nogales, and its immediate environs. Reaches of the channel are also based on somewhat more arbitrary channel lengths, for the purposes of developing estimates of the number of structures within the floodplains of the 5-year, 10-year, and 25-year flood events. Figure 2 illustrates the study area reaches and their relationship to the subareas within the watershed.

Figure 2. Designated Reaches along Nogales Wash



The following is a summary of the channels and tributary inlets that govern runoff behavior in the critical areas of the Nogales Wash watershed. This information includes existing channel capacities at a number of locations. The description covers current (existing) conditions. Table 1 contains existing channel and inlet capacities for various reaches of Nogales Wash. Details on the hydrology and hydraulics of the study area are contained in Appendix A – Hydrology and Hydraulics.

Table 1. Existing Channel Capacities – Nogales Wash, Sonora, Mexico

Watercourse	Location	Length (m)	Capacity (cms)
Nogales Wash	International Boundary to Ave. Buenos Aires	320	150
Nogales Wash	Ave. Buenos Aires to Arroyo 5 de Febrero	1470	150
Nogales Wash	Arroyo 5 de Febrero to Arroyo Las Chimeneas	870	150 (1)
Nogales Wash	Arroyo Las Chimeneas to inlet near Calle Tepic	1230	150
Cemetery Wash	Under Calle Internacional	82	39
Cemetery Wash	Downstream from confluence of subareas Z1 & Z2	485	45
Tributary Inlet on Internacional Highway	Subarea L1	n.a.	12.4
Tributary Inlet on Internacional Highway	Subarea L2	n.a.	0.5
Tributary Inlet at Calle Pemex	Subarea M	n.a.	18.4
Tributary Inlet for Arroyo Chimeneas	Subareas O & P	n.a.	158
Tributary Inlet for Arroyo 5 de Febrero	Subarea Q	n.a.	29
Tributary Inlet south of Calle Celeya	Subareas L3 and R	n.a.	5.9
Tributary Inlet at Calle Celeya	Subareas L3 and R	n.a.	0.8
Tributary Inlet at Calle Heroes	Subarea S	n.a.	18.4
Tributary Inlet at Calle Embarcadero alignment	Subareas L4 and S	n.a.	8.9
Tributary Inlet at Calle Buenos Aires	Subarea T	n.a.	24.3
Tributary Inlet at Calle Diaz	Subarea Z1	n.a.	20.5
Tributary Inlet at Calle Vasquez	Subarea Z2	n.a.	14
Tributary Inlet at Calle Reforma	Subareas Z4 to Z5	n.a.	16.3
Grated Inlets on Calle Internacional	Subareas Z4 to Z6	n.a.	15.1(2)
Clogged grated inlet along boundary fence, east of crossing	Subarea L5	n.a.	0.55

1) Double barrel capacity is higher, but governed by single barrel sections upstream and downstream.
2) Capacity for all 8 grates combined.

Peak discharges for existing and future without-project conditions are contained in Tables 2 to 4. These results are presented for the 5-, 10-, and 25-year flood events. More information on the derivation of peak discharges may be found in Appendix A.

Table 2. Peak Discharge and Runoff Volume for 5-Year Flood Event

Existing and Future Without-Project Conditions					
Location (Concentration Point)	Drainage Area (km^2)	5-Year Existing Conditions		5-Year Future w/o Project Conditions	
		Peak Discharge (cms)	Runoff Volume (1000 m^3)	Peak Discharge (cms)	Runoff Volume (1000 m^3)
Inlet to Nogales Wash Underground Culvert (A-K)	32.69	79.5	637.3	142.5	1061.5
Underground Flow at Nogales Wash Inlet (Diversion A-K)	32.69	79.5	637.3	142.5	1061.5
Overland Flow at Nogales Wash Inlet (Div AK (br))		0.0	0.0	0.0	0.0
Overland Flow at Conc. Point AM	33.54	6.3	23.5	8.5	34.2
At Chimeneas Dam (O)	10.07	23.6	142.1	50.0	322.4
Inlet at Arroyo Chimeneas (O+P)	21.96	49.2	492.2	74.4	702.8
Underground Flow at Conf Arroyo Chimeneas (UG A-M, O-P)		123.2	1140.2	142.5	1061.5
Overland Flow at Conf Arroyo Chimeneas (OL A-P)	56.40	8.6	37.8	77.4	751.3
Underground at Conf 5 de Febrero (UG A-M, O-R)		142.5	1294.9	142.5	1061.5
Overland Flow at Conf 5 de Febrero (OL A-R)	63.78	8.4	38.6	96.9	976.1
Calle Diaz (Z1)	0.75	5.4	23.7	5.4	23.7
Calle Vasquez (Z2)	1.22	6.6	36.5	6.8	38.3
Underground Z1-Z2	1.97	10.3	60.2	10.6	62.1
Cemetery Wash at MEX-15 (Z4)	2.68	8.0	38.8	16.1	85.8
Cemetery Wash at Calle Reforma (Z4-Z5)	3.44	10.4	61.7	20.5	109.8
Cemetery Wash Tributary (Z6)	0.59	2.6	10.4	4.4	18.6
Underground Z4-Z6	4.03	12.4	72.2	20.7	124.2
Underground Combine Cemetery Wash Z1-Z2, Z4-Z6	6.00	22.7	132.4	30.7	186.3
Underground Flow at Conf C Buenos Aires (UG A-M, O-T)		147.1	1357.6	142.5	1061.5
Overland Flow at Conf C Buenos Aires (OL A-T at Boundary)	66.11	8.3	38.6	98.6	1047.3
Total overland Flow at International Boundary	72.47	9.6	50.4	98.9	1063.4
Total Flow (overland and underground) at International Boundary	72.47	178.0	1540.4	253.8	2311.2

Table 3. Peak Discharge and Runoff Volume for 10-Year Flood Event (Q10)

Existing and Future Without-Project Conditions					
Location (Concentration Point)	Drainage Area (km^2)	10-Year Existing Conditions		10-Year Future w/o Project Conditions	
		Peak Discharge (cms)	Runoff Volume (1000 m^3)	Peak Discharge (cms)	Runoff Volume (1000 m^3)
Inlet to Nogales Wash Underground Culvert (A-K)	32.69	114.8	836.7	190.3	1293.2
Underground Flow at Nogales Wash Inlet (Diversion A-K)	32.69	114.8	836.7	150.0	1219.4
Overland Flow at Nogales Wash Inlet (Div AK (br))		0.0	0.0	40.3	73.8
Overland Flow at Conc. Point AM	33.54	8.6	29.2	43.1	116.2
At Chimeneas Dam (O)	10.07	37.1	199.5	66.6	393.4
Inlet at Arroyo Chimeneas (O+P)	21.96	67.5	631.0	98.9	857.6
Underground Flow at Conf Arroyo Chimeneas (UG A-M, O-P)		125.8	969.8	150.0	1219.4
Overland Flow at Conf Arroyo Chimeneas (OL A-P)	56.40	58.5	558.2	142.5	991.7
Underground at Conf 5 de Febrero (UG A-M, O-R)		125.8	969.8	150.0	1219.4
Overland Flow at Conf 5 de Febrero (OL A-R)	63.78	80.2	759.6	169.1	1267.6
Calle Diaz (Z1)	0.75	7.7	28.8	7.7	28.8
Calle Vasquez (Z2)	1.22	9.5	44.6	9.8	46.6
Underground Z1-Z2	1.97	15.0	73.4	15.2	75.4
Cemetery Wash at MEX-15 (Z4)	2.68	12.5	54.1	21.4	104.7
Cemetery Wash at Calle Reforma (Z4-Z5)	3.44	15.3	82.1	26.9	133.9
Cemetery Wash Tributary (Z6)	0.59	3.9	13.7	6.3	22.6
Underground Z4-Z6	4.03	18.5	95.8	22.6	140.0
Underground Combine Cemetery Wash Z1-Z2, Z4-Z6	6.00	33.4	169.2	37.0	215.3
Underground Flow at Conf C Buenos Aires (UG A-M, O-T)		125.8	969.8	150.0	1219.4
Overland Flow at Conf C Buenos Aires (OL A-T at Boundary)	66.11	83.9	837.8	171.3	1355.0
Total overland Flow at International Boundary	72.47	84.4	852.2	171.6	1385.9
Total Flow (overland and underground) at International Boundary	72.47	233.6	1991.2	338.9	2820.7

Table 4. Peak Discharge and Runoff Volume for 25-Year Flood Event (Q25)

Existing and Future Without-Project Conditions					
Location (Concentration Point)	Drainage Area (km^2)	25-Year Existing Conditions		25-Year Future w/o Project Conditions	
		Peak Discharge (cms)	Runoff Volume (1000 m^3)	Peak Discharge (cms)	Runoff Volume (1000 m^3)
Inlet to Nogales Wash Underground Culvert (A-K)	32.69	173.6	1123.4	286.6	1624.9
Underground Flow at Nogales Wash Inlet (Diversion A-K)	32.69	150.0	1075.9	150.0	1304.7
Overland Flow at Nogales Wash Inlet (Div AK (br))		23.6	47.5	136.6	320.2
Overland Flow at Conc. Point AM	33.54	26.9	101.9	139.8	374.6
At Chimeneas Dam (O)	10.07	59.6	282.0	99.8	495.1
Inlet at Arroyo Chimeneas (O+P)	21.96	101.2	830.4	141.8	1079.4
Underground Flow at Conf Arroyo Chimeneas (UG A-M, O-P)		150.0	1075.9	150.0	1304.7
Overland Flow at Conf Arroyo Chimeneas (OL A-P)	56.40	128.6	955.1	279.7	1476.8
Underground at Conf 5 de Febrero (UG A-M, O-R)		150.0	1075.9	150.0	1304.7
Overland Flow at Conf 5 de Febrero (OL A-R)	63.78	161.8	1222.4	321.2	1826.0
Calle Diaz (Z1)	0.75	11.9	36.4	11.9	36.4
Calle Vasquez (Z2)	1.22	15.0	56.6	15.3	58.8
Underground Z1-Z2	1.97	23.7	92.7	23.9	94.7
Cemetery Wash at MEX-15 (Z4)	2.68	19.8	76.2	31.7	131.7
Cemetery Wash at Calle Reforma (Z4-Z5)	3.44	23.2	111.7	39.7	168.6
Cemetery Wash Tributary (Z6)	0.59	6.5	18.8	9.7	28.6
Underground Z4-Z6	4.03	22.8	117.6	26.0	153.2
Underground Combine Cemetery Wash Z1-Z2, Z4-Z6	6.00	46.5	210.2	49.0	247.9
Underground Flow at Conf C Buenos Aires (UG A-M, O-T)		150.0	1075.9	150.0	1304.7
Overland Flow at Conf C Buenos Aires (OL A-T at Boundary)	66.11	164.9	1322.9	324.8	1936.5
Total overland Flow at International Boundary	72.47	165.4	1354.2	326.9	1999.1
Total Flow (overland and underground) at International Boundary	72.47	340.1	2640.3	502.1	3551.6

Vegetation

The Nogales Wash watershed is considered part of a semi-desert grasslands complex near the eastern edge of the Sonoran Desert. Native vegetation in the upper portion of the watershed includes mesquite, scrub oak, manzanita, and other chaparral-type plants. Pinyon pine, juniper, and ponderosa pine occupy small areas in the uppermost-elevations of the watershed. Lower elevations exhibit desert scrub vegetation, such as salt bush, creosote, cacti, and native and non-native grasses.

Fish and Wildlife

Wildlife resources of Nogales Wash and tributaries are considered highly degraded. Riparian habitat in the watershed is scarce and becoming more so each day. Resource value of the riparian zone is considered quite high, as it attracts wildlife from adjacent grasslands to feed. Bird surveys in the general watershed area (including portions within the U.S.) have identified as many as 87 species that utilize riparian woodlands (COE, 1988). No detailed fish and wildlife surveys of the study area could be identified. Wildlife expected to utilize the riparian zone include coyote, raccoon, coatimundi, striped and hooded skunk, wood rat, desert pocket mouse, round tailed ground squirrel, Sonoran mud turtle, tree lizard, and Couch's spadefoot toad.

Further study on flood control alternatives for Nogales Wash and the City of Nogales, Sonora, will have to include the evaluation of potential impacts to environmental resources. These studies would be conducted in concert with more detailed technical and economic studies.

Cultural Resources

The Nogales Wash watershed possesses a long and vital cultural history. It is believed that various pre-historic residents of the area utilized the watershed until approximately 1450 A.D., when the area was depopulated. There are numerous theories on the reasons behind this occurrence; however, by the time of Spanish incursion, there were scattered bands of farmers of the Pima and Sobaipuri tribes occupying the floodplains. These early residents of the watershed were not believed to have had much impact on the nature of flooding in the watershed, although they dug ditches and diverted low-flows for irrigation of crops.

In 1701, Jesuit priests established a mission at Guevavi, north of the study area. They were followed by the Franciscans in 1767, who concentrated their presence even further north. It is believed that some of this shift was caused by the depredations of Apache Indians, as the area was largely abandoned into the 1860's. Some time in the 1860's, the first outside settlement began, with small numbers of ranchers settling in the valley. It is not known if any of these settlers occupied the study area. In 1865, a military post was constructed at the mouth of Potrero Creek, north of the study area. This post was abandoned the following year.

