ATTACHMENT 7:

Technical Justification of Projects

SANTA CLARA VALLEY WATER DISTRICT

Proposition 1E Round 2
Stormwater Flood Management Grant Program
Permanente Creek Flood Protection Proposal

Attachment 7

Santa Clara Valley Water District
Permanente Creek Flood Protection Project Grant Proposal

Technical Justification of Project

In accordance with PSP requirements, **Attachment 7** consists of the following items:

- ✓ Documentation of the technical justification of the physical benefits claimed for the Permanente Creek Flood Protection Project.
- ✓ **Appendices** that include copies of the referenced technical documents that support the physical benefit claims.

Contents

Project Description and Summary of Benefits

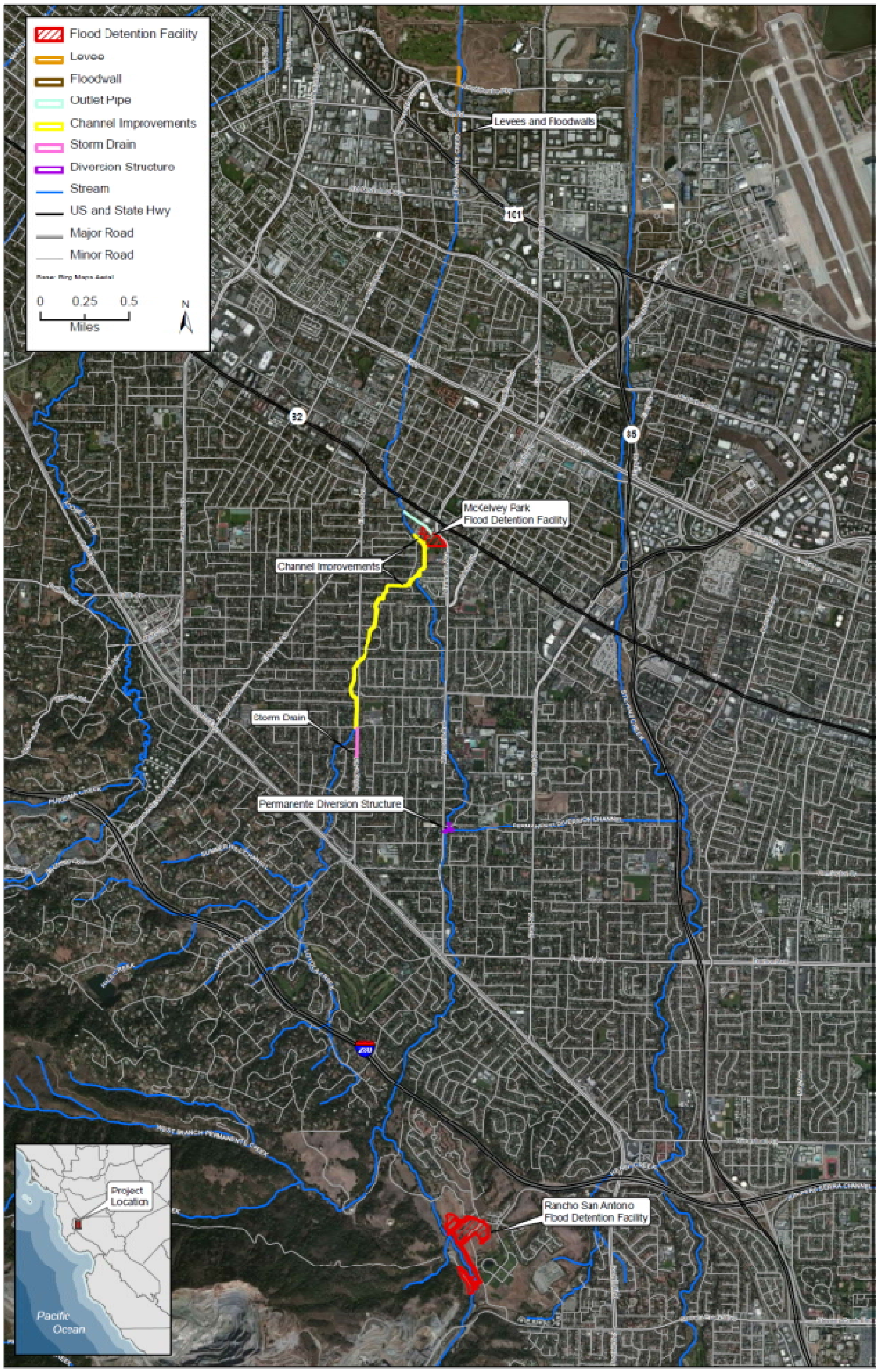
The Santa Clara Valley Water District (District) is seeking Proposition 1E Stormwater Flood Management Grant (SWFM) funding to implement flood protection for the cities of Mountain View, Los Altos, and Cupertino, California along the Permanente Creek. The District initiated the Permanente Creek Flood Protection Project study to identify flood protection, maintenance, structural repair, and habitat restoration opportunities within the watershed.

Project Description

Recurrent flooding along Permanente Creek represents a long-term hazard to public safety, property values, and economic stability in the cities of Mountain View, Los Altos and Cupertino. Flooding in the Permanente Creek watershed is documented as far back as 1868, with significant flooding events occurring in 1911, 1940, 1950, 1952, 1955, 1958, 1963, 1968, 1983, 1995, and 1998. As a result, over the years, the District and other local agencies have undertaken a number of projects to improve flood protection for land uses adjacent to Permanente Creek. In recent decades, however, economic and public safety risks from flooding have increased as development has become increasingly dense. Implementation of the proposed project would provide 1% flood protection for thousands of residents, businesses, and public infrastructure along the Permanente Creek corridor. The proposed project would consist of the following project elements, shown in **Figure 7-1**:

- A 15-acre flood detention basin at Rancho San Antonio County Park.
- A 5-acre flood detention basin occupying McKelvey Park.
- A new diversion structure to improve the "flow split" at the Permanente Creek Diversion Channel.
- Floodwalls and levees along Permanente Creek from U.S. Highway 101 (US-101) to just north of Amphitheatre Parkway.
- Replacement of selected concrete portions of Permanente and Hale Creeks with wider and deeper concrete channels.

Figure 7- 1. Permanente Creek Flood Protection Project Area Overview



The Rancho San Antonio County Park Flood Detention Facility would provide off-stream flood storage at the upstream end of the Project corridor. The proposed 15-acre detention basin, currently an undeveloped area of the Park, would be contoured for a natural appearance and the bottom would be graded to create swales to aid in development of wetland vegetation. Appropriate native wetland, riparian, and upland vegetation would be planted within and adjacent to the detention area. The new detention area would be connected to Permanente Creek via inlets consisting of a spill structure and pipes placed approximately 2 to 10 feet underground. Once the flood peak passes, the stored floodwaters would drain into Permanente Creek by gravity flow, typically within one to four days. The entire 15-acre area would be available to the public for recreation the majority of the time.

The McKelvey Park Flood Detention Facility would consist of an off-stream detention basin at a 5-acre baseball facility owned by the City of Mountain View. The existing playing fields would be taken out of use, and the entire park would be excavated and lowered, with the playing fields being restored at the new ground level. The new detention basin would be about 15 feet deep and connected to the Permanente Creek channel. Once the flood peak passes, the stored floodwaters would drain back into the Permanente Creek by gravity flow and pumping, typically within one to four days. The playing fields would then be cleaned and returned to play-ready conditions.

The New Permanente Diversion Structure would replace the existing diversion structure, improving existing performance and reliability. The new diversion structure would consist of a screened opening at the bottom of the rebuilt trapezoidal concrete channel that would allow low flows to enter a concrete vault via a pipe connection to lower Permanente Creek. There would also be a high-flow weir built into the structure vault to direct flows higher than the downstream capacity into the vault.

The addition of new floodwalls and improvements to existing levees along the western side of Permanente Creek (from US-101 to Amphitheatre Parkway) will aid in flood performance and address the potential for long-term sea level rise as a result of global climate change. Floodwalls would be constructed on the land side of the levee top and would extend 2 to 4 feet above the existing top-of-bank elevation. Floodwalls would also extend several feet below the levee top as a retaining wall and would be supported by an augmented fill prism at the outboard levee toe. The floodwalls will be constructed with 4 feet of freeboard to accommodate potential impacts from sea level rise. In lieu of a floodwall downstream of Amphitheatre Parkway, the existing west bank levee would be raised 2 to 3 feet above the existing elevation. In lieu of floodwalls between Amphitheatre Parkway and Charlestown Road, three walls would be constructed against a building on the west bank of Permanente Creek to flood-proof openings in that structure that are susceptible to flooding.

Figure 7- 2. View of U-Shaped Concrete Channel at Permanente Creek

The improvements to Permanente and Hale Creeks involve changes to the existing concrete channels. For Permanente Creek, this involves deepening and enlarging the existing concrete channels, substantially increasing the channels' cross-section and flood conveyance capacity. At Hale Creek, a portion of the existing concrete channel would be replaced with a steeper and deeper concrete channel. This involves replacement of bridges at several crossings to match the profile of the new channels.

The main benefits of the Project are protection from flood damage for an estimated 2,695 parcels (including homes, 160 businesses, and four schools/institutions) from a 100-year flood. This project was initiated under the District's Clean, Safe Creeks Plan. The Clean, Safe Creeks Plan ensures that the

District meets its flood protection responsibilities in a way that is consistent with its overall mission to provide environmentally sensitive water resources management and reflects the idea that a properly managed stream or river corridor can and should support multiple objectives that benefit the community and natural environment. In concert with the project construction, the District will identify opportunities for environmental enhancement such as stream restoration, trails, parks, and open space for consideration by the District's Board. The project will also reduce long-term maintenance requirements, such as removal of sediment buildup in channels.

Summary of Benefits

As shown in **Table 7-1**, implementation of the Permanente Creek Flood Protection Project would provide several physical and measurable benefits.

Table 7-1. Summary of Quantifiable Physical Benefits

Permanente Creek Flood Protection Project	
Flood Protection Benefits	• 2,695 structures in Mountain View north of El Camino Real removed from the FEMA 100-year floodplain • Reduced response associated with a 2,168-ton reduction in debris generated from a 100-year flood and • Number of households that are expected to be displaced from their homes due to the 100-year flood is reduced from 4,572 to 415 households (reducing the number of people seeking temporary shelter in public shelters from 12,535 1,043)
Water Supply Benefits	• None
Water Quality Benefits	• None
Environmental Benefits	• 5-cubic feet per second (cfs), or 99 acre-feet per year (AFY), increase in flows in the Permanente mainstem downstream of the diversion structure, enhancing Cold Freshwater Habitat • 20 acres of undeveloped land and potential high-value habitat would be conserved by the project in perpetuity.
Recreation/Public Access Benefits	• 9 parking spaces in a new equestrian parking lot at Rancho San Antonio County Park • One new restroom at Rancho San Antonio County Park • 1200 feet of new trails installed at Rancho San Antonio County Park • New 0.7-acre mini-park at McKelvey Park
Energy-Related Benefits	• None
Other Physical Benefits	• None

Note: Qualitative benefits are summarized in Attachment 8.

Technical Justification for Physical Benefits Claimed

The District has been studying and implementing flood control improvements on Permanente Creek Flood Protection Project for more than half a century, with the first studies and improvements dating back to the mid-1950s. As such, a wealth of information is available for both the with- and without project conditions to substantiate the physical benefits claimed. Planning, design, and environmental documentation for the proposed are complete. Specific studies and actions completed to-date include the following.