In 1880, a rail line was constructed through the Nogales Wash canyon, connecting Sonora, Mexico, and settlements in Arizona. Speculation in land along this route resulted in settlement of the land along the U.S./Mexican boundary to take advantage of the new port-of-entry at this location. The resulting town was referred to as "Line City." The developing town on the Mexican side of the border became Villa Riva. The name Nogales (Spanish for walnut) eventually became accepted due to the railroad usage of this name for their depot. Railroad access provided the means for more rapid growth on both sides of the boundary.

No detailed cultural resources assessment of the area was identified for use in this study. A survey of historical properties and buildings, potential archaeological sites, and other cultural resources will be especially important in the event of pursuit of some measures discussed in this report. Further study on flood control alternatives for Nogales Wash and the City of Nogales, Sonora, will have to include the evaluation of potential impacts to cultural resources. These studies would be conducted in concert with more detailed technical and economic studies.

Population

Population of the metropolitan area of the City of Nogales, Sonora, was estimated at 200,000 persons in the year 1988 (COE, 1988). Current population of the Ambos Nogales and its environs is unofficially estimated to be as much as 400,000.

Development

Development of the Nogales Wash watershed has exceeded all past projections. In the middle and lower portions of the watershed, development has occupied most open land up to the rim of many smaller subareas. It appears that similar development will occur throughout much of the remaining watershed. Inspection of aerial photos indicates that typical residential development in Nogales ranges from 8 to 10 houses per acre. Yards are small, and rooftops are generally connected directly to driveways and sidewalks. Paved or hard-packed streets tend to follow natural watercourses, providing an efficient runoff conveyance system. Figure 3 illustrates the extent of current development (shown in grey), main flowpaths, above-ground and underground conveyance, and existing detention. The effects of development on hydrology and hydraulics are evident. Development has paved over and replaced much of the pervious ground within those areas. Impervious cover rates have increased dramatically. This has had a significant effect on runoff volume and peak discharge.

Figure 3. Existing Conditions Development, Flow Paths, Conveyance, and Detention

Chapter 3 – Problem Identification and Opportunities

Flooding

At only 72.47 square kilometers, the Nogales Wash watershed is relatively small. With its rugged topography and steep slopes, it creates hazardous flood conditions by contributing high volumes of runoff very quickly to the floodplain. With a narrow floodplain and inadequate drainage capacity, the potential for highly damaging flooding is a constant threat to the community. Significant depths of flood waters occur during relatively frequent flood events.

As previously shown in Table 1, inlet structures and channels are undersized. Approximately 550 structures are flooded in a 25-year flood event. Flooding occurs as runoff issues from steep hillsides surrounding the city, collects in natural drainage ways, and is funneled into low-lying streets and swales. Flood flows are typically carried in city streets throughout much of the study area. Flood flows reaching the inlets frequently overwhelm the ability of the structure to accommodate the volume of water. The main inlet of the covered channel segment of Nogales Wash is overtopped in as little as a 14-year event under existing conditions. This is expected to drop to as frequent as a 5-year event under future without-project conditions. Floodwaters attempting to enter storm drains further downstream have little chance of conveyance, due to frequent debris blockage, but also due to the covered channel of Nogales Wash being filled to capacity during relatively frequent flood events. Street flooding upstream and downstream of certain storm drain inlets occurs, on average, every year.

Recent rates of development and paving of pervious surfaces has greatly increased the threat of flood damage and risks to human life. This trend may exacerbate the situation even more in the future. Thousands of residents live and work within the floodplain. Numerous commercial structures serving the community and the tourist trade occupy the floodplain, and are susceptible to frequent inundation and damage. Interruptions to traffic and pedestrian access are numerous. Commercial structures are largely constructed at, or only slightly above, the grade of the streets. Overflow in the floodplain easily enters adjacent structures, causing damage to structures and contents, as well as threats to personal safety.

Historical Flood Damages

The City of Nogales, Sonora, has a long history of flooding. The IBC reports that major floods occurred within the city in 1905, 1909, 1914, 1915, 1926, 1930, and 1931, leading to the construction of the existing flood control system. The flood of 1930 caused five deaths (U.S. and Mexico), and caused over $5.6 million in damages (1986 dollars). The flood control channel system that was constructed in the wake of these floods has prevented a great deal of damage, but has grown increasingly incapable of handling even minor flood events.

The flood of October 1977 resulted in over one million dollars in damages (U.S. and Mexico), inundated over 40 homes on both sides of the border, and caused significant damage to the International Waste Water Treatment Plant. It also resulted in the deaths of three people. This event was estimated to have a recurrence interval of only eight years. Further flooding in 1978 to 1980 and 1983 resulted in more damage.

Damage in recent years has not been quantified. Damages from flood flows have occurred almost every year, and in some cases, several times in one season. Loss of life due to flooding occurred in July 2003 and July 2004.

Projected Inundation

Inundation associated with the 5-, 10-, and 25-year events is shown in Figure 4. Depths of flooding associated with the floodplain are contained in Table 5.

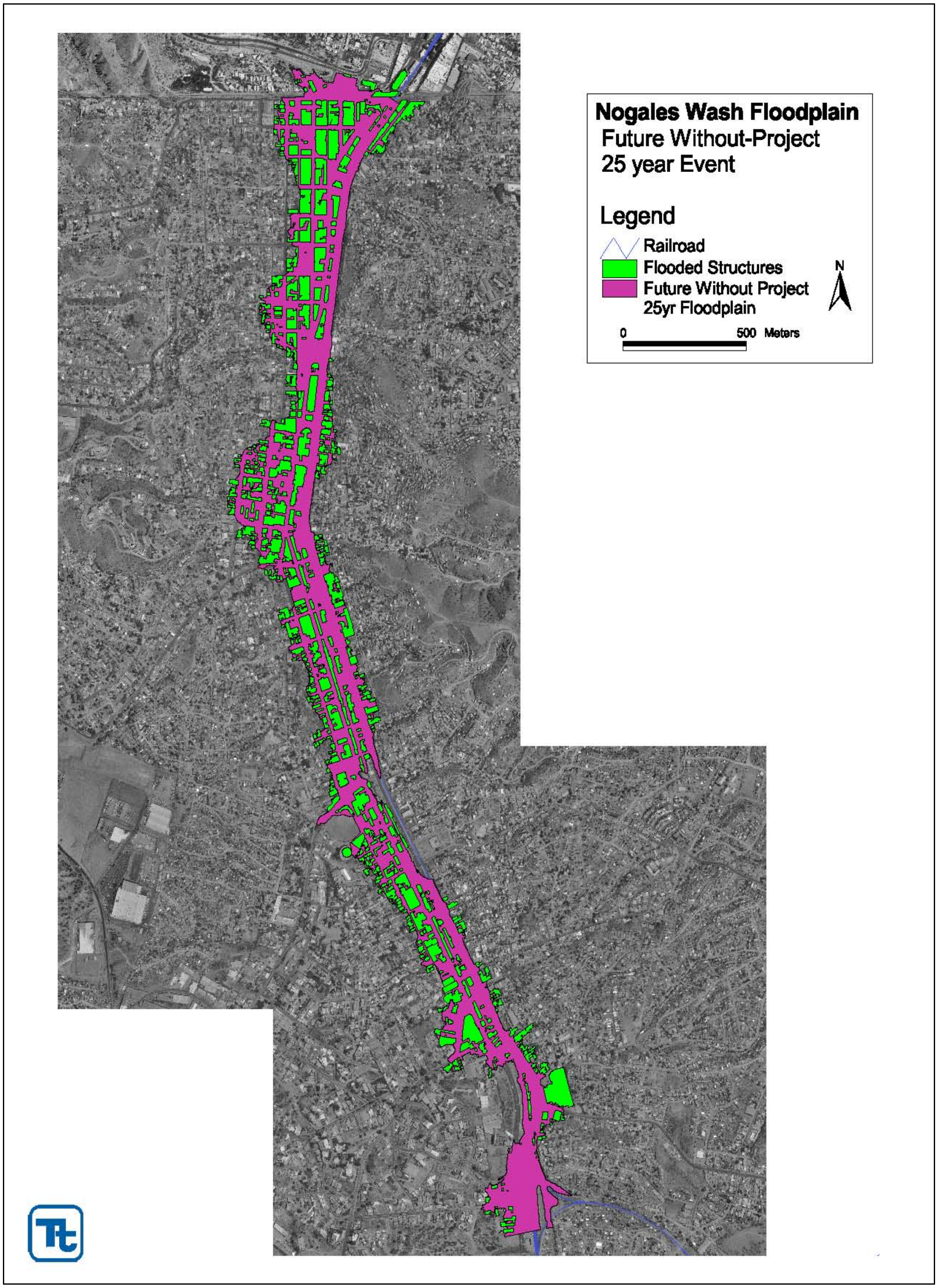
Table 5. Depth (meters) of Flooding - Existing Conditions

Comparison of Average Flood Depths (meters)								
			5-year Event		10-year Event		25-year Event	
Reach	From	To	Existing	Future without Project	Existing	Future without Project	Existing	Future without Project
1	5 de Febrero	International Border	0.30	0.72	0.66	0.97	0.95	1.34
2	Arroyo Chimeneas	5 de Febrero	0.22	0.53	0.45	0.73	0.69	1.12
3	Inlet at Nogales Wash	Arroyo Chimeneas	0.39	0.50	0.49	0.79	0.69	0.85
4	Upstream of Under-ground Inlet	Inlet at Nogales Wash	0.71	0.95	0.85	0.97	0.94	1.21

Discharge-Frequency Information

Peak discharges for the 5-, 10-, and 25-year flood events were given in Tables 2 through 4. Discharges are given for the existing condition, and for the future "without-project" condition. The future "without-project" condition assumes that development occurs within the watershed at a rate similar to that evident over the past several decades, and that full "build-out" of the watershed occurs. Impervious cover rates reflect these changes. Peak discharges developed in this analysis exceed those of past studies due to the high rates of development that have actually occurred. Development has far exceeded anticipated rates of growth assumed in prior studies. Details on the development of revised discharge-frequency relationships are contained in Appendix A – Hydrology and Hydraulics.

Figure 4. Nogales Floodplain for the 25-Year Future Without Project Conditions



Chapter 4 – Plan Formulation

Introduction

The goal of this planning process is to provide potential solutions to the flood problems affecting the City of Nogales, Sonora, and to make a recommendation as to the most effective plan for potential implementation. The planning process on a study of this type is highly iterative. Once the study team determines the nature of the problem, resources affected, and the physical characteristics of the watershed and the runoff affecting flood behavior, one may develop preliminary measures to address the problem. Numerous measures were examined in this study.

Planning Goals and Objectives

As stated, the primary goals established for this study effort are to: (1) reduce the threat of flooding to life and safety of residents and visitors, and (2) the effective reduction of flood damages to structures and their contents within the City of Nogales, Sonora.

The objective of the study is to identify the most effective solution or solutions. Solutions should provide minimal impacts to existing infrastructure, be technically feasible, and sound in concept.

This study does not include formal analysis of economic benefits, but in some cases, the impacts of proposed alternatives are described in terms of the number of structures that are flooded. Likewise, there is not a formal analysis of environmental, cultural, or social impacts, but these factors were considered in selecting potential sites for structural features. A thorough analysis of these issues would be warranted if further development or implementation of proposed measures is pursued.

Planning Constraints

Planning constraints include the following:

- Minimization of impacts to existing structures and areas of human occupancy;
- Minimization of impacts to historic properties (where those could be readily identified);
- Minimization of disruption to vehicular, pedestrian, and railroad traffic and facilities;
- Minimization of induced damages (damages to adjacent or downstream properties) due to implementation of recommended activities;

Potential Management Measures

The study team identified the following measures as being appropriate for reducing flood damage within the study area:

- Flood Proofing
- Relocation
- Flood Warning
- Floodplain Management
- Channel Modification/Enlargement
- Inlet Improvement
- Detention

Development of Alternative Measures

Each measure was conceptually developed by the study team to a level of detail sufficient to allow its comparison to other potential measures. Concept level applications were discussed in light of their: (1) potential reduction of the threat to life and safety of residents and visitors, and (2) the effective reduction of flood damages to structures and their contents. The ability to significantly affect both primary criteria was considered critical for further consideration. Structural measures were conceptually design to target floodwaters resulting from the occurrence of a 5-, 10-, and 25-year future-conditions flood event. Some measures were quickly deemed inappropriate for further development.

Evaluation and Screening of Measures

The previous list of potential measures was analyzed for their potential in reducing flood damages and the risk to life and safety to residents and visitors. The following discussion and evaluation of measures allowed for the screening of measures that did not satisfy the goals and objectives established for the study. Table 9, which follows this discussion, summarizes the screening process.

Flood-Proofing

Flood-proofing consists of the application of engineered components to existing structures, bridges, and infrastructure within a flood-prone area. Examination of potential flood-proofing measures indicates that the most effective measure would likely be the application of water-resistant door and window coverings to structures in the floodplain. This measure would require application to approximately 550 structures within the future-conditions 25-year floodplain.