Previous Studies and Actions by the District:

- *Permanente Diversion Channel:* In 1956, a "Preliminary Report on the Improvement of a Portion of Permanente Creek in Zone NW-1, Project 3" was prepared by Thelo A. Perrot Consulting Engineer for the Santa Clara County Flood Control and Water Conservation District. The report was prepared in response to the 1955 flooding, and proposed the construction of a diversion channel which would carry high flows from Permanente Creek to Stevens Creek. The concrete trapezoidal Permanente Diversion channel was constructed circa 1960. An earthen trapezoidal channel was also constructed on Permanente Creek downstream of Portland Avenue. The work is detailed in the 1959 "Permanente Creek Cross Channel" plans.
- *Hale Creek Improvements:* In 1956, a "Preliminary Engineering Report, Hale Creek Improvement Project No. 9, Zone NW-1" was prepared by Don Reinoehl Consulting Engineers for the Santa Clara County Flood Control and Water Conservation District. The study recommended numerous improvements to Hale Creek, including lining portions of the invert with concrete, building a debris basin upstream of Fremont Avenue, and replacing six bridges and culverts. Based on this work, in the early 1960's a concrete-lined trapezoidal channel was constructed on Hale Creek beginning at the confluence with Permanente Creek and extending upstream to Rosita Avenue. This work is detailed in the "Hale Creek Improvement Zone N.W.-1 "Northwest"; Project No. 9, Unit 1" plans dated 1959 and 1960.
- *Permanente Creek – Bay to Highway 101:* In the early 1960's, a trapezoidal channel was constructed on Permanente Creek from Mountain View Slough to Highway 101. Portions of the channel were lined with concrete, but the majority of the channel was unlined. The work is detailed in the 1960 "Permanente Creek Improvements" plans.
- *Permanente Creek Vertical – Walled Concrete Channel:* In 1961, a soils report entitled "Proposed Improvements of Permanente Creek" was prepared by Cooper & Clark Consulting Engineers for the Santa Clara County Flood Control and Water Conservation District. The study consisted of the analysis of 9 soil borings from Highway 101 to Mountain View Avenue to determine if the soils were suitable for the construction of a concrete vertical walled channel. In 1962 a vertical-walled concrete channel was constructed from El Camino Real to Hale Creek. The work is detailed in the 1962 "Permanente Creek – Hale Creek to El Camino Real" plans. In 1967 a vertical-walled concrete channel was constructed on Permanente Creek from Highway 101 to Villa Street. The project is detailed in the 1965 plans, "Permanente Creek - Bayshore Highway to Villa St."
- *Permanente Creek – Villa St. Culvert and California/El Camino Culvert:* In the early 1960's, two box culverts were constructed: the Villa St. culvert and the California/El Camino culvert. A concrete-line trapezoidal channel was constructed between the two culverts. The work is detailed in the following plans: "Permanente Creek - El Camino Real to Latham St", 1962; "Permanente Creek - Villa St. to 485 ft. South of Villa St.", 1963; "Permanente Creek - 485 ft. South of Villa St. to California St.", 1964; and "Permanente Creek, California St. to Latham St., 1964.
- *Mountain View Slough Studies:* In 1964, the Santa Clara County Flood Control and Water District prepared a "Report on a Study of Drainage of the Mountain View Bay Front Area and Permanente and Stevens Creeks Outfall Channels." The report proposed that a slotted weir be installed to reduce sedimentation in Mountain View slough. The report also studied methods of draining the lowland areas near the Bay in Mountain View; the study concluded that pumping is the most effective method of draining these areas. In 1966 the "Mountain View Slough Slotted Weir Study" was prepared by Lynne Burst for the District. This study concluded that a slotted weir in Mountain View Slough, as proposed in the 1964 study, would not be effective in reducing sedimentation in the slough. The slotted weir was therefore not installed.

- *Mountain View Slough – East Levee Raising:* In 1976 the Final Environmental Impact Report on the Proposed Mountain View Slough Levee Repair Project was prepared by the Santa Clara Valley Water District. The report studies the environmental impacts of raising the eastern levee of Mountain View Slough. In 1993 the eastern levee of the Mountain View Slough was raised. This work is detailed in the 1993 plans, "Permanente Creek, Mt. View Slough East Levee Raising and Maintenance Access Road". The West levee was not altered.
- *Permanente Creek and Permanente Diversion Planning Study and Improvements:* The 1979 "Permanente Creek Planning Study, Final Engineer's Report" addressed flooding, erosion, and sedimentation problems on Permanente Creek from Portland Avenue to Hale Creek and along the Permanente Diversion Channel. The plan recommended modifications to the diversion channel and to the creek near Portland Avenue which would provide 25-year protection to that area. The plan also proposed flood-proofing El Camino Hospital to provide one-percent flood protection. Construction of reservoirs in the upper portion of the watershed was evaluated but could not be justified due to a low benefit/cost ratio.

  In 1981 the following work was performed on Permanente Creek: the trapezoidal channel downstream of Portland Avenue was lined with concrete; and sacked concrete was installed in the channel upstream of Cuesta Drive and downstream of Marilyn Drive. In 1981 the following work was also performed on the Permanente Diversion Channel: a 183-centimeter (72-inch) pipe was installed under Blach Jr. High School to supplement the capacity of the existing double box culvert; floodwalls near Carmel Terrace were raised; and the Diversion Channel entrance to the box culvert under Highway 85 was modified. This work was detailed in the 1980 plans "Permanente Diversion and Permanente Creek."
  In 1981, El Camino Hospital was flood-proofed to ensure that the hospital was protected against the one-percent flood. Flood-proofing measures included the installation of earth mounds, floodwalls, and ramps.
- *Permanente Diversion – Remedial Measures at Blach School:* In 1984 a study entitled "Permanente Diversion Channel Remedial Flood Control Measures (at Altamead Drive and Blach School), Engineer's Report and Negative Declaration", was prepared to address flooding, sediment and maintenance problems on the Permanente Diversion near Altamead Drive. The study proposed removing the existing buried culverts and replacing them with a vertical-walled open channel in order to allow for easier sediment removal. The study was prepared in response to the 1983 flooding of Blach Jr. High School and surrounding areas. In 1986 the double box culvert and the 183-centimeter (72-inch) pipe under Blach Jr. High School along the Permanente Diversion Channel were removed and replaced with a vertical walled concrete channel. This work is detailed in the 1985 plans "Permanente Diversion Channel."
- *Study of Proposed Permanente Creek Flood Control Dam:* In 1996, a report entitled "Preliminary Geologic Evaluation of Permanente Creek for the Proposed Siting of a Flood Control Dam" was prepared by the District to provide a preliminary reconnaissance evaluation of the geological conditions at a proposed dam site in the upper watershed of Permanente Creek. The study concluded that the proposed dam site may not be feasible due to geologic conditions. The study identified two alternative dam sites where geological conditions were more favorable; however, both of these locations would provide less flood storage. To date, no flood control dam has been constructed in the watershed.
- *Permanente Creek Flood Protection Project Planning Study Report:* In July 2008, the District completed a Planning Study Report that identified and evaluated 26 conceptual alternatives to address flooding along Permanente Creek and identified a preferred alternative.
- *Environmental Impact Report*: The Draft Environmental Impact Report (EIR) for the Permanente Creek Flood Protection Project was released in September 2009, and the Final EIR was certified in June 2010. A Final Subsequent EIR (SEIR) was released in November 2012 with minor project modifications. The SEIR is provided as **Appendix 7-1** to this attachment.

Previous Studies and Actions by Other Agencies

- *FEMA Floodplain Studies:* In 1980, the Federal Emergency Management Agency (FEMA) published Flood Insurance Studies for the Cities of Mountain View and Los Altos. The purpose of these studies was to identify the existence and severity of flood hazards within these cities.
- *U.S.G.S. Sediment Studies:* In 1989, the U.S. Geological Survey published the Water-Resources Investigations Report 89-4130, "Effects of Limestone Quarrying and Cement-Plant Operations on Runoff and Sediment Yields in the Upper Permanente Creek Basin, Santa Clara County, California. The report was prepared in cooperation with the District. The report quantified the impact of the upstream cement and aggregate quarry on creek sedimentation.

Because the project has been fully evaluated and designed, the projected physical benefits are well-defined and justifiable. The following sections provide the technical justification to support these claimed benefits.

Description of Benefits

Without the project, 2,700 parcels in the project area will continue to be flooded in 25-, 50-, 75-, and 100-year events, consistent with historical flooding. Historic flooding events are summarized below.

Background

The Santa Clara Valley at one time supported extensive riparian vegetation and wildlife along the banks of the Lower Peninsula watersheds. The banks of the Permanente and Hale Creeks, prone to regular flooding, supported a diverse and biologically rich habitat. As the valley portions of the watershed were converted to farms and orchards, the creeks were significantly altered. The creek floodplains were converted to farms and then to urbanized use. Flooding became a major problem in the watershed.

The Permanente watershed has a history of recurring floods which have adversely impacted the safety and economic stability of the residents and businesses within the floodplain. Recurrent flooding along Permanente and Hale Creeks presents a long term hazard to public health and safety, property values, and economic stability in the Cities of Los Altos and Mountain View. Hydraulic models of Permanente and Hale Creeks have shown that more than 3,000 parcels would likely be subject to flooding in a one-percent event (**Figure 7-2** – Watershed Flood Map). Flood protection structures constructed in the 1960's have deteriorated and thousands of feet of concrete channels need to be repaired or replaced.

Historical Flooding

Flooding within the Permanente watershed has been documented as far back as 1862. Flooding which has occurred on Permanente Creek, Hale Creek, and Permanente Diversion is described below. **Figure 7-3** identifies the location of recent flooding areas.

Permanente Watershed – January 1911. A large flood occurred in the watershed in January, 1911. Mr. R.E. Nordyke, a resident of the Hale Creek area, reported that "water flowed down Springer Road like a river". The January 20, 1911 Mountain View Register-Leader reported that "Saturday, January 14, 1911 goes down into history as a record breaking day for rainfall in Mountain View. The actual rainfall for that date was 4.60 inches, the greatest recorded in the history of Mountain View." (FEMA, 1980). Flood records are once again poor; however, it is reported that the flood of 1911 was larger in magnitude than the flood of December 1955.

Permanente Creek – February 1940. Several homes and some agricultural land in the vicinity of El Camino Real and Mountain View Avenue suffered light damage. Highways were also damaged and motorists were inconvenienced by the flooding.

Permanente Creek – November 1950. November flooding along Permanente Creek caused significant damage to agricultural and commercial properties. The following report ran in the November 20, 1950 Mountain View Register-Leader: "Swollen by the heaviest rains in 32 years, Permanente Creek burst its banks . . . and sent torrents of muddy water rushing into Mountain View streets, causing thousands of dollars of damage to merchandise in El Camino stores. . . Countless other thousands of dollars of damage was done to orchard land along Miramonte Road by the swirling waters as tons of precious top soil were swept away in the flood" (FEMA, 1980).