Flood-proofing of this type would require immediate application by building residents in order for it to be effective. There is some doubt as to whether or not this could be applied to many of the affected structures within a timeframe of as little as 30 minutes, particularly to structures with multiple windows and doors. It is also visually obtrusive and would create an aesthetically detracting presence given the historic nature of the community. The fitting of structures with solid window covering and gaskets in frames would change the essential nature of the city. Due to the importance of outside visitation, this measure could cause a decline in visitation to the city, and hence, income to the community.

Flood-proofing has no effect on the flood flows themselves and impacts to vehicular, pedestrian, and railroad traffic would remain unchanged. Due to the importance of the city as an income generator, as a transshipment point for produce and goods, and for railroad shipments between the United States and Mexico, disruptions would remain very costly, and their effects regional or even national in impact. In addition, flood-proofing does not solve the critical issue of threats to life and safety. Flood waters will still flow unimpeded through city streets. The risk of high velocity flows on pedestrians and vehicular occupants would remain unabated. Due to the significant depth and velocity of flood flows through city streets, the risk of drowning from flooding would remain quite high. Therefore, the measure of flood-proofing, while also viewed as a viable option for individual residents of the floodplain, cannot be recommended for widespread application as a single measure, or even as a primary component of a package of recommendations.

Relocation

Relocation of structures and infrastructure to locations outside the floodplain has been done in some limited applications in the United States. Its application in small communities at high risk has proven successful. However, the City of Nogales has several issues that contribute to the lack of viability of this measure. The floodplain has numerous structures, many of them large, and many of them historic in nature. Relocation of numerous key institutional and commercial concerns, including the mainline railroad, is not possible. Therefore, relocation is not considered a technically feasible means of reducing the costs and threats of flooding, and is not recommended for further consideration.

Flood Warning

Flood warning is the process of providing advanced warning of imminent flooding to residents of flood-prone areas, allowing them to evacuate to an area of safety. Flood warning has been used in many locations, providing residents with sufficient warning to allow them to proceed to high ground, avoiding threats to life and safety.

The Nogales Wash watershed is fairly small. Slopes in the watershed are very steep, and areas of runoff retention are few. The watershed's response to rainfall is extremely fast and warning times would be excessively short. Estimated time to peak for localized flood events may be as little as 15 minutes. While a warning system may provide some measure of warning to people within channels or city streets, it would provide little time for residents in some areas, and even less opportunity for residents to remove valuable contents. The concept of an early warning system consisting of rain gauges linked by satellite to a centralized facility, may provide a significant benefit to life and safety of occupants of the floodplain, it does little to nothing to solve the existing flood problem.

The effects of flood flows on vehicular and railroad traffic would likely remain unchanged. The anticipated time from warning to arrival of the flood peak would allow insufficient time for removal of vehicles and trains from the flood inundation area. Due to the importance of the city as an income generator, as a transshipment point for produce and goods, and for railroad shipments between the United States and Mexico, disruptions would remain very costly, and their effects regional or even national in impact. Therefore, the measure of flood warning, while viewed as a viable option for partial application to risks to life and safety, cannot be recommended for application as a single measure, or even as a primary component of a package of recommendations.

Floodplain Management

Floodplain management has proven to be a highly viable means of reducing flood damage within floodplains. Its application is generally through the use of restrictive development policies. These regulations generally require that development provides infrastructure that prevents the addition of flood flow volume, or the increase of peak discharge, to downstream reaches of the channel. This is usually accomplished by installation of detention structures or retro-fitting of structures and infrastructure.

Much of the Nogales Wash floodplain within the city was developed long before effective regulation and a full understanding of the magnitude of development that would occur in the watershed. While floodplain management may be applied to re-development of properties in the floodplain, many of these properties are historic in nature, and highly unlikely to be re-developed in such a way that damage could be prevented. The potential for meaningful change in floodplain occupancy or structure modification is long past.

As with other non-structural measures, the effects of flood flows on vehicular, pedestrian, and railroad traffic would remain unchanged. Due to the importance of the city as an income generator, as a transshipment point for produce and goods, and for railroad shipments between the United States and Mexico, disruptions would remain very costly, and their effects regional or even national in impact.

In addition, floodplain management does not solve the critical issue of threats to life and safety. Flood waters will still flow unimpeded through city streets. The risk of high velocity flows on pedestrians and vehicular occupants would remain unabated. Due to the significant depth and velocity of flood flows through city streets, the risk of drowning from flooding would remain quite high. Therefore, the measure of flood plan management, while feasible as a modification to existing General Plans and re-development policies for the floodplain, cannot be recommended for widespread application as a single measure, or even as a primary component of a package of recommendations.

Channel Modification/Enlargement

The existing channel of Nogales Wash is primarily a single box culvert constructed of reinforced concrete, with an estimated conveyance capacity of approximately 150 cms. An 870-meter section between Arroyo 5 de Febrero and Arroyo Chimeneas is a double barrel box, but the capacity is limited by the much-longer single box. The existing channel can convey slightly less than a 5-year flood event give future-conditions.

The total future-conditions 25-year flood event peak discharge at the international boundary is currently estimated at approximately 541 cms. Enlargement of the existing channel to a 4-barrel box culvert of similar individual dimensions would convey a flow of approximately 600 cms and would be more than adequate to accommodate the future inflow at the inlet of the structure, and side drainage from tributaries. A 2-barrel box culvert having similar individual dimensions would be adequate to convey the 5-year future conditions event, and a 3-barrel box culvert would be adequate to convey a 10-year future-conditions event.

While this measure may improve conveyance of flood flows through the study reach, it would still require improvement of numerous inlets and tributaries to function in a fully effective manner. Excess flood flow (from events larger than the 25-year event) would continue to flood the surface of the floodplain, due to a lack of capacity to control larger events. In addition, the underground channel enlargement would have to continue for approximately 1300 meters through Nogales, Arizona to a point of disposal in an open channel section of Nogales Wash. There will likely be additional downstream impacts that result from concentrating the flows in the underground channel.

The existing right-of-way above the covered channel is currently occupied by a variety of roads, structures, infrastructure, and even railroad tracks and facilities. The cost of removal and/or relocation of these features would be significant. Disruption to traffic, both vehicular and railroad, would be costly and regional or national in scope. While technically feasible, it is not believed that this measure could be implemented from a political standpoint. The level of disruption to existing businesses it would cause and its effects on traffic and international trade may be more than the City can endure. Therefore, it is not recommended for future consideration.

Inlet Improvements

Improvement of various inlet structures on tributaries contributing to Nogales Wash will contribute to the reduction of flood overflow within the floodplain. Improvement would consist of more effective capture and conveyance of flood flows into and through the storm drain system. This measure can be performed individually, in areas of most critical need, for maximum cost-effectiveness. Table 6 contains a comparison of tributary inlet capacities, and the discharges they might be expected to accommodate under future conditions.

Table 6. Comparison of Tributary Inlet Capacities and Expected Future Discharges

Location	Subareas	Capacity (cms)	Q5 (cms)	Q10 (cms)	Q25 (cms)
Tributary Inlet on Internacional Highway	Subarea L1	12.4	0.19	0.24	0.32
Tributary Inlet on Internacional Highway	Subarea L2	0.5	0.74	0.94	1.30
Tributary Inlet at Calle Pemex	Subarea M	18.4	3.8	5.2	7.6
Tributary Inlet for Arroyo Chimeneas	Subareas O & P	158	74.4	98.9	141.8
Tributary Inlet for Arroyo 5 de Febrero	Subarea Q	29	29.0	38.9	58.6
Tributary Inlet south of Calle Celeya	Subareas L3 and R	5.9	0.31	0.39	0.54
Tributary Inlet at Calle Celeya	Subareas L3 and R	0.8	8.7	11.8	17.6
Tributary Inlet at Calle Heroes	Subarea S	18.4	11.3	15.1	21.7
Tributary Inlet at Calle Embarcadero alignment	Subareas L4 and S	8.9	1.22	1.57	2.16
Tributary Inlet at Calle Buenos Aires	Subarea T	24.3	8.8	11.7	17.4
Tributary Inlet at Calle Diaz	Subarea Z1	20.5	5.4	7.7	11.9
Tributary Inlet at Calle Vasquez	Subarea Z2	14	6.8	9.8	15.3
Tributary Inlet at Calle Reforma	Subareas Z4 to Z5	16.3	20.5	26.9	39.7
Grated Inlets on Calle Internacional	Subareas Z4 to Z6	15.1(1)	8.6	16.9	33.1
Clogged grated inlet along boundary fence, east of crossing	Subarea L5	0.55	1.39	1.80	2.49

(1) Capacity for all 8 grates combined.

As indicated in Table 6, some tributary inlets are capable of accommodating the 25-year and larger flood events in their existing configuration, unless blocked by debris.

The tributary inlet governing subarea L1 is capable of conveying vastly more discharge than the subarea will generate in a 25-year event (see Figure 5). However, the tributary inlet governing subarea L2 on the International Highway is severely undersized (see Figure 6). It currently conveys less than a 5-year event, and contributes approximately 1 cms to overland street flow downstream of this point. Its replacement is an obvious point of improvement.

Figure 5. Tributary Inlet for Subarea L1 at International Highway.

Figure 6. Undersized Tributary Inlet for Subarea L2 at International Highway.

The tributary inlet at Calle Pemex is also capable of conveying at least a 25-year inflow (see Figure 7). Likewise, the inlet for Arroyo Chimeneas is capable of conveying at least the 25-year flood inflow (see Figure 8). However, the tributary inlet for Arroyo 5 de Febrero is incapable of conveying even a 5-year flood event (see Figure 9). It will contribute as much as 60 cms during a 25-year event to the over bank area. This is a highly significant contribution to downstream flooding.

The tributary inlet south of Calle Celeya possesses significantly greater capacity than needed to convey a 25-year flood event (see Figure 10). The tributary inlet at Calle Heroes is only capable of conveying an event of between 10- and 25-year recurrence (photo unavailable). Its improvement would aid in the control of events larger than this level of protection.

Tributary inlets at Calle Embarcadero alignment (Figure 11), Calle Buenos Aires (Figure 12), and Calle Diaz (photo unavailable) are all capable of conveying a 25-year flood event. The inlet at Calle Buenos Aires may not convey a 50-year event, but the others have significant capacity in excess of the 25-year event.

The inlet at Calle Vasquez (see Figure 13) is only capable of conveying an event of between 10- and 25-year recurrence. Its improvement would aid in the control of events larger than this level of protection.

The inlet at Calle Reforma (see Figure 14) is capable of conveying slightly more than a 25-year flood inflow.

Grated inlet structures along Calle Internacional may be incapable of handling events much in excess of the 5-year discharge. Their improvement will aid in the control of overland flow downstream of these points.

The grated inlet along the boundary fence east of the crossing is severely undersized (see Figure 15). It is incapable of conveying even a 5-year event. It may contribute as much as 2.5 cms to over bank flooding downstream of this point during a 25-year flood event.

Improvement of these storm drain inlets may aid in the reduction of flood inundation in the tributary areas immediately downstream of their location. However, if not combined with enlargement measures in Nogales Wash downstream, and their conveyance structures along the intervening reach, the potential for backwater effects remains. In addition, control of flows upstream may also be required to ensure that flows approaching the inlet are guided accurately to the inlet and do not bypass the structure for an alternate flow path.