Figure 7-2: Watershed Flood Map

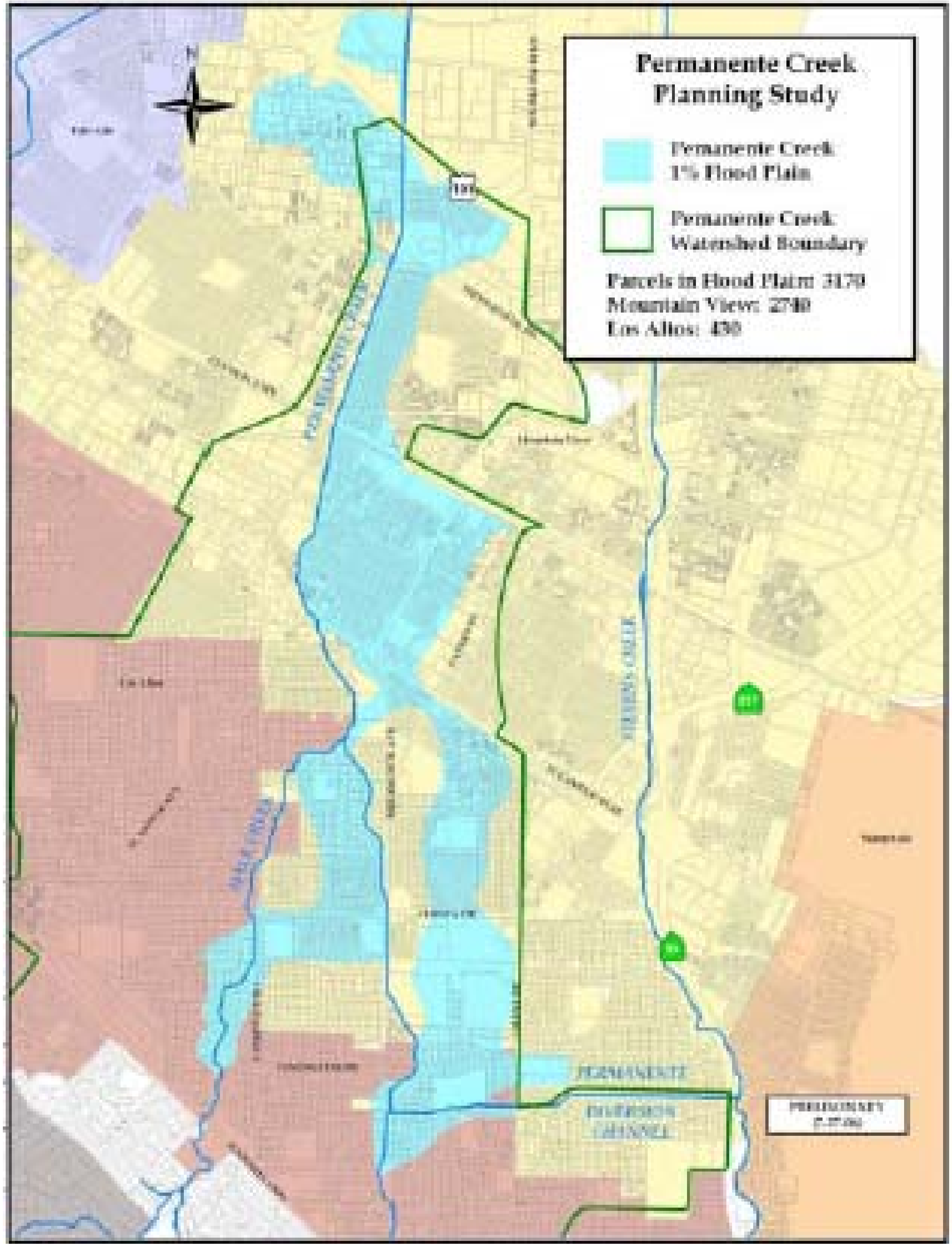
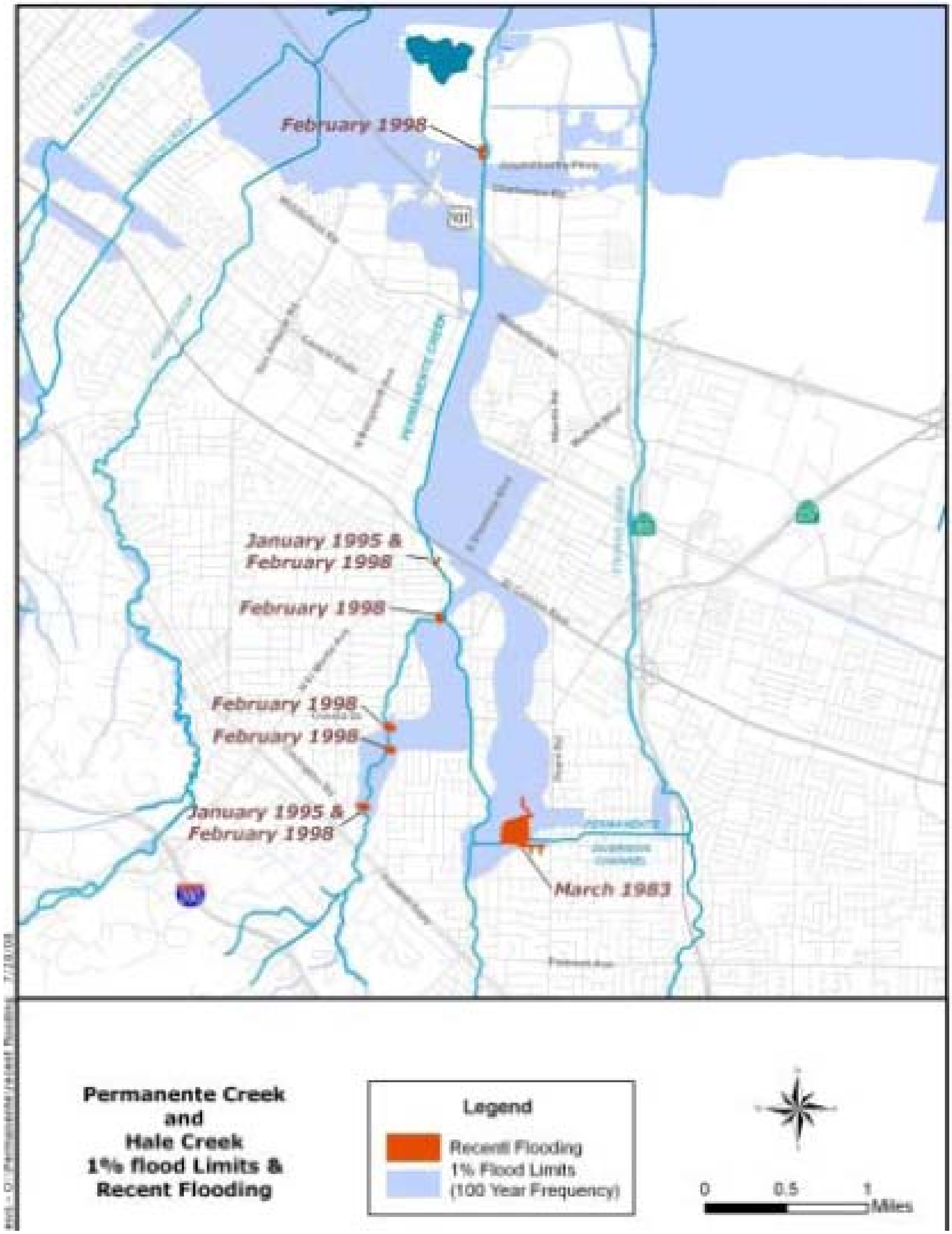


Figure 7-3: Locations of Recent Flooding Events



Permanente Watershed – 1862. A flood of great magnitude occurred in 1862. Records of the flood are poor; however, it is reported that the flood of 1862 was larger in magnitude than the flood of December 1955.

Permanente Creek – January 1952. Flooding along Permanente Creek caused significant damage to properties in Los Altos and Mountain View. The January 14, 1952 Mountain View Register-Leader reported that "Mountain View's new sewage plant was nearly under water, the El Camino Real underpass to Highway School was cut off to traffic, six homes on Springer Road were isolated, an office on El Camino and a house on Grant Road were inundated, . . . and navy pump crews prevented lapping waters from flowing into buildings at Moffet Homes" (FEMA,1980). Flooding also occurred near San Ramon Avenue, San Luis Avenue, Middlefield Road., and at the intersection of El Camino Real and El Monte Avenue.

Permanente Creek and Hale Creek- December 1955. One of the greatest storms in modern times in Santa Clara County occurred in December 1955, the so-called "Christmas Storm." Most of the flooding occurred in the lower reaches of Permanente Creek where approximately 770 acres were inundated with floodwaters. Flooding near El Camino Real and Highway 101 was reported. During the flood, downed trees and debris blocked culverts and caused the creek to overtop its banks. Residential homes, agriculture, and commercial business in Mountain View and Los Altos sustained losses. Salt ponds at Mountain View Slough suffered extensive losses due to the flow of fresh water into the ponds. Several bridges and culverts in Mountain View were extensively damaged and eroded. Approximately 100 people residing in lowland areas were evacuated from their homes for a period of two weeks as a result of the flooding. The Mountain View Register-Leader reported that Police, Fire, and City crews were called on " to battle swollen Permanente Creek and flooded streets fed by rains which poured into the area without letting up" (FEMA, 1980). At Hale Creek, water overtopped the creek's banks near Marilyn Dr., Rosita Ave., Covington Drive, and Mountain View Avenue. Flooding in this area was reported to be up to 1 foot deep. Significant flooding is also reported to have occurred in the upstream portion of the watershed, in the vicinity of Magdalena Avenue and Hillview Road. Damages in the Permanente watershed totaled at $142,500 in 1955 dollars.

Permanente Creek – April 1958. In 1958, flooding occurred along both the upper and lower reaches of Permanente Creek. Flooding in the upper reaches was confined to areas near the creek. Water overtopped the banks at several locations and flooded streets, sidewalks, and yards in Los Altos and Mountain View (U.S. Army Corp of Engineers; June, 1959). In the lower reaches of the creek, flooding was more severe. Flooding is reported to have occurred near Middlefield Road, Barbara Road, El Camino Real (to a depth of 2 feet), and in downtown Mountain View near Evelyn Avenue and Franklin Street (to a depth of 1 foot). Flooding in the vicinity of Bayshore Highway resulted in significant damage to both residential and agricultural properties. Damages in the Permanente watershed were totaled at $95,200 in 1958 dollars.

Permanente Watershed – January 1963. Minor street flooding occurred in the Permanente watershed in January 1963.

Permanente Watershed – January 1968. Minor street flooding occurred in Mountain View and Los Altos due to 1.48 inches of rain which fell within a 24 hour period.

Permanente Diversion – March 2, 1983. On March 2, 1983, Permanente Diversion overtopped its banks and flooded Blach Jr. High School to a depth of 1/2 foot. Street flooding also occurred, as well as minor mud damage to the garages of three homes on Altamead Drive. The flooding was related to operations conducted at the Kaiser Cement Plant located in the upper Permanente Watershed. Immediately after the flood, Kaiser staff reported that the outlet to a large water "retention structure" had become plugged. On March 2, the plug burst, which resulted in the release of a large slug of water to Permanente Creek. County Communications reported that a large (about 20-foot deep) "wall" of water was observed traveling down Permanente Creek from Kaiser Cement. (Internal District memo, April 29, 1983) When the slug of water reached the box culvert near Blach Jr. High School, the water overtopped the banks. The capacity of the box culvert was significantly reduced due to sediment which had accumulated within the culvert.

Permanente Creek and Hale Creek – January 1995. The storm of January 9-10, 1995, resulted in flooding on Permanente and Hale Creeks. Permanente Creek overflowed its banks causing damage to two units of an apartment building on Park Drive in Mountain View. The flood water in the apartments rose to a level of about 2 feet, and also inundated the adjoining garage, driveway, and a parking area. Hale Creek overbanked at Covington Road in Los Altos, resulting in street flooding.

Permanente Creek and Hale Creek – February 1998. The storms of February 2 through February 7, 1998 resulted in over-banking of the west levee of Permanente Creek, immediately downstream of Amphitheater Parkway in the City of Mountain View. Floodwaters just barely spilled over the bank and into an empty lot adjacent to the creek. Permanente Creek also overtopped its banks just upstream of Park Avenue; minor flooding of a parking lot occurred. During the storm of February 2-3, 1998, Hale Creek overflowed its banks at Covington Road, Rosita Avenue, Arboleda Drive, and at the intersection of Mountain View Avenue and Raymundo Avenue. This resulted in minor street flooding.

Future Flooding

Without the project, Permanente Creek flooding will continue into the future.

Although it is impossible to determine the exact location of future flood events, potential flooding problems along Permanente Creek, Hale Creek, and Permanente Diversion can be identified by developing maps of the expected flooding using hydraulic engineering numerical analysis software. The one-percent flood is the design flood for this project per the project objectives. The one-percent flood is defined as a flood that has a one percent probability of occurrence in any given year. This flood does not necessarily happen once in a hundred years; it can occur in consecutive years or even twice in the same year.

Figure 7-4 depicts the areas subject to flooding from a one-percent event based on FEMA versus the District's definition of flooding. The major difference between the two flood mappings is that the District considers all areas that are inundated as flooded, while FEMA maps only show areas that experience greater than 0.3 meter (1 foot) flooding. Numerical models of Permanente and Hale Creeks and the Permanente Diversion show that approximately 3,200 parcels would be subject to flooding from a one-percent flood.

Table 7-2 shows the results of a numerical modeling analysis showing the current capacities versus one-percent flows for all of the reaches of Permanente Creek in the project area. Reaches that do not have one-percent capacity are highlighted in red. As can be seen, most reaches of Permanente Creek are far below the capacity required for the one-percent flood. This underscores the importance of implementing the proposed project.