Figure 7. Tributary Inlet at Calle Pemex

Figure 8. Tributary Inlet for Arroyo Chimeneas

Figure 9. Tributary Inlet for Arroyo 5 de Febrero

Figure 10. Tributary Inlet South of Calle Celeya

Figure 11. Tributary Inlet at Calle Embarcadero Alignment

Figure 12. Tributary Inlet at Calle Buenos Aires

Figure 13. Tributary Inlet at Calle Vasquez

Figure 14. Tributary Inlet at Calle Reforma

Figure 15. Grated Inlet Structure Along Calle Internacional

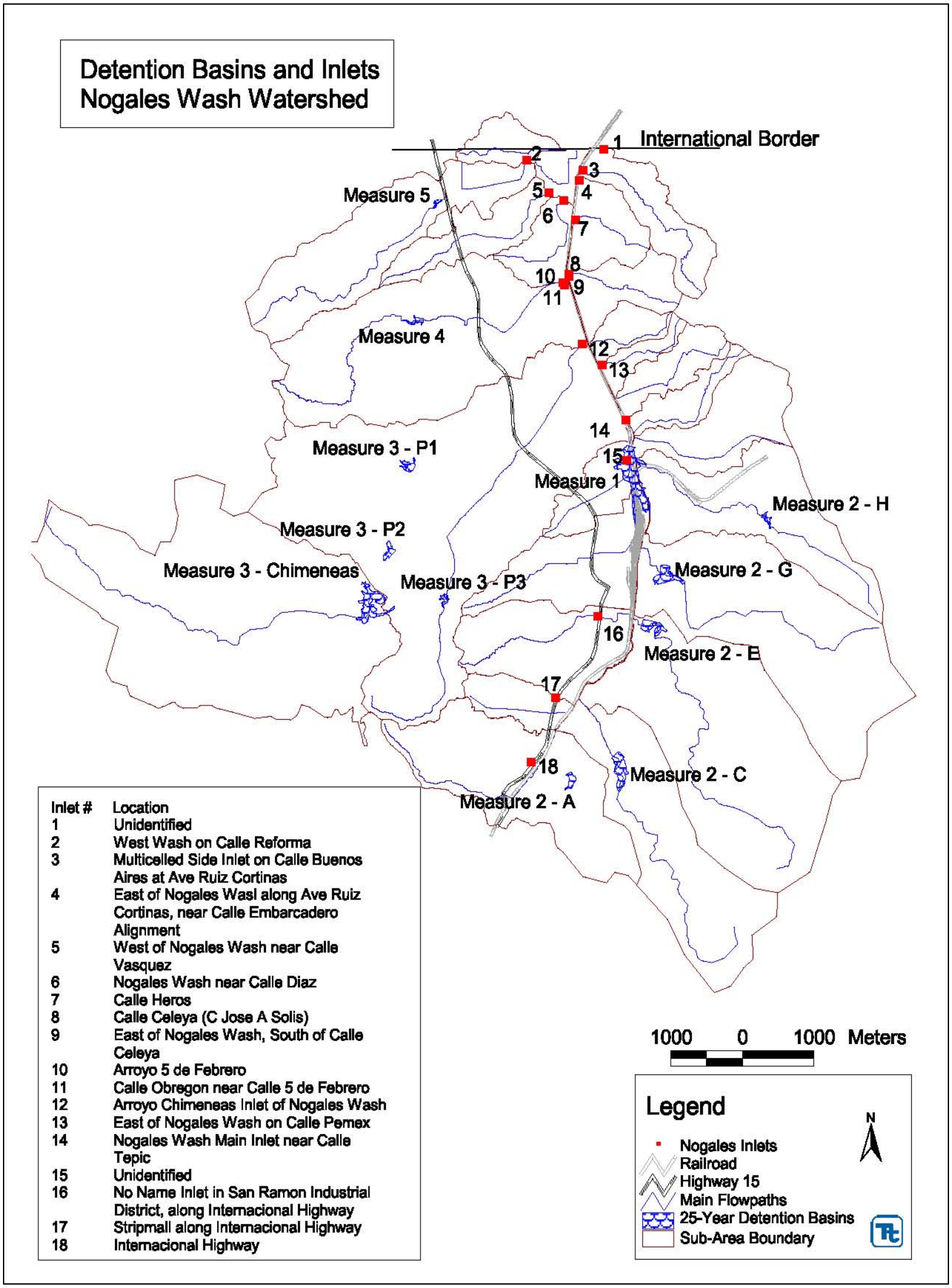
Individual treatment of inlet problems appears to be a cost-effective solution to limited flooding problems along tributary reaches. In addition, it may be a measure that can be implemented in select areas without the inducement of damages in downstream areas. However, this measure cannot be recommended as a stand-alone solution to flooding within the City of Nogales, but must be combined with other measures as a comprehensive alternative.

Detention

Detention of floodwaters consists of a structure that will detain flood flows until such time as the downstream channel system is capable of conveying them safely through flood-prone areas. Detention is a viable means of temporarily removing flood flow volume from a flood event, and reducing the resulting flood peak in areas downstream of the structure. This measure may consist of a single large structure, or a group of smaller structures placed in appropriate locations.

For the purposes of determining potential flood damage reduction, a number of detention structures were modeled. Their effects on downstream flood extent and depth, and the number of structures inundated, were determined. The locations of the basins modeled are shown in Figure 16.

Figure 16. Locations of Detention Basins and Inlets



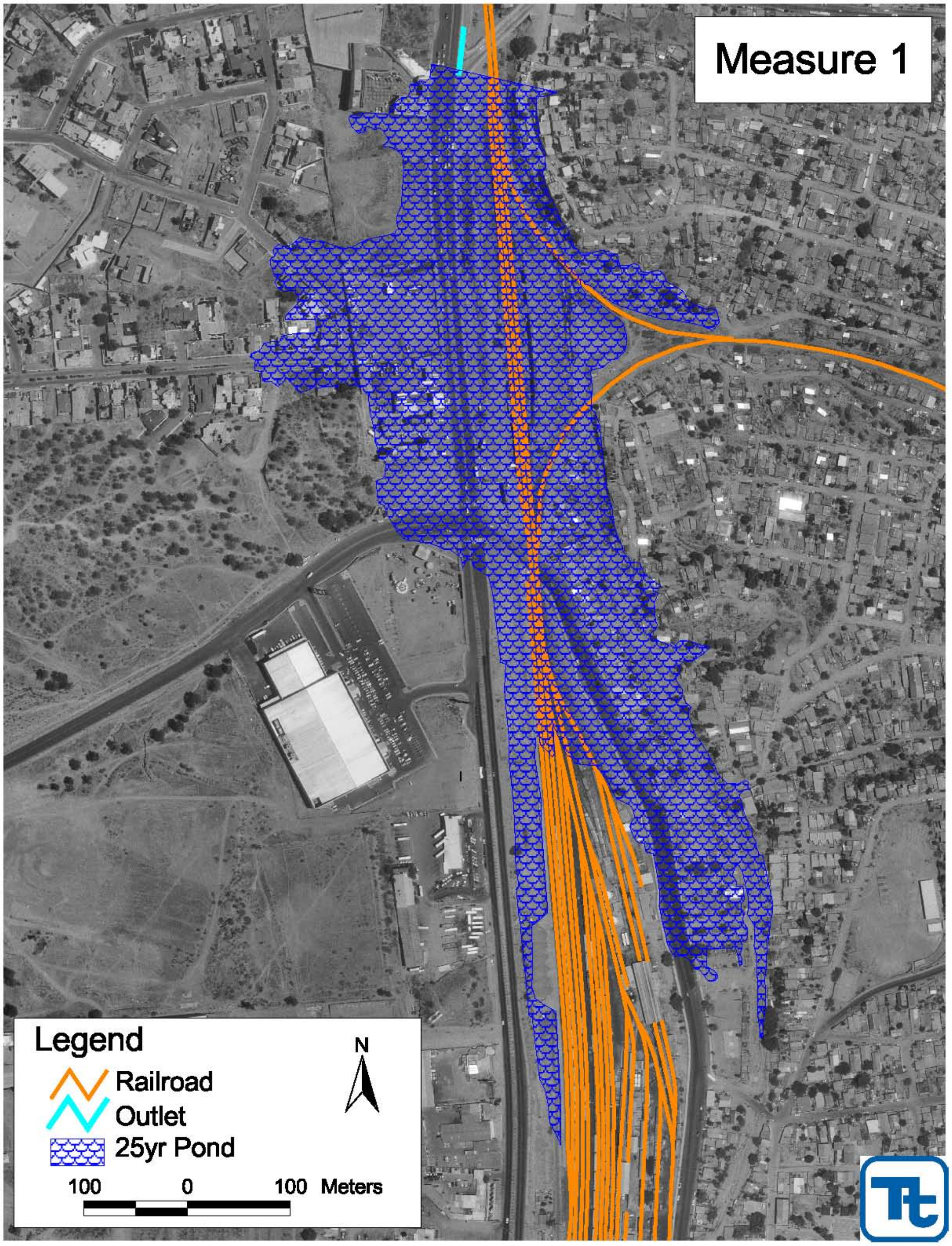
Measure 1

Due to the high degree of development in the floodplain, and the unsuitability of other downstream sites, only one location was considered technically feasible for siting of a single large basin. This basin is referred to as Measure 1, and its location and conceptual impoundment area is illustrated in Figure 17. This basin was located upstream of the inlet to the Nogales Wash box culvert in an area where the valley narrows considerably. The resulting structure would be approximately 15 meters in height, and store approximately 3,200,000 cubic meters of water during a 25-year flood event. It would inundate an area of approximately 1.1 square kilometers. It would require the removal of approximately 15 commercial and industrial structures, 110 residential structures, a number of storage tanks, and a large portion of the railroad yards located upstream of this point.

A detention basin at this site would cause tremendous disruption to roads, utilities, infrastructure, and railroad trackage and facilities. Its impacts on residents and business operators would be substantial. Even maximization of available storage would not cause a significant improvement in damage reduction. Flooding of the floodplain downstream would still occur, due to the large number of uncontrolled tributaries downstream of this point.

A single stand-alone detention basin cannot be recommended for implementation. Even in its least impacting configuration, it still possesses far too many dis-benefits. Additionally, a basin at this site would still create too many impacts at half the modeled height needed for effective storage and damage reduction downstream to take place.

Figure 17. Measure 1



Measure 2

Measure 2 consists of a group of above-ground basins that were located in the tributaries upstream of the inlet to the Nogales Wash box culvert. These basins, located in subareas A, C, E, G, and H, were sited for maximum effectiveness in reducing flood flows in downstream areas, as well as avoiding the largest number of structures while doing so.

The detention basin in subarea A would be approximately 17 meters in height, and sited in such a way to avoid relocation of local roads. Total storage at the 25-year flood event level would be approximately 304,000 cubic meters of flood water. It would require the relocation of approximately five houses and four other structures. This basin configuration is illustrated in Figure 18, and includes the maximum impoundment extent caused by a 25-year flood event.

The detention basin in subarea C would be approximately 10 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 397,000 cubic meters of flood water. It would require the relocation of approximately six houses and three other structures. This basin configuration is illustrated in Figure 19, and includes the maximum impoundment extent caused by a 25-year flood event.

The detention basin in subarea E would be approximately 10 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 215,000 cubic meters of flood water. It would require the relocation of one house and two other structures. This basin configuration is illustrated in Figure 20, and includes the maximum impoundment extent caused by a 25-year flood event.

The detention basin in subarea G would be approximately 6 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 223,000 cubic meters of flood water. It would require the relocation of approximately five houses and four other structures. This basin configuration is illustrated in Figure 21, and includes the maximum impoundment extent caused by a 25-year flood event.

The detention basin in subarea H would be approximately 8.5 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 75,000 cubic meters of flood water. It would still require the relocation of approximately 20 houses and 15 other structures. This basin configuration is illustrated in Figure 22, and includes the maximum impoundment extent caused by a 25-year flood event.

Figure 18. Measure 2 in Subarea A

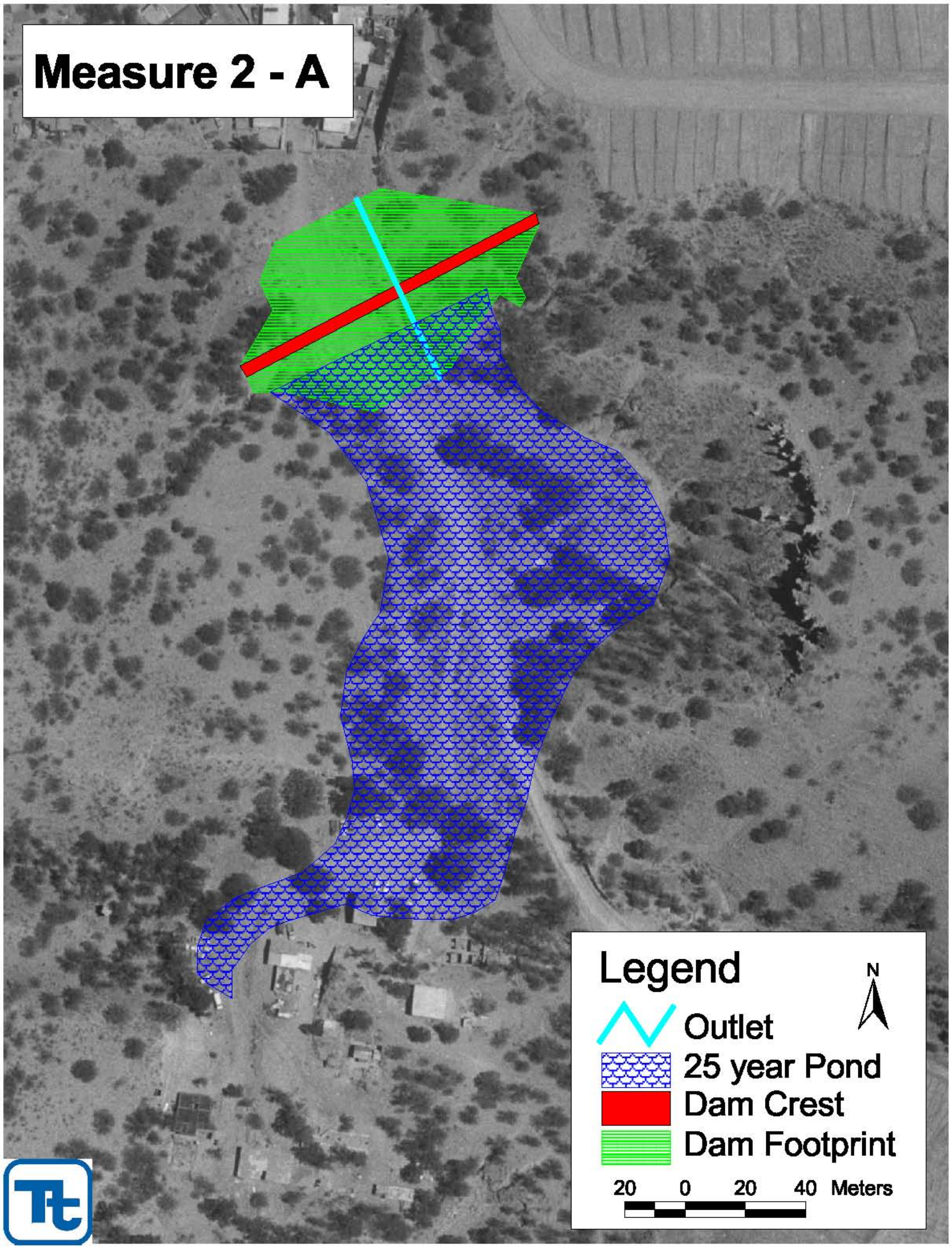


Figure 19. Measure 2 in Subarea C

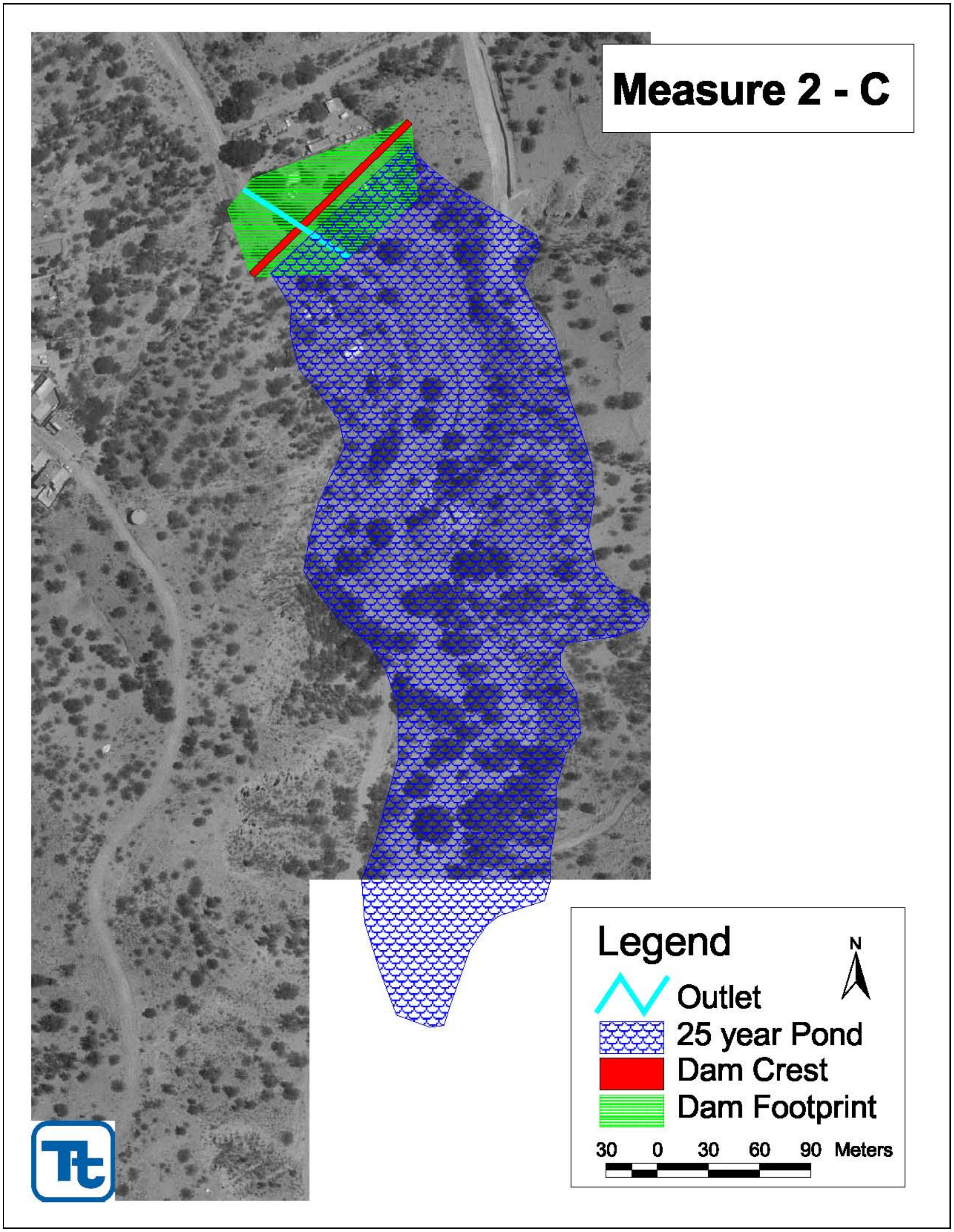


Figure 20. Measure 2 in Subarea E

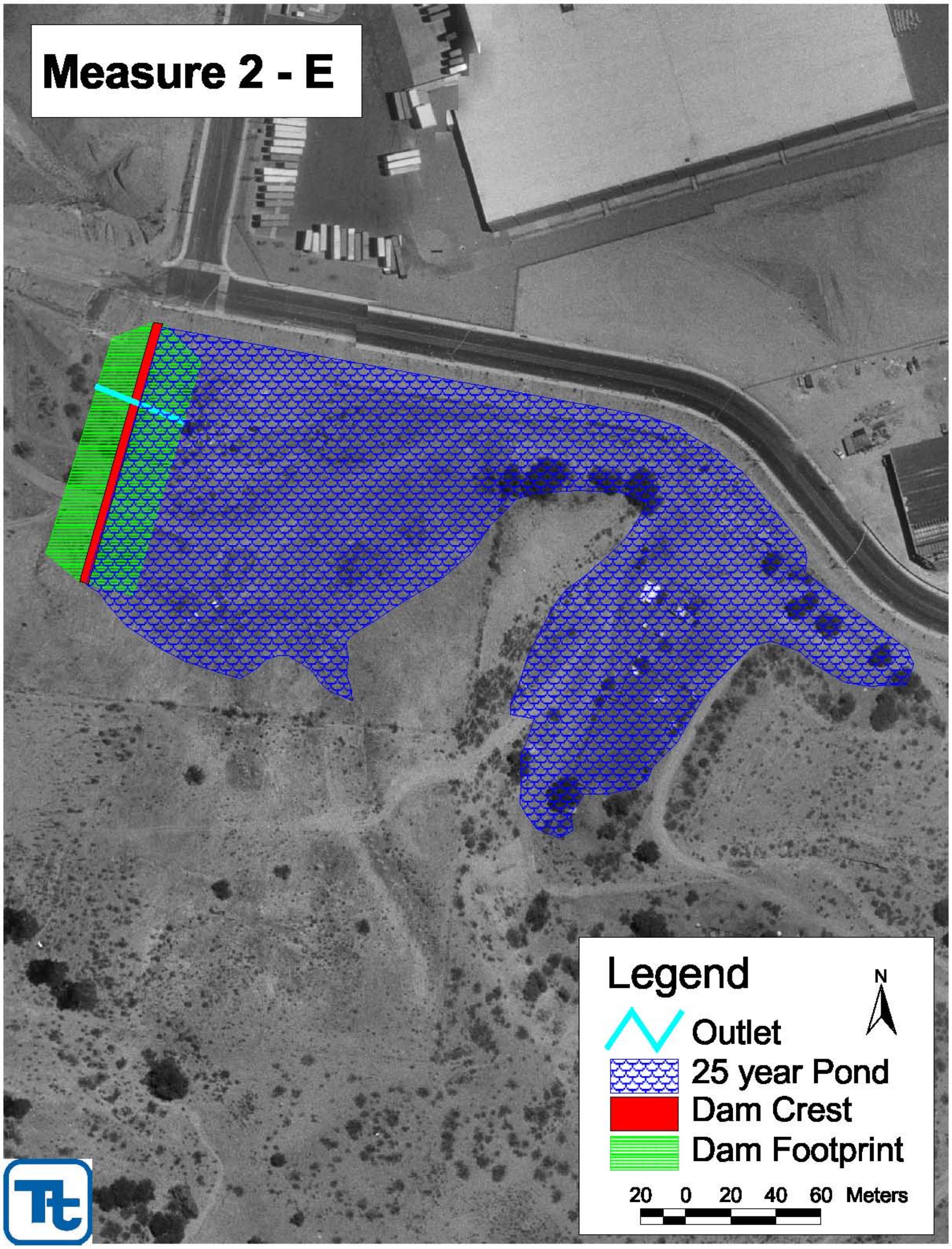


Figure 21. Measure 2 in Subarea G

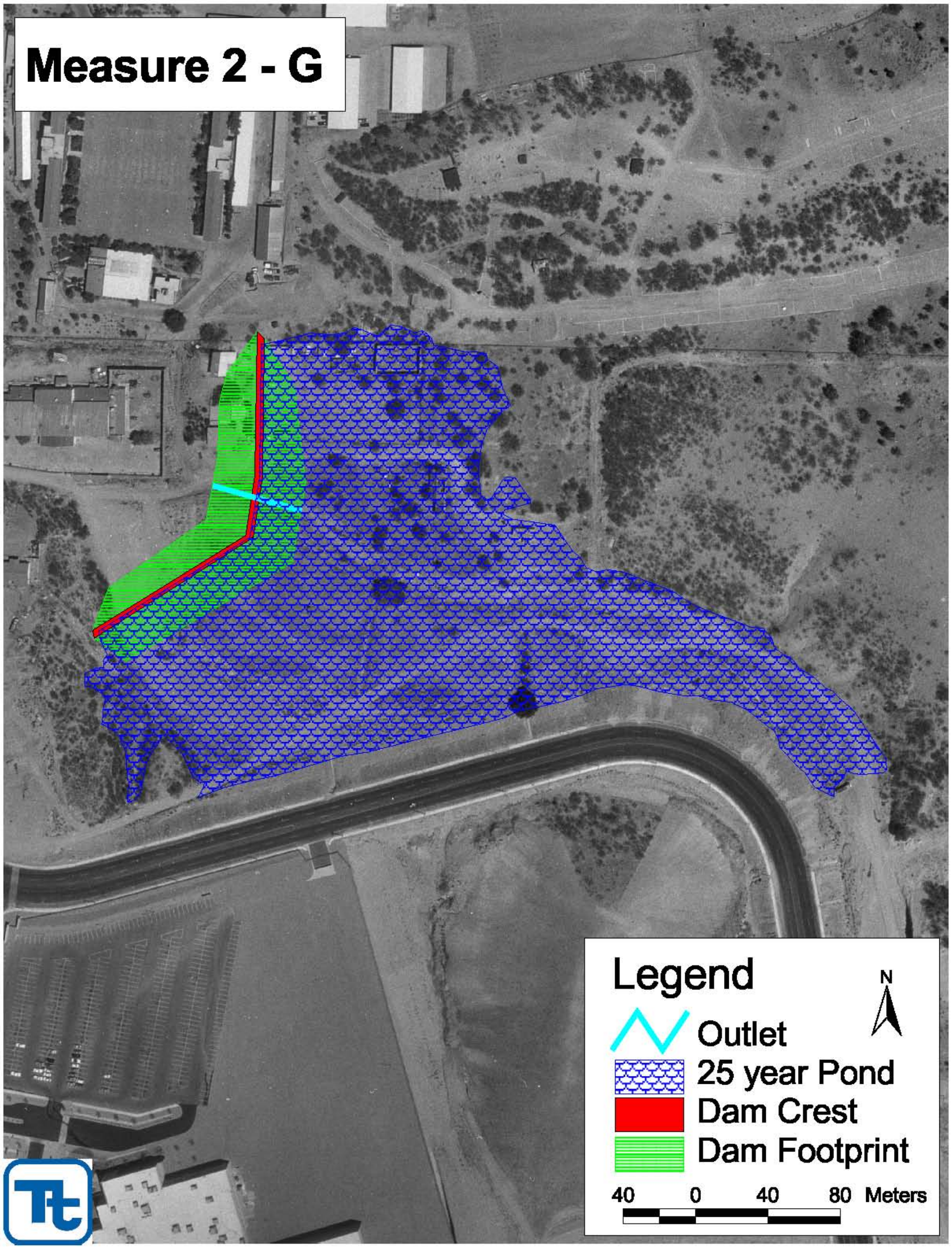
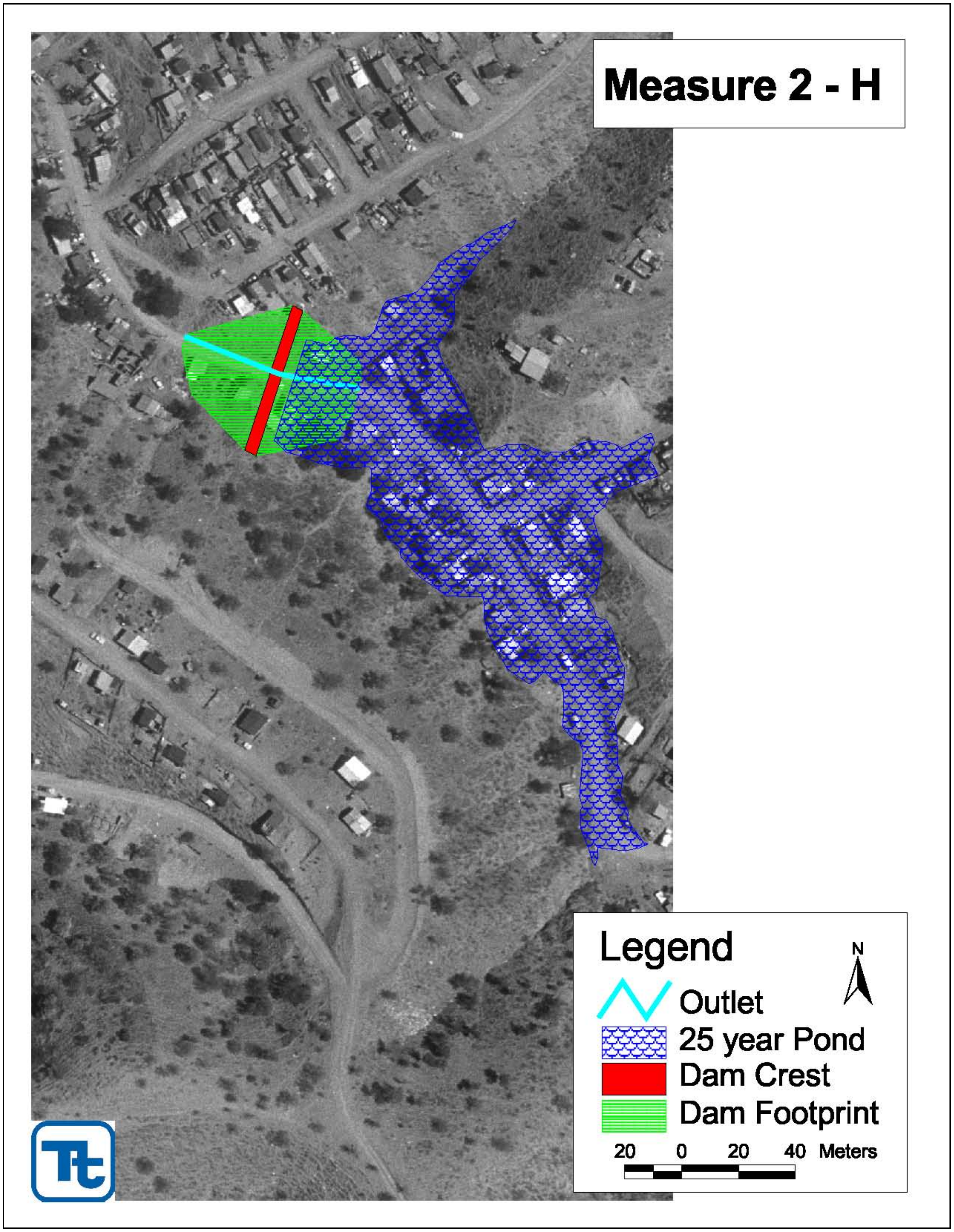