This is especially true in the middle creek reaches built in the 1960s. For Hale Creek, approximately half of the concrete portion and the majority of the natural portion cannot pass the one-percent flow. Permanente Diversion can generally pass the one-percent flow, with the exception of the portion between Grant Rd. and the Diversion's upstream end. There is a choke-point built into the channel upstream of Grant Rd. which controls the channel to 40 cubic meters per second (cms). This was built into the channel purposely to avoid induced flooding downstream in Stevens Creek. Stevens Creek currently does not have sufficient capacity to carry the one-percent flow (even with zero freeboard).

Figure 7-4: FEMA and District Flooding Comparison

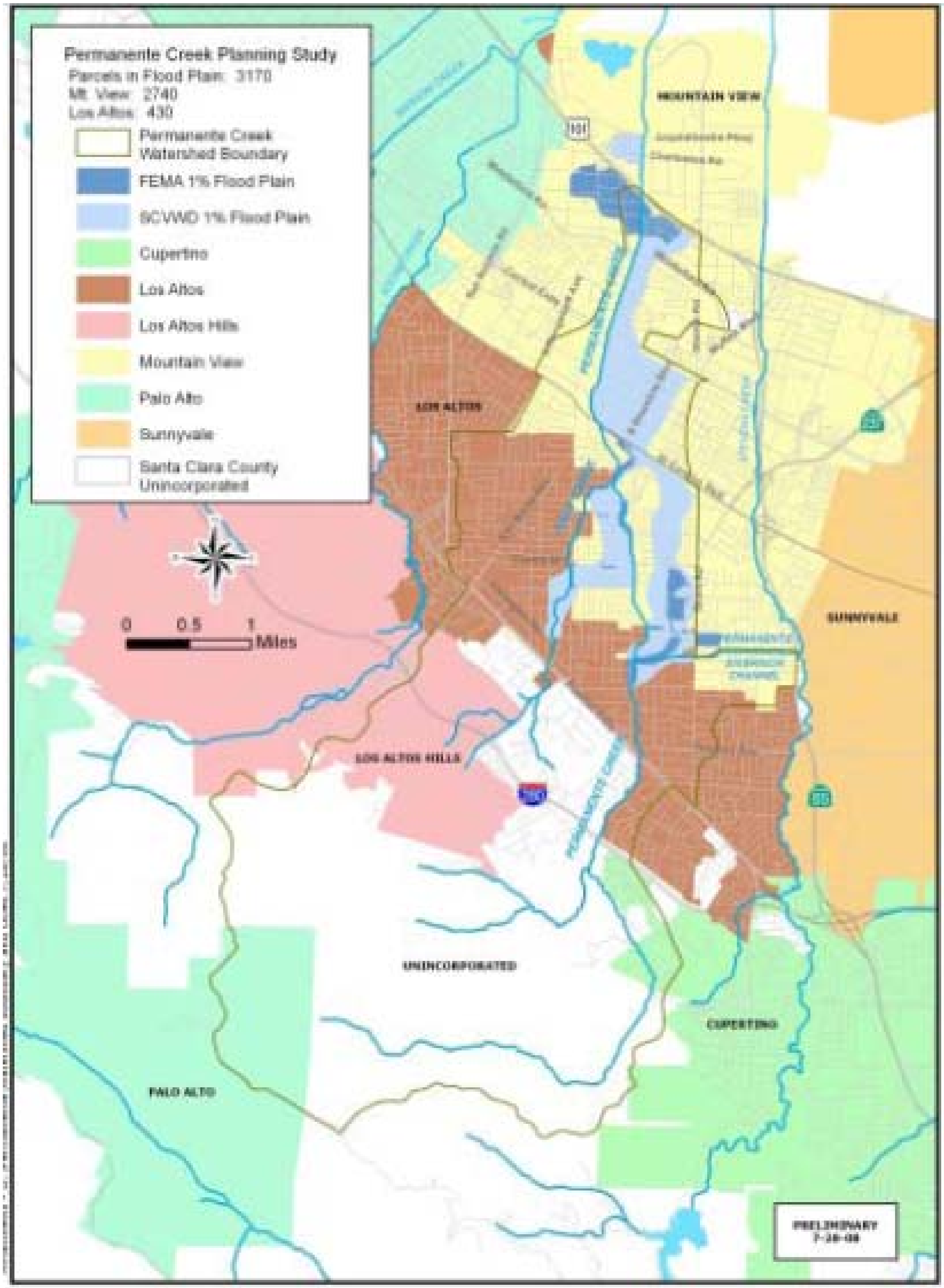


Table 7-2: Current Creek Reach Capacities

Reach	1% Flow		Reach Capacity	
	CMS	CFS	CMS	CFS
Permanente Creek Location:				
San Francisco Bay to U/S end of Salt Ponds	74	2600	26	900
Salt Ponds to Boat Pond	74	2600	30	1050
Boat pond Bridge	74	2600	35	1200
Boat Pond to Shoreline	74	2600	148	5200
Shoreline Parkway Bridge	74	2600	100	3500
Shoreline to Rengstorff	74	2600	100	3500
Rengstorff Walkway Bridge	74	2600	100	3500
Rengstorff to Golf Course	74	2600	57	2000
Golf Course Bridge	74	2600	64	2250
Golf Course to New Ditch	74	2600	66	2300
New Ditch Bridge	74	2600	44	1550
New Ditch to Amphitheater	74	2600	43	1500
Amphitheater Parkway Bridge	74	2600	131	4600
Amphitheater to Charleston	74	2600	44	1550
Charleston Road Bridge	74	2600	73	2600
Charleston to Hwy 101	74	2600	40	1400
Highway 101 Bridge	74	2600	42	1500
Hwy 101 to Old Middlefield	71	2500	40	1400
Old Middlefield Way Bridge	71	2500	27	950
Old Middlefield to Rock	71	2500	52	1850
Rock Street Bridge	71	2500	35	1250
Rock to Middlefield	71	2500	58	2050
Middlefield Road Bridge	71	2500	38	1350
Middlefield to San Ramon	71	2500	65	2300
San Ramon Avenue Bridge	71	2500	37	1300
San Ramon to San Luis	71	2500	47	1650
San Luis Avenue Bridge	71	2500	51	1800
San Luis to Montecito	71	2500	50	1750
Montecito Avenue Bridge	71	2500	43	1500
Montecito to Hackett	71	2500	53	1900
Hackett Avenue Bridge	71	2500	55	1950
Hackett to Hetch Hetchy	71	2500	57	2000
Hetch Hetchy Bridge	71	2500	27	950
Hetch Hetchy to Central	71	2500	31	1100
Central Expressway Bridge	71	2500	33	1150
Central to SPRR	65	2300	92	92

Reach	1% Flow		Reach Capacity	
	CMS	CFS	CMS	CFS
SPRR Bridge	65	2300	38	1350
SPRR to Villa	65	2300	28	1000
Villa Street Culvert	65	2300	34	1200
Villa Culvert to El Camino Culvert	65	2300	34	1200
El Camino Real Culvert	65	2300	34	1200
El Camino Real to Private Bridge	65	2300	36	1250
Private Bridge	65	2300	36	1250
Private Bridge to Park	65	2300	36	1250
Park Drive Bridge	65	2300	28	1000
Park to Mountain View	65	2300	18	650
Mountain View Avenue Bridge	65	2300	21	750
Mountain View to Hale Creek Confluence	65	2300	18	650
Hale Creek Confluence to Marilyn	40	1400	10	350
Marilyn Drive Bridge	40	1400	8	300
Marilyn to Barbara	40	1400	6	200
Barbara Avenue Bridge	40	1400	7	250
Barbara to Miramonte/Cuesta	40	1400	8	300
Miramonte/Cuesta Culvert	40	1400	12	400
Miramonte/Cuesta to Villa Siena	37	1300	16	550
Villa Siena Bridge	37	1300	17	600
Villa Siena to St. Francis Walkway	37	1300	19	650
St. Francis Walkway Bridge	37	1300	25	900
St. Francis Walkway to St. Francis Exit	37	1300	25	900
St. Francis Exit Bridge	37	1300	25	900
St. Francis Exit to St. Francis Entrance	37	1300	27	950
St. Francis Entrance Bridge	37	1300	20	700
St. Francis Entrance to Abandoned Bridge #30	37	1300	25	900
Abandoned Bridge #30	37	1300	40	1400
Abandoned Bridge #30 to Abandoned Bridge #31	37	1300	35	1250
Abandoned Bridge #31	37	1300	23	800
Abandoned Bridge #31 to Covington	37	1300	16	550
Covington Road Bridge	37	1300	14	500
Covington to 54” Diversion Pipe	37	1300	9	300
54” CMP (note: pipe regularly clogs with sediment)	37	1300	6	200
Diversion to Gage	76	2700	48	1700
Gage Bridge	76	2700	159	5600
Gage to Portland	76	2700	82	2900
Portland Avenue Bridge	76	2700	59	2100

Reach	1% Flow		Reach Capacity	
	CMS	CFS	CMS	CFS
Portland to Aura	76	2700	27	950
Aura Way Bridge	76	2700	90	3200
Aura to Fremont	76	2700	134	4700
Fremont Avenue Bridge	76	2700	182	6400
Fremont to Foothill	76	2700	172	6100
Hale Creek Location:				
Permanente Creek to Mt. View	31	1100	56	2000
Mt. View Avenue Bridge	31	1100	22	800
Mt. View to Arroyo	31	1100	22	800
Arroyo Road Bridge	31	1100	52	1850
Arroyo to Marilyn	31	1100	35	1250
Marilyn Drive Bridge	31	1100	35	1250
Marilyn to 7th Day Adventist	31	1100	41	1450
7th Day Adventist Bridge	31	1100	18	650
7th Day Adventist to North Sunshine	31	1100	26	900
North Sunshine Drive Bridge	31	1100	18	650
North Sunshine to South Sunshine	31	1100	26	900
South Sunshine Drive Bridge	31	1100	42	1500
South Sunshine to Springer	31	1100	25	900
Springer Road Bridge	31	1100	23	800
Springer to 400 Springer	31	1100	30	1050
400 Springer Road Bridge	31	1100	26	900
400 Springer to Cuesta	31	1100	42	1500
Cuesta Avenue Bridge	31	1100	21	750
Cuesta to Arboleda	31	1100	28	1000
Arboleda Avenue Bridge	31	1100	23	800
Arbolida to Rosita (including 4 private bridges)	31	1100	20	700
Rosita Avenue Bridge	31	1100	23	800
Rosita to Rock Rip-Rap Section	24	830	15	550
Rock Rip-Rap Section	24	830	25	900
Rock Rip-Rap Section to Covington	24	830	15	550
Covington Road Bridge	24	830	10	350
Covington to Foothill Expressway	24	830	11	400
Permanente Diversion Location:				
Hwy 85 Bridge	40	1400	65	2300
Hwy 85 to Diericx	40	1400	113	4000
Diericx Drive Bridge	40	1400	51	1800
Diericx to Grant	40	1400	68	2400

Reach	1% Flow		Reach Capacity	
	CMS	CFS	CMS	CFS
Grant Road Bridge	40	1400	105	3700
Grant to Permanente Creek	40	1400	40	1400
Stevens Creek Location:				
San Francisco Bay to Highway 101	229	8100	164	5800
Highway 101 to El Camino Real	221	7800	108	3800
El Camino Real to Permanente Diversion	218	7700	227	8000

Methods Used to Estimate Benefits

The Permanente Creek Flood Protection Project Planning Study, completed in July of 2008, reviewed a thorough range of potential alternatives to address historic and projected future flooding issues. Twenty-six conceptual alternatives were identified, including no-project, structural, flood detention, floodproofing, and restoration alternatives. The conceptual alternatives were analyzed for whether they met the project's objectives, were technically buildable, were affordable, and had available right-of-way.

Following completion of the Planning Study, the District completed an Environmental Impact Report (EIR) for the proposed project consistent with California Environmental Quality Act (CEQA) requirements. The SEIR was completed in November 2012 and is provided as **Appendix 7- 1** to this attachment. 60% design has been completed for the project; design drawings and specifications have been provided as **Appendix 7- 2** to this attachment.

The physical benefits claimed by this project are justified by the extensive body of data that has been developed documenting flooding issues and solutions along Permanente Creek.

With- and without project flooding conditions were simulated using FLO-2D floodplain modeling. The FLO-2D flooding results (flood limits and depths) were inputted into the HAZUS-MH FLOOD application to estimate economic losses.