Figure 22. Measure 2 in Subarea H



Each of the five basins was analyzed individually to determine which would have the largest effect on peak discharge at the inlet to the Nogales Wash covered channel. Based on the 25-year future-conditions event, basin G was most effective followed respectively by basins E, C, A, and H. Combinations of the basins were analyzed by starting with the most effective basin (Basin G), and incrementally adding one basin at a time in order of effectiveness. The results are shown in Table 7 below. Since the peak flow rates continue to decrease as basins are added, it is recommended to keep all the basins in detention measure 2 for the final alternative analysis.

Table 7. Basin Incremental Effectiveness Analysis

Measure Descriptions	25-Year Future Conditions Peak Flow Rate (cms)
Baseline, No Detention	286.6
Basin G	243.8
Basin G + Basin E	213.2
Basin G + Basin E + Basin C	208.8
Basin G + Basin E + Basin C + Basin A	199.2
Basin G + Basin E + Basin C + Basin A + Basin H	190.0

Measure 3

Detention Measure 3 addresses the 21.96 km^2 Arroyo Chimeneas watershed, comprised of subareas O and P. It includes modifications to the existing Chimeneas Dam, which controls subarea O (10.07 km^2), and three additional three detention basins in subarea P (11.89 km^2). The existing Chimeneas Dam has no apparent low flow outlet, so the 167,200 m^3 of storage capacity below the spillway crest could easily be filled by a previous event. The available flood storage would be based only on the storage in the surcharge above the spillway crest elevation, and would be minimal. For purposes of this study, it was assumed that the storage capacity below the spillway crest could be increased from 167,200 m^3 to 292,600 m3 by excavating about 3.5 meters of collected sediment from the basin invert. In addition, installation of a low-flow outlet pipe that would drain the basin within 24-hours would help ensure that the flood storage was available soon after an event.

Detention Measure 3 also includes three above-ground detention basins located on tributaries that contribute runoff in subarea P, downstream of Chimeneas Dam. The basins are labeled “P1”, “P2”, and “P3” and would be located to maximize the controlled area with minimal or no impacts on existing development or infrastructure. The detention basin in subarea P1 would be approximately 10.5 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 331,000 cubic meters of flood water. It would require the relocation of two houses and approximately nine trailers. This basin configuration is illustrated in Figure 23, and includes the maximum impoundment extent caused by a 25-year flood event.

The detention basin in subarea P2 would be approximately 10 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 283,000 cubic meters of flood water. It would require the relocation of approximately five houses and eight other structures. It would also cause inundation of a portion of an automobile scrap yard. This basin configuration is illustrated in Figure 24, and includes the maximum impoundment extent caused by a 25-year flood event.

The detention basin in subarea P3 would be approximately 8 meters in height, and sited in such a way to avoid the largest number of structures possible. Total storage at the 25-year flood event level would be approximately 78,000 cubic meters of flood water. It would require the relocation of approximately eight houses and eight other structures. This basin configuration is illustrated in Figure 25, and includes the maximum impoundment extent caused by a 25-year flood event.

The modifications to Chimeneas Dam would create a structure approximately 15 meters in height, and sited in such a way to avoid the largest number of structures possible. It would require the relocation of approximately one house and no commercial and industrial structures, as well as a park and appurtenant features. This basin configuration is illustrated in Figure 26, and includes the maximum impoundment extent caused by a 25-year flood event.

Figure 23. Measure 3 in Subarea P1

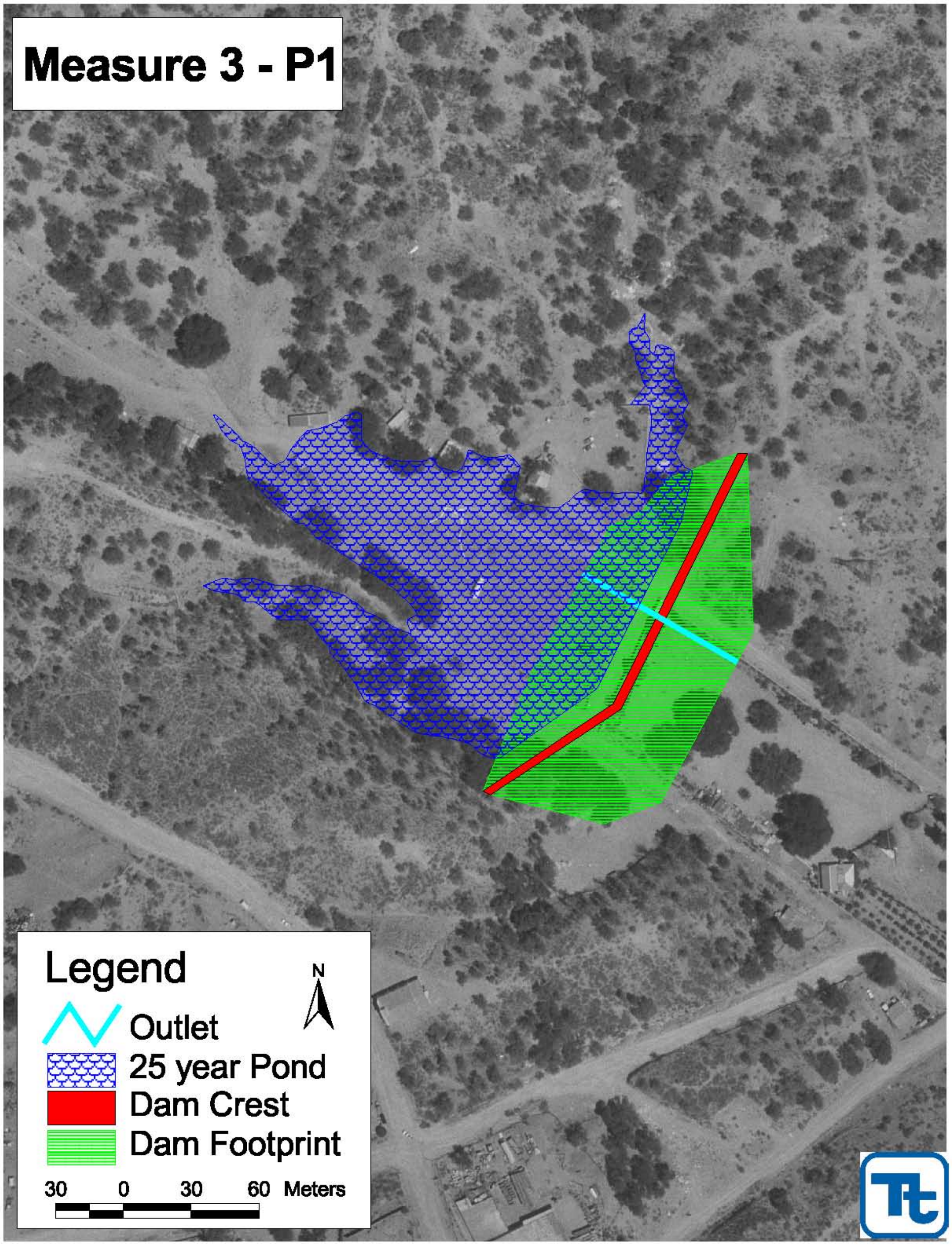


Figure 24. Measure 3 in Subarea P2

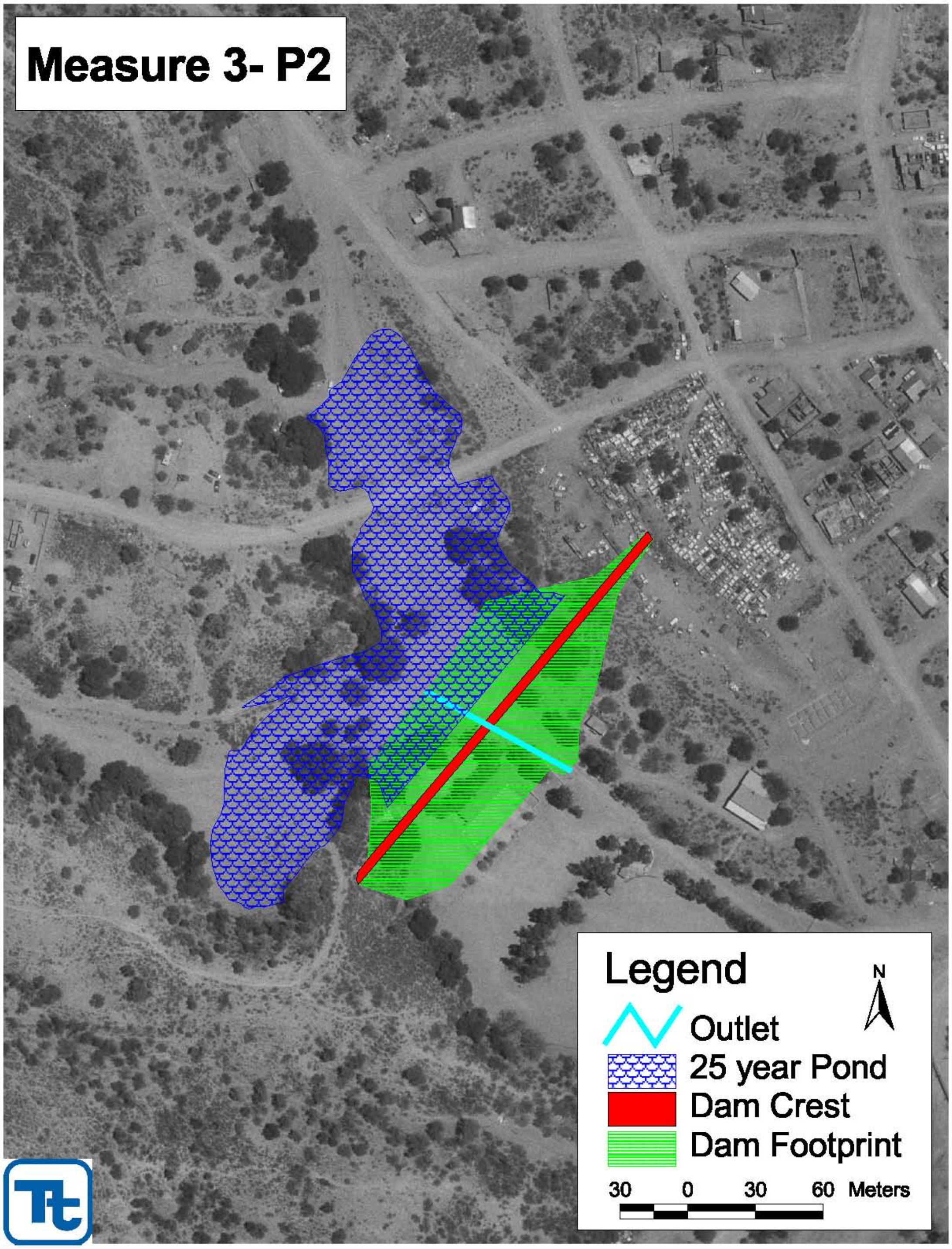


Figure 25. Measure 3 in Subarea P3

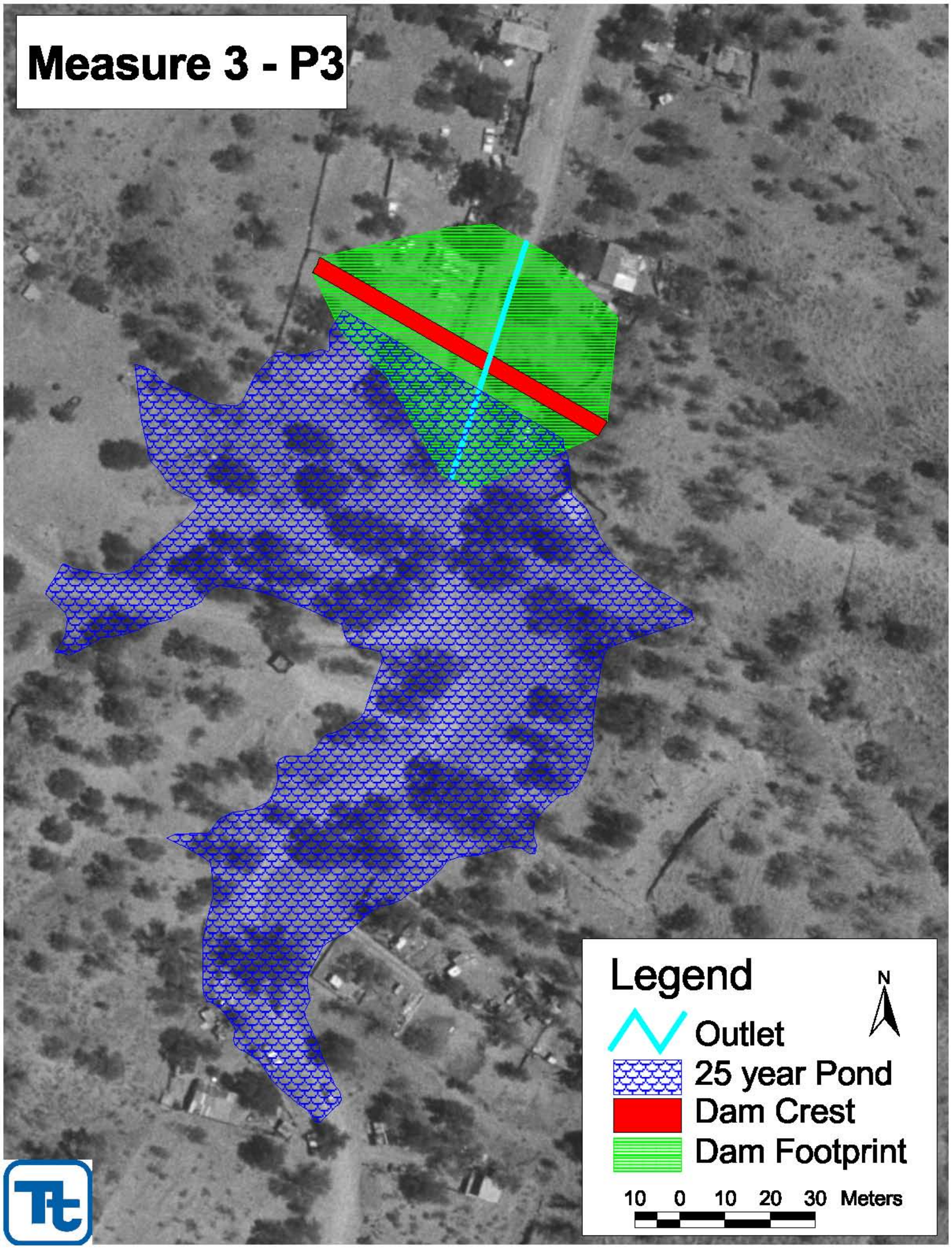
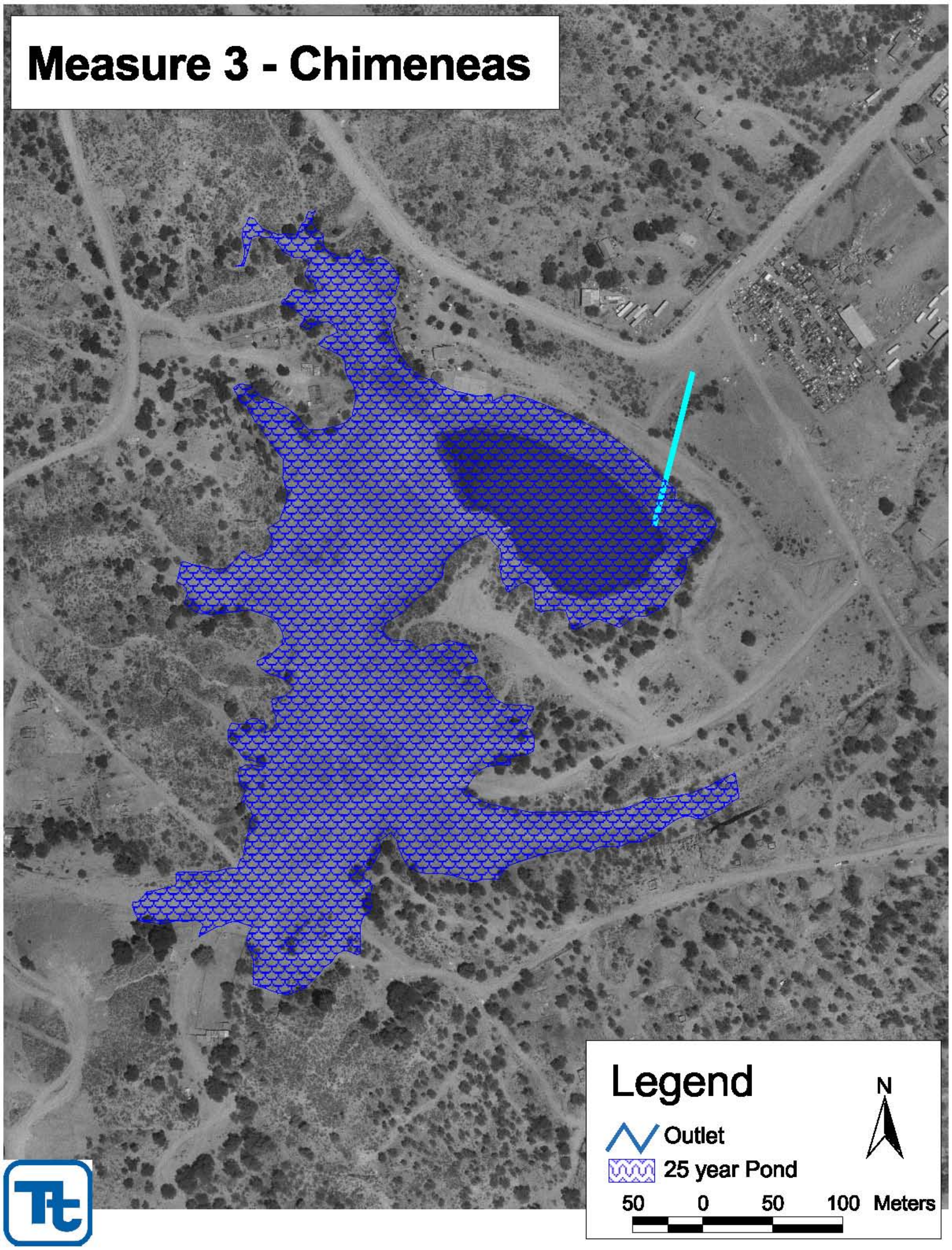


Figure 26. Measure 3 at Chimeneas



Measure 4

Measure 4 consists of a single basin constructed in subarea Q. This basin was sited for maximum effectiveness in reducing flood flows in downstream areas, as well as avoiding the largest number of structures while doing so.

The detention basin in subarea Q would be approximately 10 meters in height, and sited in such a way to avoid the largest number of structures possible. It would not require the relocation of any structures. This basin configuration is illustrated in Figure 27, and includes the maximum impoundment extent caused by a 25-year flood event.

Measure 5

Measure 5 consists of a single basin constructed in subarea Z4. The detention basin in subarea Z4 would be approximately 11 meters in height, and sited in such a way to avoid the largest number of structures possible. It would require the relocation of approximately seven trailers within the impoundment area. This basin configuration is illustrated in Figure 28, and includes the maximum impoundment extent caused by a 25-year flood event.

Figure 27. Measure 4

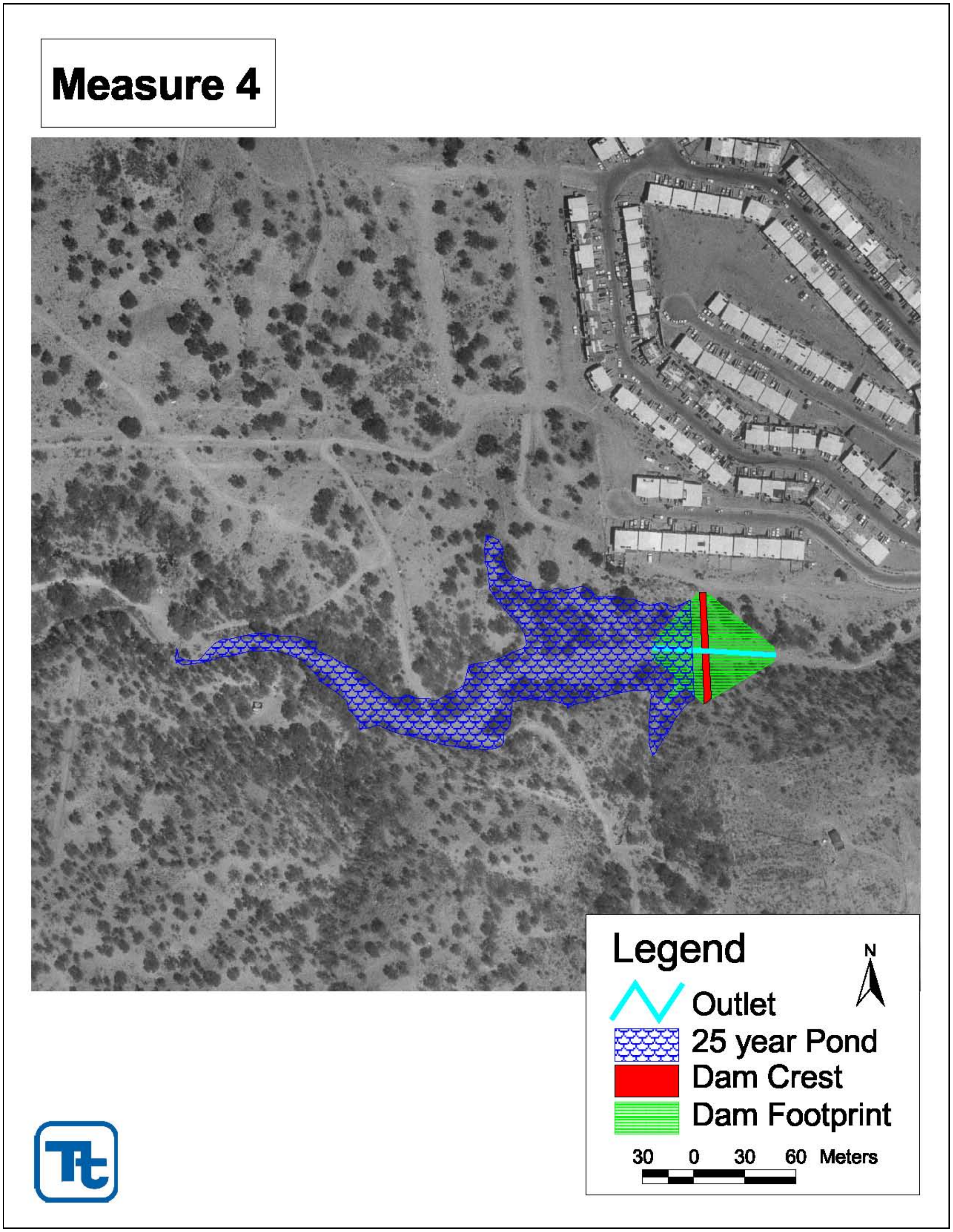
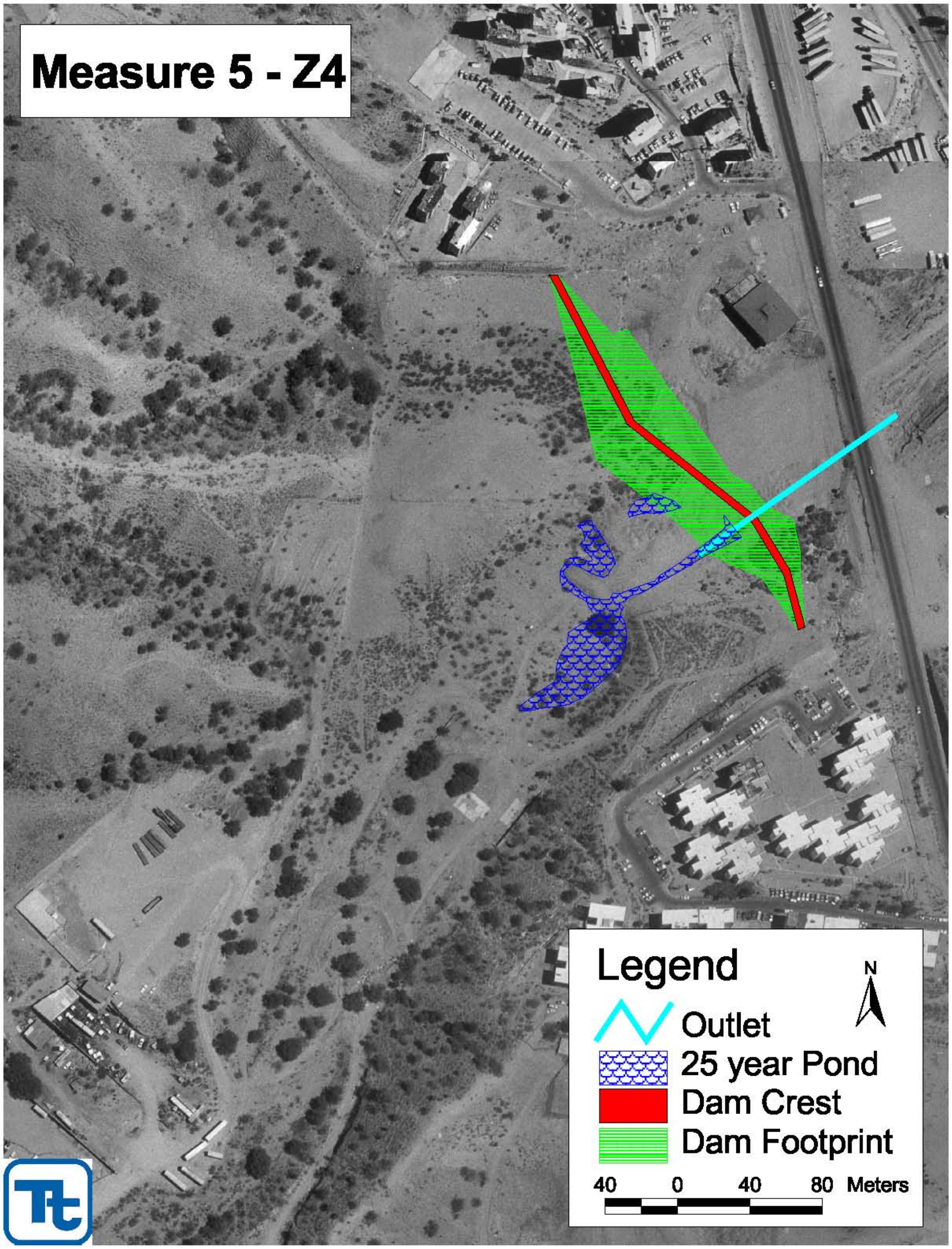