Floodplain Modeling Using FLO-2D Software

Two-dimensional floodplain models were developed for the Permanente Creek Flood Protection Project. The Project includes three creeks: Permanente Creek, Hale Creek, and the Permanente Diversion. The FLO-2D application was used to analyze without-project and with-project conditions for the 25, 50, and 100 year flood event. It should be noted that the 10 year event is also described to provide a condition in which no flooding would be expected with- or without project.

The flood modeling was carried out with two separate models, one simulating Hale Creek flooding (Hale Model) and the other simulating Permanente Creek and Permanente Diversion flooding (Permanente Model).

One-Dimensional vs. Two-Dimensional Modeling

At one time, one-dimensional (1-D) modeling was considered the standard for determining floodplains, though they are significantly limited in their ability to accurately represent floodplains. Two-dimensional (2-D) applications have existed for some time, but until recently, they have been unstable, and the level of effort required to develop, calibrate, and validate these models has made their use infeasible. In recent years, as technological advances have vastly improved the stability and efficiency of 2-D modeling, it has become standard in floodplain simulation. The Permanente Project study area is predominantly flat and unconfined. As such, 2-D modeling was selected for floodplain simulation.

FLO-2D software was used to simulate overland flooding with- and without the Project. FLO-2D is a volume and momentum conservation flood routing application that combines 1-D channel modeling with 2-D floodplain modeling (the flow exchange between the channel and floodplain is carried out by an interface routine). Rainfall and hydrographs are routed over unconfined flow surfaces or in channels using the dynamic wave approximation to the momentum equation. The software includes a number of components to simulate street flow, buildings and obstructions, sediment transport, spatially-variable rainfall and infiltration, floodways, and many other flooding details. Predicted flow depth and velocity between the grid elements represent average hydraulic flow conditions computed for a small timestep (on the order of seconds).

FLO-2D is used to perform simulations, but pre-processors (including GDS, Profile) and post-processors (including Mapper, Profile, and Hydrog) within FLO-2D are used in creating the model. The GDS (Grid Developer System) was the main processor used to build the models. The GDS allowed for data to be input graphically. Once the data was input, the *.dat files were created. In addition to using GDS, the FLO-2D GUI (Geographical User Interface) and the text editor UltraEdit were also used to make changes and update the *.dat files. The pre-processor Profile was used in the development of the channel reaches. Mapper was used to create the floodplain shapefiles.

FLO-2D Model General Assumptions and Limitations

Primary assumptions and limitations involve spatial and temporal resolution of the grid system, dependent on the size of the grid elements and rate of rise in the hydrograph. Each grid element is represented by a single elevation, n value and flow depth. Key assumptions include:

- One dimensional channel flow: no secondary currents and no vertical velocity distribution are simulated. Rapidly varying flow, such as a hydraulic jump, is not simulated.
- Psuedo two dimensional modeling: steady flow is assumed for the duration of the timestep. During the timestep, the discharge flux in all eight directions for each grid element is calculated one direction at a time.
- Quasi two dimensional solution: the momentum equation is solved by computing the average flow velocity across a grid element boundary one direction at a time.

For more detailed information on FLO-2D assumptions, please refer to the Reference Manual provided as **Appendix 7- 3** to this attachment.

Permanente Project Models and Input Data

The flood modeling was carried out with two separate models, one simulating the Hale Creek flooding (Hale Model) and the other simulating the Permanente Creek and Permanente Diversion flooding (Permanente Model). Key model inputs and assumptions are summarized below.

- Grid: FLO-2D uses a grid net with square elements to simulate the flow over land. The Hale Model has 75ft x75ft grid elements while the Permanente Model has 50ft x 50ft elements.
- Digital Terrain Model: Different forms of data can be used to generate the floodplain grid depths. The data is converted to point files containing northings, eastings, and elevations. It is then interpolated in FLO-2D to give each grid element an elevation. The 2006 Santa Clara County 1 ft LiDAR (Light Detection And Ranging) data was used as the basis for the Permanente Model. In 2000, the District had a consultant generate aerials and 1 meter contour data for the Permanente Project. This data was used as the basis for the Hale Model.
- Hydrology: The SCVWD Hydrology data (Hec 1 and Hec-HMS) was used to determine the flow hydrographs for the different events at the different locations for both of the models.
- Floodplain details: Area Reduction Factors and Width Reduction Factors were used for both models to estimate the surface area taken up by structures. The factors used for the two models varied and were estimated using geo-referenced aerial images. For example, a value of 1 (100%) was used for a grid element if a structure encompassed all of the element and a value of 0.5 (50%) was used if a structure encompassed approximately half of the grid element.
- Streets: FLO-2D models the roadways as 1-D, U-frame channels. They have a width and a curb height to carry flows. Aerial images were used to estimate the widths of the streets and the curb height was estimated at 0.5 feet for most the streets.

- Channels: FLO-2D models creeks as 1-D. Surveyed cross sections can be used for natural creeks and U frame or trapezoidal shapes can be used for concrete channels. The Hale and Permanente Models used all of these, depending on the channel type.
- Bridges: FLO-2D does not have the capability to model hydraulic structures such as bridges, so it incorporates rating curves (flow vs depth) to simulate these structures. No structures needed to be simulated for the Permanente Model. For the Hale Model, hydraulic structures were simulated using rating curves generated from the Permanente Project Hec-Ras models.

Portland Avenue Flooding Estimation

The Permanente Model did not include the small portion of flooding at Portland Avenue along Permanente Creek. With-project conditions would not have any flooding at this location. Without-project conditions would have flooding for the 100-year and the 50-year events. These flooding scenarios were estimated using the District's and FEMA's current floodplain maps and assuming a 1 foot depth.

Hazus Modeling

Outputs from FLO-2D were used as inputs to Hazards-United States (Hazus) to simulate economic beefits associated with flood damage reductions generated by the proposed Project. Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from floods using Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts. Hazus simulations were performed to determine without-project and with-project physical flood impacts for the 25-year, 50-year, and 100-year flood events. Additional information on Hazus is provided in the Hazus technical manual, provided as **Appendix 7- 4**. Hazus output files for the with- and without project condition for each modeled event are provided in **Appendix 7- 5**.

Estimated Benefits

The following types of physical benefits are summarized in this section:

- Avoided flood damages
- Water supply benefits
- Water quality benefits
- Environmental benefits
- Recreation / public access benefits
- Energy benefits
- Other benefits

For each category of benefits, the following information is provided.

- Description of physical benefits and methods used to estimate physical benefits
- Acknowledgment of all new facilities, policies, and actions required to obtain the physical benefits
- Description of any potential adverse physical effects in that category

Uncertainty of the benefits, and factors that lead to uncertainty and quantified estimates of physical benefits described using PSP Table 7 are provided in later sections of this attachment.

Avoided Flood Damages

Based on the Hazus modeling completed, the proposed project would provide the physical flood protection benefits summarized in **Table 7-3**, including building structural damages, debris removal requirements, and displaced households and people seeking public shelter. This information was developed using FLO-2D and Hazus, as described above.

Facilities, Policies and Actions Required to Obtain Flood Protection Benefits

In order to achieve the benefits described herein, all of the following project components must be constructed. Project components include:

- A 15-acre flood detention basin at Rancho San Antonio County Park.

- A 5-acre flood detention basin occupying McKelvey Park.
- A new diversion structure to improve the "flow split" at the Permanente Creek Diversion Channel.
- Floodwalls and levees along Permanente Creek from U.S. Highway 101 (US-101) to just north of Amphitheatre Parkway.
- Replacement of selected concrete portions of Permanente and Hale Creeks with wider and deeper concrete channels.

Potential Adverse Effects

No adverse flood-related effects are projected to result from project implementation.

Without-Project Conditions

Without the project, flooding in the project area would continue at historical rates. **Table 7-3** summarizes with- and without-project conditions for the 25-year, 50-year, and 100-year flood events. In the 100-year flood, 93 non-essential buildings would be damaged, 12 essential facilities would be damaged, 2,263 tons (or approximately 91 truckloads) of debris would be generated, 4,572 households would be displaced, and approximately 12,535 displaced people would seek shelter in public shelters.

Table 7-3: Summary of Flood Damages With- and Without the Project

Type of Damage	25-Year Flood			50-Year Flood			100-Year Flood		
	w/o Proj.	With Proj.	Diff.	w/o Proj.	With Proj.	Diff.	w/o Proj.	With Proj.	Diff.
Acres flooded	204	11	193	610	14	596	950	115	835
Number of Structures in the Floodplain	985	48	937	2,301	61	2,240	3,074	379	2,695
Number of Non-Essential Facilities Damaged	0	0	0	27	0	28	93	0	93
Number of Essential Facilities Damaged	3	0	3	9	0	9	12	3	9
Tons (truckloads) of Debris Generated	160 (6)	1 (<1)	159 (>5)	868 (35)	1 (<1)	867 (>34)	2,263 (91)	95 (4)	2,168 (87)
Number of displaced people	4,285	147	4,138	10,197	183	10,014	13,717	1,246	12,471
Number of people requiring short-term shelter	3,622	111	3,511	9,074	136	8,938	12,535	1,043	11,492

Water Supply Benefits

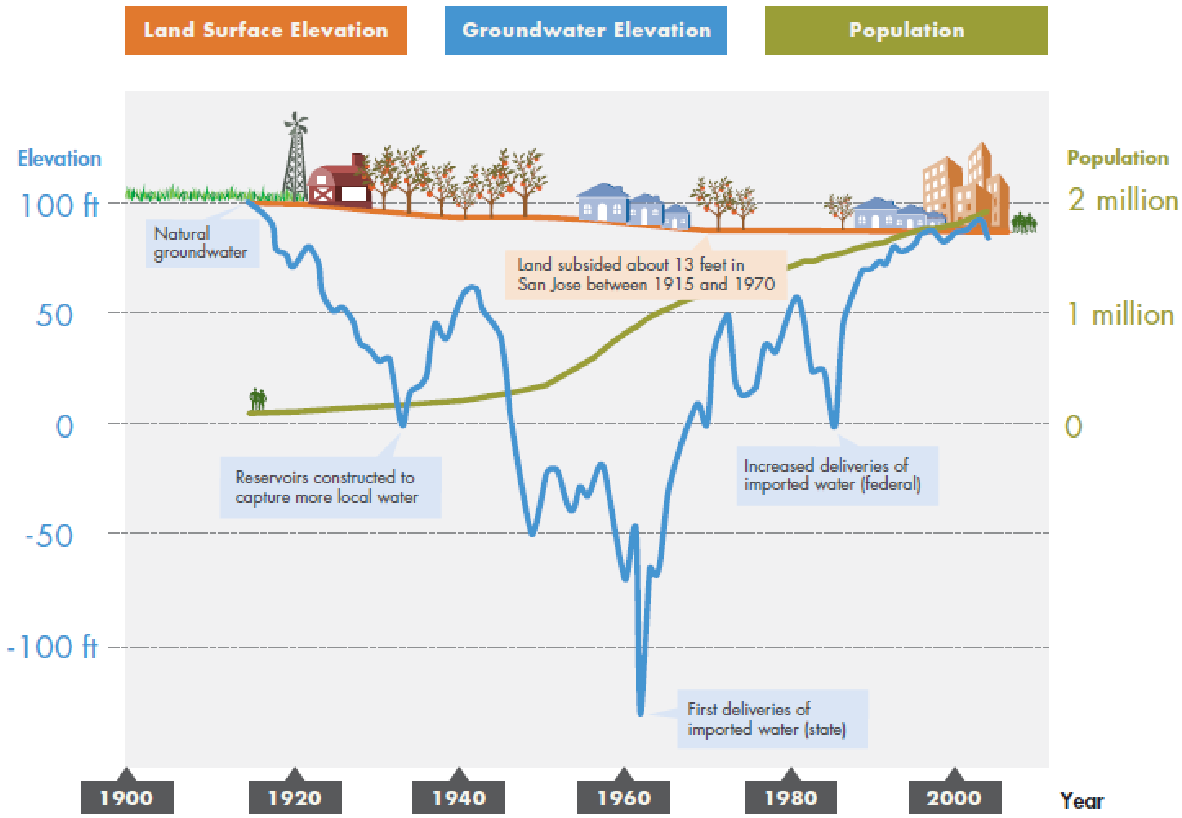
Background

As discussed on pages 1 – 3 of the Water Supply and Infrastructure Master Plan (provided in **Appendix 7-6**), the District recognizes that sustainable, high-quality water is essential for life, a healthy environment, and a prosperous economy and has made significant investments to develop water supplies and infrastructure to meet the county's water needs. As Santa Clara County's population has increased from about 1.3 million in 1980 to about 1.8 million in 2010, its water demand has grown. Water use increased from about 290,000 acre-feet (AF) in 1980 to about 329,000 acre-feet in 2010. The Association of Bay Area Governments projects that the county's population will increase to about 2.4 million by 2035. This increase will equate to increase in water use to about 423,000 AF by 2035. Water use would be higher, by about 51,000 AF in 2010 and 98,500 AF in 2030, if not for the community's efforts to conserve water.