Figure 28. Measure 5



Evaluation of Detention Measures

Analysis of the remaining detention measures, consisting of basins A, C, E, G, H, P1, P2, P3, Q, and Z4 indicated that various combinations of measures could provide a better reduction in flooding downstream. The effects of detention measure 2 (basins A, C, E, G, H), detention measure 3 (Chimeneas Dam modifications and basins P1, P2, and P3), detention measure 4 (basin Q), and detention measure 5 (basin Z4) were evaluated by comparing the 25-year future-conditions peak discharge at concentration points throughout the watershed (Appendix A – Hydrology and Hydraulics). Measure 2 proved to be most effective in terms of reducing peak throughout the Nogales Wash mainstem area, followed by measure 3, 4, and 5 respectively. Combinations of the detention measures were evaluated by starting with the detention measure 2, and incrementally adding detention measures 3, 4, and 5. The effects of the alternatives are shown in Table 8.

Table 8. Number of Flooded Structures

Measure (1)	Inundated Structures		Total Inundated Structure Area	
	Total Number	Incremental Change	Total Inundated Area (m^2)	Incremental Change (m^2)
Future Without Project	539	0	350,000	0
Measure 2	457	82	308,800	41,200
Measures 2 & 3	437	20	307,700	1,100
Measures 2, 3, & 4	435	2	306,800	900
Measures 2, 3, 4, & 5 (2)	435	0	306,800	0

1) 25-year Future-Conditions Event
2) Measure 5 affects Cemetery Wash and does not affected inundation on the Nogales Wash mainstem.

Evaluation of these results indicated that the most effective of these combinations of measures is the combination of measures 2 and 3. This was based not only on the reduction in reduced square footage of inundated structures, but also on the potential cost (based solely on the number of basins) per square meter of flooding reduced per basin. In other words, the potential cost of adding measure 4 or measures 4 and 5 to measures 2 and 3 is not as effective in terms of the minimal additional reduction in square footage flooded.

Evaluation of the peak discharges for various concentration points along the system indicates modest reductions at most points. Table 9 contains 5-, 10-, and 25-year without-, and with-project peak discharges, for concentration points at locations within the flood-prone area. Implementation of measure 2 and 3 results in a reduction of approximately 1/3 of the peak inflow to the inlet to Nogales Wash for the 5-, 10-, and 25-year events. The effect on the peak discharge gradually diminishes further downstream, but is still quite significant in the reduction of overland flow at many locations. While underground flow is rapidly maximized (with no reduction by the time one reaches the confluence with Arroyo Chimeneas), overland flow during the 25-year event is reduced by almost 50% at the confluence of Arroyo 5 de Febrero and Calle Celeya, and 48% at the confluence at Calle Buenos Aires. The reduction for lesser (more frequent) events is even more dramatic. A 46% reduction in overland flow occurs at the International Boundary under this scenario.

Table 9. Without and With-Project Peak Discharges (cms)

Location (Concentration Point)	Drainage Area (km^2)	5-year		10-year		25-year	
		Future-Without Project (cms)	Future Rec. Plan* (cms)	Future-Without Project (cms)	Future Rec. Plan* (cms)	Future-Without Project (cms)	Future Rec. Plan* (cms)
Inlet to Nogales Wash Underground Culvert (A-K)	32.69	142.5	82.5	190.3	134.3	286.6	192.1
Underground Flow at Nogales Wash Inlet (Diversion A-K)	32.69	142.5	82.5	150.0	134.3	150.0	150.0
Overland Flow at Nogales Wash Inlet (Div AK (br))	32.69	0.0	0.0	40.3	0.0	136.6	42.1
Overland Flow at CP AM	33.54	8.5	8.4	43.1	11.6	139.8	47.1
Subarea O at Chimeneas	10.07	50.0	50.0	66.6	66.6	99.8	99.8
Outflow from Chimeneas Dam		34.8	7.8	46.0	8.2	66.6	21.4
O+P	21.96	74.4	45.0	98.9	57.3	141.8	83.3
Underground Flow at Confluence of Arroyo Chimeneas (UG A-M, O-P)	55.03	142.5	82.5	150.0	134.3	150.0	150.0
Overland Flow at Confluence Arroyo Chimeneas (OL A-P)	56.40	77.4	49.4	142.5	63.4	279.7	129.5
Subarea Q Calle 5 de Febrero	6.36	29.0	29.0	38.9	38.9	58.6	58.6
Subarea R Calle Celeya	1.02	8.7	8.7	11.8	11.8	17.6	17.6
Underground Flow at Confluence 5 de Febrero and Calle Celeya (UG A-M, O-R)	62.41	142.5	82.5	150.0	134.3	150.0	150.0
Overland Flow at Confluence 5 de Febrero and Calle Celeya (OL A-R)	63.78	96.9	72.2	169.1	97.8	321.2	176.6
Calle Diaz (Z1)	0.75	5.4	5.4	7.7	7.7	11.9	11.9
Calle Vasquez (Z2)	1.22	6.8	6.8	9.8	9.8	15.3	15.3
Underground Z1-Z2	1.97	10.6	10.6	15.2	15.2	23.9	23.9
Cemetery Wash at MEX-15 (Z4)	2.68	16.1	16.1	21.4	21.4	31.7	31.7
Cemetery Wash at Calle Reforma (Z4-Z5)	3.44	20.5	20.5	26.9	26.7	39.7	39.6
Cemetery Wash Trib (Z6)	0.59	4.4	4.4	6.3	6.3	9.7	9.7
Underground Z4-Z6	4.03	20.7	20.7	22.6	22.6	26.0	26.0
Underground Combine Cemetery Wash Z1-Z2, Z4-Z6	6.00	30.7	30.7	150.0	37.0	49.0	49.0
Underground Flow at Confluence 5 C Buenos Aires (UG A-M, O-T)	64.74	142.5	82.8	150.0	134.3	150.0	150.0
Overland Flow at Confluence 5 C Buenos Aires (OL A-T at Border)	66.11	98.6	74.6	171.3	102.4	324.8	181.7
Total Overland Flow at International Boundary	72.47	98.9	75.0	171.6	104.0	326.9	187.3
Total Flow (Overland and Underground) at International Boundary	72.47	253.8	170.0	338.9	272.1	502.1	365.9
*Future Conditions with Recommended plan; includes Detention Measures 2 and 3							

Therefore, it was determined that the combination of measures 2 and 3, which would include the detention basins in subareas A, C, E, G, H, P1, P2, and P3, is most effective. The resulting impacts in terms of flood depths are shown in Table 6.

Table 10. Depth (meters) of Flooding – With Measures 2 and 3

Comparison of Average Flood Depths (meters)											
			5-year Event			10-year Event			25-year Event		
Reach	From	To	Existing	Future without Project	Future with Project (M2 & M3)	Existing	Future without Project	Future with Project (M2 & M3)	Existing	Future without Project	Future with Project (M2 & M3)
1	5 de Febrero	International Border	0.30	0.72	0.63	0.66	0.97	0.73	0.95	1.34	0.99
2	Arroyo Chimeneas	5 de Febrero	0.22	0.53	0.41	0.45	0.73	0.48	0.69	1.12	0.70
3	Inlet at Nogales Wash	Arroyo Chimeneas	0.39	0.50	0.47	0.49	0.79	0.53	0.69	0.85	0.75
4	Upstream of Under-ground Inlet	Inlet at Nogales Wash	0.71	0.95	0.76	0.85	0.97	0.92	0.94	1.21	0.98

Summary of Results

This study considered a number of non-structural and structural alternatives to reduce flood damages in the City of Nogales, Sonora. Non-structural measures such as floodplain management, flood-proofing, and relocation have been ruled out as viable approaches for widespread application because of cost, impacts, and lack of effectiveness. The hydrologic and hydraulic analyses of structural alternatives such as channel improvements, inlet improvements, and numerous detention options indicate that there is no single approach that will provide a complete solution to the flooding problem along the mainstem Nogales Wash that runs through the City center.

- Channel improvement to the underground portion of Nogales Wash could provide a partial solution, but does not address tributary areas. More importantly, it would have to be extended approximately 1300 meters north of the international boundary, through a heavily urbanized portion of Nogales, Arizona, to reach an adequate and safe point of disposal.

- Inlet improvements would provide immediate and relatively cost-effective relief from nuisance (e.g. < 2-year) flooding in the streets and neighborhoods in the nearby vicinity. They can also provide some measure of improvement for 5-, 10-, and 25-year events that are localized on given tributary.

- Detention provides perhaps the best element, in a comprehensive solution to downstream flooding. It can be located on mostly under-developed land and will have minimal impact on existing land uses, businesses, transportation, or commerce and tourism. Unfortunately, as there is no convenient point of storage that controls a majority of the watershed, this measure must be implemented at a large number of locations to provide significant benefit, and even then can only provide a partial solution to flooding.

Recommendations

Inlet improvements would provide the most immediate measure of improvement to the existing flood problem, and can be pursued with no need for additional study. Therefore, inlet improvement should be the initial element in a comprehensive treatment of the flood control problem.

Floodwater detention would be most effective in developing a comprehensive solution. Since there is no convenient point of storage that controls a majority of the watershed, this measure must be implemented at a large number of tributary locations. The proposed basins can provide significant reduction in flooding for intervening areas, and provide a measure of flood damage reduction in the mainstem channel. Therefore, tributary detention basins are recommended as the next element in a larger flood damage reduction effort. Given that urban growth in the watershed is continuing at a rapid pace, it is further recommended that this alternative be considered quickly, before suitable detention sites become developed. Figure 29 contains an illustration of basin sites and inlet improvement features contained in the Recommended Plan.

It is recommended that the results of this study be discussed with City officials and representatives from the agencies responsible for its potential implementation. Should this combination of measures be determined to be politically supportable, and a decision is made to pursue floodwater detention, an optimization study of detention basin options would logically follow the pursuit of inlet improvements on tributaries. This effort would include consideration of dam safety requirements, land ownership, utilities, environmental and social impacts, and cultural resource issues.

Figure 29. Recommended Plan