The community uses water for a number of purposes, including residential, commercial, industrial, landscape irrigation, and agriculture. The community values a reliable supply of water for all these purposes. Residents need water for basic sanitation. Commerce and industry need water for product manufacturing and delivery. Farmers need water to grow crops. Water shortages would have severe economic consequences. Water reductions of 10 to 30 percent, if imposed on commerce or industry, could result in a decrease in the local economy's revenue of $900 million to more than $10 billion. In addition, shortages can lead to groundwater overdraft and land subsidence, which can damage infrastructure and increase flooding risks.

Voters approved the formation of the Santa Clara Valley Water Conservation District, a predecessor to today's water district, in 1929 to develop and manage water supplies to meet the county's needs. Northern Santa Clara County had experienced land subsidence from pumping more groundwater than could be replaced or replenished through rainfall. In response, the District constructed six reservoirs in the 1930s to store winter rains for groundwater recharge and summer irrigation use. Four additional reservoirs were constructed in the 1950s, nearly tripling storage to about 169,000 AF. Still, local supplies were insufficient to meet the county's growing population and subsidence continued. In 1965, the District began importing water from the State Water Project for groundwater recharge and use at drinking water treatment plants. The District began receiving water from the Federal Central Valley project in 1987. By the end of the 20th century, groundwater levels recovered and land subsidence was halted. The historic relationship between population growth, groundwater levels, subsidence, and water sources is illustrated in **Figure 7-5**. As population and water use increases, the District will need to develop additional water supplies in order to meet the county's water needs and avoid land subsidence.

Figure 7-5: Relationship between Population Growth, Groundwater Levels, and Subsidence



The District operates an integrated water supply system to meet demands in Santa Clara County. Local surface water and water imported from the Sacramento-San Joaquin River Delta (Delta):

- replenish the local groundwater subbasins, which are pumped for use by individual well owners and retail water suppliers,
- supply the District's drinking water treatment plants for purification,
- are delivered directly to agricultural water users, and
- help meet environmental needs.

The District manages groundwater supplies in conjunction with surface water supplies. In wet years, excess supplies are stored in the local groundwater basin or in a groundwater bank in Kern County for use in dry years. This helps the District manage the natural variations in rainfall and the associated variations in water supply availability.

Increased groundwater recharge resulting from the proposed project would provide increased groundwater supply, a critical component of the District's water supply portfolio.

Expected Benefits and Methods Used to Develop Estimates

The project would not provide measurable water supply benefits.

Facilities, Policies and Actions Required to Obtain Benefits

Because there are no water supply benefits associated with the project, no facilities would need to be constructed to achieve these benefits.

Potential Adverse Effects

As discussed on page 4-8 of the SEIR, monitoring wells installed to support the detailed design of Rancho San Antonio show groundwater depths ranging from 4 to 10 feet in the northeastern portion of the project footprint and from 19 to 20 feet in the southern portion. Construction of the detention facility at Rancho San Antonio would lower the existing ground surface elevation by approximately 8 to 15 feet. As the monitoring data shows, groundwater elevations in the northeastern portion of the project area higher than the finished grade of the basin, construction may result in localized changes in the perched layer. Groundwater that may seep from the basin slope would be intercepted by native vegetation and would quickly percolate back into the soil or drain into Permanente Creek, so would not affect supply or recharge of the groundwater or water quality. Once the flood peak passes, the stored floodwater in each detention facility would drain back into Permanente Creek. For the McKelvey Park Flood Detention Facility, flood flows would drain back into Permanente Creek via gravity flow and pumping. For the Rancho San Antonio County Park Flood Detention Facility, flood flows would drain back into Permanente Creek via gravity flow. None of the project elements would require the use of groundwater. Stormwater from the McKelvey Park Flood Detention Facility that flows back into Permanente Creek would not affect supply or recharge of the groundwater. However, detention and temporary storage of floodwater at the Rancho San Antonio County Park Flood Detention Facility would have a minor localized effect on groundwater supply or recharge because seepage from the basin wall would drain into the creek along with flood flows as the basin drains. However, this effect on groundwater would occur only during a 10-year or greater storm event. There would be no long-term impact related to increased groundwater use or a reduction in supply, and no mitigation is required.

Without-Project Conditions

Without the project, no new water quality benefits or impacts are expected.

Water Quality Benefits

Background

As discussed on page 4-4 of the SEIR, water quality in streams generally depends on the mineral composition of the soils and associated parent material in the watershed, the hydrologic and hydraulic characteristics of the stream and its watershed, and the types of contaminant sources present in the watershed.

Because of the urbanized nature of the Permanente Creek watershed, surface water quality in the project area is directly affected by stormwater runoff from adjacent streets and properties delivering fertilizers, pesticides, metals, hydrocarbons, and other pollutants. Although the District does not monitor water quality in the Permanente Creek system or other creeks, it can be assumed that pollutant levels in the creeks are highest following the first storm flows of the season when constituents accumulated during the dry season are “flushed” into the creeks.

Due to the rugged topography and highly erodible soils in the upper watershed, surface water quality in Permanente and Hale Creeks is also affected by sediment. In the lower, tidally influenced portion of Permanente Creek, water quality may be affected by sediments entering the creek from South San Francisco Bay. In addition to these natural sources of sediment, surface water quality in the watershed is also affected by anthropogenic sediment sources. Mining associated with the Lehigh Southwest Cement Company Permanente Quarry generates large volumes of waste rock, sand particulates, and dust, which can be transported by surface water runoff to Permanente Creek during storm events. Additionally, urbanization has modified the hydrologic characteristics of the watershed, resulting in more rapid and greater peak storm flows, increased creek bed and bank erosion, and higher sediment loads (Santa Clara Valley Water District 2008).

In general, groundwater quality in the Santa Clara Valley is good; water from public supply wells meets state and federal drinking water standards without treatment (Santa Clara Valley Water District 2001). However, there are some known concerns. Near the Bay margin, historic groundwater overdraft has created areas of saltwater intrusion, where groundwater salinity is elevated by contact with seawater infiltrating into subsurface aquifers. Improperly abandoned wells have also conducted contamination from the surface into subsurface aquifers. In addition, as described in Chapter 11 of the SEIR, groundwater contamination resulting from past industrial uses has been identified in a number of areas. Groundwater quality in the portion of the project area north of Middlefield Road has been widely affected by regional volatile organic compound (VOC) plumes likely associated mainly with historic industrial uses. Soils and groundwater have also been affected by golf course lawn care chemicals; complex hydrocarbons and metals associated with the former Palo Alto/Los Altos Sewage Treatment Plant; and historic gasoline and petroleum hydrocarbon spills and runoff mainly associated with former gas station, dry cleaning, and painting businesses and the Jones Hall U.S. Army Reserve Center. Groundwater impacts from pesticides may be concentrated in the portion of the project area between Middlefield Road and Foothill Expressway where historic uses were largely agricultural. The area adjacent to the Permanente Diversion was formerly occupied by orchards, greenhouses, and packing plants, and the hazardous materials investigation identified impacts associated with possible historic spills at former greenhouses and/or packing plants in the areas adjoining the alignment (D&M Consulting Engineers 2002).

Expected Benefits and Methods Used to Develop Estimates

The project would not provide measurable water quality benefits.

Facilities, Policies and Actions Required to Obtain Benefits

Because there are no water quality benefits associated with the project, no facilities would need to be constructed to achieve these benefits.

Potential Adverse Effects

Based on analysis completed in the SEIR and summarized on page 4-10, temporary water quality impacts generated by the project would be less than significant or less than significant with mitigation.

Without-Project Conditions

Without the project, no new water quality benefits or impacts are expected.

Environmental Benefits

Background

As described on pages 5-1 through 5-6 of the SEIR, the project area is located in the southwestern region of the San Francisco Bay Area, which is characterized by warm dry summers and mild wet winters, with most of the rainfall occurring between November and April. Vegetation is adapted to this Mediterranean-type climate regime, and the landscape is a mosaic of drought-adapted tree, shrub, and grassland communities. Permanente Creek is a perennial stream that originates in the largely undeveloped eastern foothills of the Santa Cruz Mountains; the creek runs 13 linear miles through the town of Los Altos Hills and the cities of Los Altos, Cupertino, and Mountain View and discharges into South San Francisco Bay via Mountain View Slough. Hale Creek, a principal tributary, joins Permanente Creek approximately 0.5 miles upstream of El Camino Real in the city of Mountain View. The last 2.5 miles of the creek upstream of the Bay are tidally-influenced.

Immediately to the south and southwest of the project area, the Santa Cruz Mountains support a combination of protected open space and rural residential development. The project corridor itself is located on the Santa Clara Valley floor; lands to the east and west of the project corridor are largely developed except for urban parks. Existing land uses adjacent to the creek, thus, range from open space in the creek's upper reaches to residential development in the cities of Mountain View and Los Altos and commercial and light industrial uses approaching Mountain View's Bay margin. Immediately upstream from the creek's point of discharge into Mountain View Slough, it crosses through Shoreline at Mountain View Park. Consistent with its setting, much of the creek's urban length has been channelized or otherwise improved for flood protection, although portions remain unlined or only minimally altered.

Twelve habitat types occur in the project corridor: annual grassland, abandoned orchard, valley foothill riparian, ruderal, open water, tidal salt marsh, tidal brackish marsh, freshwater wetland, seasonal wetland, mixed chaparral, coastal oak woodland, and developed areas.

Expected Benefits and Methods Used to Develop Estimates

As described on page 4-16 of the SEIR, the Project would slightly modify the flow split between the Permanente Creek Diversion Channel and Permanente Creek in floods smaller than the 10-year event because a small percentage of incoming floodflow would be allowed to continue down the Permanente mainstem. For example, at an incoming flow of 1,000 cubic feet per second (cfs) (approximately equal to the 5-year floodflow in Permanente Creek immediately upstream of the diversion structure), the new diversion structure would pass approximately 50 cfs to downstream Permanente Creek but would still divert the majority of the flow (approximately 950 cfs) to Stevens Creek. At very low flows, the post-project flow split would change substantially from existing conditions because the Project would be specifically designed to route summer low flows into the downstream Permanente mainstem. This is expected to result in about a 5-cfs increase in flows in the Permanente mainstem downstream of the diversion structure, which could enhance Cold Freshwater Habitat, as summer low flows from the Permanente Diversion Channel consist largely of nuisance flows from adjacent developed areas warmed by their passage along the unshaded concrete channel. Assuming summer low flows occur for approximately 10 days per year, a 5 cfs average increase in flow would equate to approximately 99 AFY of additional flow in the Permanente mainstem to provide Cold Water Habitat enhancements.

In addition, by creating two new detention basins, 20 acres of undeveloped land and potential high-value habitat would be conserved by the project in perpetuity.

Facilities, Policies and Actions Required to Obtain Benefits

In order to achieve the benefits described herein, all of the following project components must be constructed. Project components include:

- A 15-acre flood detention basin at Rancho San Antonio County Park.
- A 5-acre flood detention basin occupying McKelvey Park.
- A new diversion structure to improve the “flow split” at the Permanente Creek Diversion Channel.
- Floodwalls and levees along Permanente Creek from U.S. Highway 101 (US-101) to just north of Amphitheatre Parkway.
- Replacement of selected concrete portions of Permanente and Hale Creeks with wider and deeper concrete channels.

Potential Adverse Effects

Table S-1 on pages S-2 through S-9 of the SEIR (attached) identifies expected environmental impacts of the proposed project, which consist primarily of temporary construction-related impacts. As shown in this table, potential adverse impacts of the project will be reduced to less than significant with mitigation.

Without-Project Conditions

Without the project, the adverse impacts and environmental benefits described herein and summarized in **Table 7-1** will not be achieved.

Recreation/Public Access Benefits

Background

As summarized on pages 12-1 and 12-2 of the SEIR, there are numerous recreational facilities in the project region, managed by a number of local jurisdictions and agencies. This summary focuses on the agencies most relevant to the proposed project: those that manage trails and parks along the Permanente Creek alignment and/or offstream facilities proposed for shared recreational/flood protection use as part of the Project. These include the following.

- The County Department of Parks and Recreation owns and/or maintains 28 parks encompassing nearly 45,000 acres (County of Santa Clara Department of Parks and Recreation 2012). County parks located near the project corridor include Stevens Creek County Park and Rancho San Antonio County Park.
- The Midpeninsula Regional Open Space District is a public agency that owns and manages over 60,000 acres of land in 26 open space preserves, 24 of which are open to the public. MROSD covers an area of 550 square miles in 17 cities (Atherton, Cupertino, East Palo Alto, Half Moon Bay, Los Altos, Los Altos Hills, Los Gatos, Menlo Park, Monte Sereno, Mountain View, Palo Alto, Portola Valley, Redwood City, San Carlos, Saratoga, Sunnyvale, and Woodside) (Midpeninsula Regional Open Space District 2012b). Rancho San Antonio is co-managed by MROSD and the County of Santa Clara through an Operations and Management Agreement with the Santa Clara County Parks and Recreation Department; this includes MROSD’s 3,988-acre open space preserve as well as adjoining 165-acre County park (Midpeninsula Regional Open Space District 2012c).
- MROSD manages the parking areas and associated facilities immediately northwest of the proposed detention facility location. The current location of the proposed basin is outside of the area managed by the MROSD.
- The City of Mountain View Parks Division manages 32 urban parks, as well as 4 miles of bicycle and pedestrian trails along Stevens Creek, Permanente Creek, and the Hetch-Hetchy ROW. It also manages Shoreline at Mountain View Regional Park and other regional open space throughout the city (City of Mountain View 2012).

Table 7-4 lists the recreational facilities in the immediate project area, including the facilities they offer and the uses they support.

Table 7-4: Summary of Recreation Facilities in the Project Area

Facility/Managing Agency(ies)	Recreational Facilities	Recreational Uses
Rancho San Antonio County Park (Santa Clara County/ MROSD)	Paved and unpaved multiuse trails, picnic areas, demonstration farm, model plane staging area	Hiking, biking, horseback riding, picnicking, nature viewing, model plane operation
McKelvey Park (City of Mountain View)	Baseball field, softball field, paved trail	Youth baseball, softball, walking, dog walking
Permanente Creek Trail (City of Mountain View)	Paved multiuse trail	Walking, bicycling, nature viewing
Shoreline at Mountain View Regional Park (City of Mountain View)	Paved and unpaved multiuse trails, Shoreline Lake, boathouse and boat rentals, 18-hole golf course, clubhouse, historic Rengstorff House, kite flying area, interpretive stations, picnic areas	Hiking, walking, running, bicycling, golfing, picnicking, nature viewing, boating, kite flying

Expected Benefits and Methods Used to Develop Estimates

As described on pages 12-4 and 12-5 of the SEIR, the Project would provide additional recreation features at Rancho San Antonio County Park and McKelvey Park. At Rancho San Antonio County Park, the existing parking lot would be expanded into the existing gravel equestrian parking area to provide nine additional passenger car parking spaces because existing passenger car parking accommodating approximately 50 cars often spills into the equestrian gravel parking area. The parking lot would be redesigned to provide the same number of passenger car spaces based on current parking demand, and replacement parking would be constructed in advance of disrupting/demolishing the existing parking area. In addition, a new restroom and a new trail spur would be installed from the Hammond Snyder Loop Trail along Cristo Rey Drive, down the slope between the Gate of Heaven Cemetery and the new basin, connecting back to the Hammond Snyder Loop Trail adjacent to the creek, for a total of approximately 1,200 feet of new trails (refer to 60% design drawings, provided as **Appendix 7- 2**). At McKelvey Park, the restored fields and other amenities at the park are being developed cooperatively with park users and the City of Mountain View to ensure that the new facility offers a community benefit and provides needed flood protection. In addition, a new 0.7-acre mini-park would be developed within McKelvey Park. Therefore, the Project could alleviate pressure to expand or improve other facilities in the project area, potentially representing a beneficial impact.

Figure 7-6: Sketch of McKelvey Mini-Park

Source: RHHA 2012.

Facilities, Policies and Actions Required to Obtain Benefits

In order to achieve the benefits described herein, all of the following project components must be constructed. Project components include:

- A 15-acre flood detention basin at Rancho San Antonio County Park.
- A 5-acre flood detention basin occupying McKelvey Park.
- A new diversion structure to improve the “flow split” at the Permanente Creek Diversion Channel.
- Floodwalls and levees along Permanente Creek from U.S. Highway 101 (US-101) to just north of Amphitheatre Parkway.
- Replacement of selected concrete portions of Permanente and Hale Creeks with wider and deeper concrete channels.

Potential Adverse Effects

As discussed on page 12-3 of the SEIR, construction of the proposed project would result in temporary unavailability of the following project element sites.

- Rancho San Antonio County Park Flood Detention Facility—A portion of the Hammond-Snyder Loop Trail and the Coyote Trail pedestrian/equestrian bridge across Permanente Creek.
- Cuesta Annex Flood Detention Facility —About one-half of Annex for construction of flood detention facility.
- McKelvey Park Flood Detention Facility —All facilities.
- Floodwall and Levees downstream of US-101—Pedestrian trail on west bank.

Construction of the other proposed facilities would not affect recreational uses and thus would have no potential to result in a need for new or expanded facilities during construction.

Without-Project Conditions

Without the project, the new recreation features summarized above would not be implemented, and the sites noted above would not experience temporary unavailability.

Energy-Related Benefits

Background

As discussed on pages 13-1 through 13-4 of the SEIR, natural gas and electric service for the project area is provided by Pacific Gas and Electric Company, commonly known as PG&E. PG&E is one of the largest combination natural gas and electric utilities in the United States, serving approximately 15 million people throughout a 70,000-square-mile service area in northern and central California. PG&E produces and purchases energy from a mix of conventional and renewable generating sources. The energy travels through PG&E's electric transmission and distribution systems to reach customers.

Expected Benefits and Methods Used to Develop Estimates

No energy-related benefits are expected to accrue from the project.

Facilities, Policies and Actions Required to Obtain Benefits

Because no energy-related benefits are expected to accrue from the project, no facilities are required to achieve these benefits.

Potential Adverse Effects

As described on page 13-11 of the SEIR, project construction would require the use of small amounts of electricity and fuel for operating construction equipment. Energy would also be used to transport materials and workers to the site. This represents a minor increase in energy use. This use of energy is typical of construction projects that are similar in size and scope to the Project and would not require new energy facilities to be constructed. The impact is considered less than significant.

Operation of the Project would entail on-site electrical consumption from pump operation at the McKelvey Park Flood Detention Facility during flooding events and the new restroom proposed at the Rancho San Antonio County Park Flood Detention Facility. Electrical use is estimated to be 6,000 kWh per year at the McKelvey Park Flood Detention Facility. No pumping would be required at the Rancho San Antonio County Park Flood Detention Facility; however, this facility would include electrical use for the new restroom. The new restroom would connect to an existing water line and be designed to include energy-efficiency features. Given the small increase in electricity use by the pumps from their occasional use (only during flooding events), operation of the pumps would not require construction of new energy facilities. A less-than significant impact would occur.

Without-Project Conditions

Without project implementation, temporary construction-related energy use would be avoided, and approximately 6,000 kWh per year of ongoing energy use would be avoided.

Other Physical Benefits

No other quantitative physical benefits have been identified for this project. Additional qualitative benefits are discussed in Attachment 8.

Uncertainty of Benefits

The following uncertainties could potentially affect the projected benefits described herein.

Table 7-5: Uncertainty of Benefits

Uncertainty	Description	Potential Impact on Benefits
Modeling assumptions	• The model simulates 1-D channel flow with no secondary currents and no vertical velocity distribution; rapidly varying flow, such as a hydraulic jump, is not simulated. • Steady flow is assumed for the duration of the timestep; during the timestep, the discharge flux in all eight directions for each grid element is calculated one direction at a time. • The momentum equation is solved by computing the average flow velocity across a grid element boundary one direction at a time.	Impact unknown; under- or over-estimated property values could result in an under- or over-estimate of projected flood protection benefits

Annual Project Physical Benefits

The following tables present the annual project benefits for each of the different physical benefits claimed for the Permanente Creek Flood Protection Project. These tables are modeled after Table 7 of the PSP.

Table 7-1a – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Reduction in number of buildings damaged			
Measure of Benefit Claimed (Name of Units): Number of Buildings Damaged			
Additional Information About this Measure: Values reflect expected annual number of buildings impacted based on damage estimates for the 10-, 25-, 50-, and 100-year flood events (see table 7-1b below)			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	1.2	0	1.185
Comments:			

Table 7-1b –Calculation of Expected Annual Damage (Number of Buildings Damaged)												
Event	Event Exceed-ance Prob.	Buildings Damaged if Flood Structures Fail	Probability Structural Failure		Expected Event Damage		Interval Prob.	Average Damage in Interval		Average Damage in Interval times Interval Probability	
			W/o Proj.	With Proj.	W/o Proj.	With Proj.		W/o Proj.	W/ Proj.	W/o Proj.	W/ Proj.
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(i)	(j)	(k)	(l)	(m)
					(c) x (d)	(c) x (e)	from (b)	from (f)	from (g)	(i) x (j)	(i) x (k)
10-Year	0.1	0	1	0	0	0					
25-Year	0.04	3	1	0	3	0	0.06	2	0	0	0
50-Year	0.02	37	1	0	37	0	0.02	20	0	0	0
100-Year	0.01	105	1	0	105	3	0.01	71	2	1	0
Expected Annual Damages Without and With Project										1.2	0

Table 7-2a – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Reduction in Debris Generated			
Measure of Benefit Claimed (Name of Units): Tons			
Additional Information About this Measure: Values reflect expected annual reduction in debris generated based on debris estimates with and without project for the 10-, 25-, 50-, and 100-year flood events (see table 7-2b)			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	30.7	1	30.2
Comments:			

Table 7-2b – Calculation of Expected Annual Damage (Ton of Debris Generated)												
Event	Event Exceed-ance Prob.	Reduction in Debris if Flood Structures Fail	Probability Structural Failure		Expected Event Damage		Interval Prob.	Average Damage in Interval		Average Damage in Interval times Interval Probability	
			W/o Proj.	With Proj.	W/o Proj.	With Proj.					W/o Proj.
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(i)	(j)	(k)	(l)	(m)
					(c) x (d)	(c) x (e)	from (b)	from (f)	from (g)	(i) x (j)	(i) x (k)
10-Year	0.1	0	1	0	0	0					
25-Year	0.04	160	1	0	160	1	0.06	80	1	5	0
50-Year	0.02	868	1	0	868	1	0.02	514	1	10	0
100-Year	0.01	2,263	1	0	2,263	95	0.01	1,566	48	16	0
Expected Annual Damages, Without and With Project										30.7	1

Table 7-3a – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Reduced Number of Displaced People Seeking Public Shelter			
Measure of Benefit Claimed (Name of Units): Number of Displaced People Seeking Public Shelter			
Additional Information About this Measure: Values reflect expected annual reduction in number of displaced people seeking public shelter based on estimates of displaced people seeking public shelter with and without project for the 10-, 25-, 50-, and 100-year flood events (see table 7-3b)			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	131	5	126
Comments:			

Table 7-3b – Calculation of Expected Annual Damage (Number of Displaced People Seeking Public Shelter)											
Event	Event Exceed-ance Prob.	People Seeking Shelter if Flood Structures Fail	Probability Structural Failure		Expected Event Damage		Interval Prob.	Average Damage in Interval		Average Damage in Interval times Interval Probability	
			W/o Proj.	With Proj.	W/o Proj.	With Proj.		W/o	W/ Proj.	W/o Proj.	W/ Proj.
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(i)	(j)	(k)	(l)	(m)
					(c) x (d)	(c) x (e)	from (b)	from (f)	from (g)	(i) x (j)	(i) x (k)
10-Year	0.1	0	1	0	0	0					
25-Year	0.04	1,428	1	0	1,428	49	0.06	714	25	43	1
50-Year	0.02	3,399	1	0	3,399	61	0.02	2,414	55	48	1
100-Year	0.01	4,572	1	0	4,572	415	0.01	3,986	238	40	2
Expected Annual Damages, Without and With Project										131.0	5

Table 7-4 – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Increased Annual Flows in Permanente Mainstem			
Measure of Benefit Claimed (Name of Units): AFY			
Additional Information About this Measure:			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	0	99	99
Comments:			

Table 7-5 – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Increased Acres of Undeveloped Land Protected			
Measure of Benefit Claimed (Name of Units): acres			
Additional Information About this Measure:			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	0	20	0
Comments:			

Table 7-6 – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Increased Number of Parking Spaces at Rancho San Antonio County Park			
Measure of Benefit Claimed (Name of Units): number of parking spaces			
Additional Information About this Measure:			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	50	59	9
Comments:			

Table 7-7 – Annual Project Physical Benefits			
Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Increased Number of Restrooms at Rancho San Antonio County Park			
Measure of Benefit Claimed (Name of Units): number of restrooms			
Additional Information About this Measure:			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	0	1	1
Comments:			

Table 7-8 – Annual Project Physical Benefits Project Name: Permanente Creek Flood Protection Project			
Type of Benefit Claimed: Feet of New Trails at Rancho San Antonio County Park			
Measure of Benefit Claimed (Name of Units): miles of new trails			
Additional Information About this Measure:			
(a)	(b)	(c)	(d)
	Physical Benefits		
Year	Without Project	With Project	Change Resulting from Project (b) – (c)
2017-2066	121,440	122,640	1,200
Comments:			

APPENDIX 7-1: Final Subsequent Environmental Impact Report

(Provided on attached CD as file Att7_SWF_TechJust_2of3)

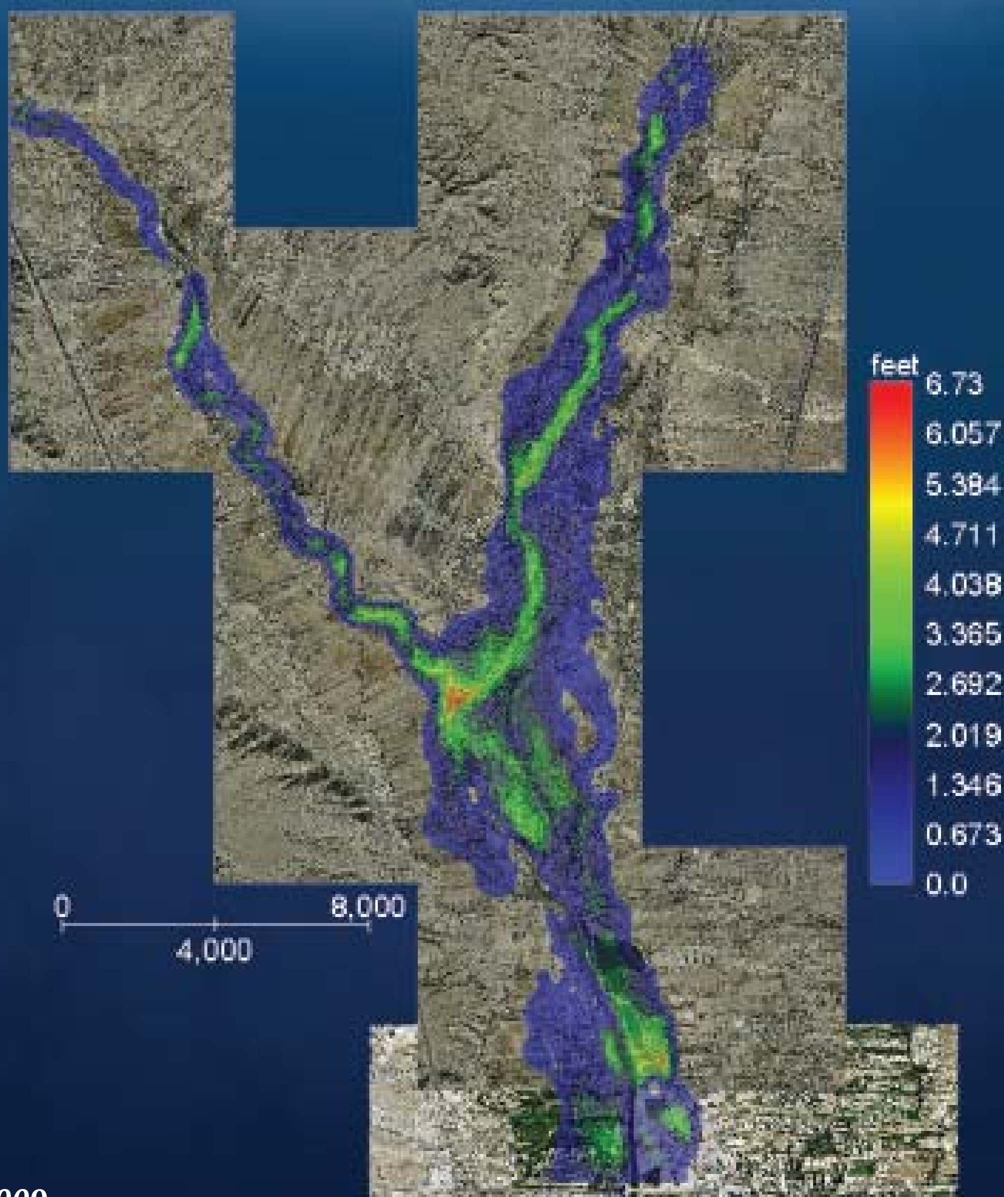
APPENDIX 7-2: 60% Design Drawings

(Provided separately as hard copy and on attached CD as file Att7_SWF_TechJust_3of3)

APPENDIX 7-3: FLO-2D Reference Manual

FLO-2D

Reference Manual



Version 2009

A few comments on modeling free surface flows…

With faster computers and higher resolution digital terrain models, flood routing models are becoming very detailed. When adding detail to a two-dimensional flood routing model, a number of factors should be considered including flood hydrology accuracy, topographic model resolution, spacing of the channel cross sections, and limited calibration data. As flood models become more detailed, the user should try to find a balance between model resolution, computer resources and budget.

Reliable flood hazard delineation requires a critical review of model applicability, modeling assumptions, and the available data bases. While finite difference models have become more versatile with increasing computer resources, inadequate hydrographic data bases still limit the accuracy of flood hazard delineation. Digital terrain models are becoming the foundation of high resolution mapping, but post-flood event surveys of high water marks and aerial photography of the area of inundation are either unavailable or perhaps were collected long after the flood waters have receded. Correlating the area of inundation with flood peak discharge can lead to the harsh realization that our best discharge measurements or gaging data have limited accuracy at high flows. Our modeling and mapping results may be only as good as the model calibration to post-flood data.

As flood inundation mapping advances with hydrograph routing, extensive topographic data bases, high resolution graphics, and unconfined hydraulic modeling, it may appear that flood modeling complexity is becoming overwhelming. Please take heart in the comments of Cunge et al. (1980):

> *"The modeler must resist the temptation to go back to one-dimensional schematization because of lack of data otherwise necessary for an accurate two-dimensional model calibration. If the flow pattern is truly two-dimensional, a one-dimensional schematization will be useless as a predictive tool..." "It is better to have a two-dimensional model partially calibrated in such situations than a one-dimensional one which is unable to predict unobserved events. Indeed, the latter is of very little use while the former is an approximation which may always be improved by complimentary survey."4*

As a final word, please remember that all software programs has an occasional glitch. Modeling bugs are inherent part of the process of adding new routines and attempting to make the model run faster. Even when a model engine is fine tuned, adding components may introduce conflicts with older subroutines or perhaps may uncover bugs that were previously undetected. FLO-2D is no exception. Version 2007 will run faster than previous models and when comparing results with previous versions, you may note some minor differences associated with the larger computational timesteps. Generally, the Version 2007 FLO-2D results should be more accurate, but we will immediately address all questions concerns over model application, accuracy or problems. On occasion there is a project application that pushes the model to new limits. Such projects can lead to new developments that benefit all users. The modeler is encouraged to share interesting projects with us. We aspire to make the FLO-2D model a comprehensive and flexible tool.

BRIEF OVERVIEW

FLO-2D is a volume conservation flood routing model. It is a valuable tool for delineating flood hazards, regulating floodplain zoning or designing flood mitigation. The model will simulate river overbank flows, but it can also be used on unconventional flooding problems such as unconfined flows over complex alluvial fan topography and roughness, split channel flows, mud/debris flows and urban flooding. FLO-2D is on FEMA's list of approved hydraulic models for both riverine and unconfined alluvial fan flood studies.

The FLO-2D software package includes a grid developer system (GDS), a Mapper program that automates flood hazard delineation, and the FREQPLOT program to analyze flood frequency. The GDS will filter DTM points, interpolate the DTM data and assign elevations to grid elements. The MAPPER program automates flood hazard delineation. MAPPER will generate very detailed flood inundation color contour maps and shape files. It will also replay flood animations and generate flood damage and risk maps. A graphical user interface (GUI) has been developed to assist the user in preparing and editing the data files.

The FLO-2D Reference Manual is devoted to a model description, theory and components. The user is encouraged to read this manual to become familiar with the overall model attributes and equations. The Data Input Manual is subdivided into a series of data files with variable descriptions and comments. The user should consult this manual when constructing data files. Separate manuals are devoted to the application of the GDS and Mapper.

The user can keep current on FLO-2D model and processor updates, training and other modeling news at the website: www.flo-2d.com.

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FLO-2D

Two Dimensional Flood Routing Model

I. INTRODUCTION

This Reference Manual discusses the physical processes of flooding. It is designed to acquaint the user with the model theory, finite difference algorithms, model components, modeling assumptions and limitations, and potential flood scenarios. A reference list is provided for further reading.

1.1 Evolution of the FLO-2D Model

The first version of the FLO-2D model was called MUDFLOW. It was initiated in 1988 to conduct a Federal Emergency Management Agency (FEMA) flood insurance study (FIS) of an urbanized alluvial fan in Colorado. FEMA had requested the investigation of flood routing models that might be suitable for simulating mudflows. The Diffusive Hydrodynamic Model (DHM) created by Hromadka and Yen (1987) distributed by the USGS was considered to be a simple finite difference model that might serve as a template to develop a more sophisticated hydraulic model for mudflows. The selection of the DHM model as a template for the MUDFLOW model was based on its availability in the public domain, its simple numerical approach and a finite difference scheme that permitted modification of the grid element attributes.

The original MUDFLOW model was only a few hundred lines of Fortran code and was limited to 250 grid elements. A six hour hydrograph took over 12 hours to run on an XT computer. After 21 years of development, the program code has grown to be in excess of 40,000 lines of code, 60 subroutines and a number of processor programs. Virtually none of the original simplistic DHM concept remains in the current FLO-2D model. FLO-2D computes overland flow in 8-directions, reports on mass conservation, utilizes a variable timestep incrementing and decrementing scheme, incorporates efficient numerical stability criteria, has unlimited array allocation (unlimited grid elements), includes graphical editing, and has output display processor programs.

FLO-2D is a physical process model that routes rainfall-runoff and flood hydrographs over unconfined flow surfaces or in channels using the dynamic wave approximation to the momentum equation. It has a number of components to simulate street flow, buildings and obstructions, sediment transport, spatially variable rainfall and infiltration, floodways and many other flooding details. Predicted flow depth and velocity between the grid elements represent average hydraulic flow conditions computed for a small timestep (on the order of seconds). Typical applications have grid elements that range from 25 ft to 500 ft on a side and the number of grid elements is unlimited.

1.2 Modeling the Hydrologic System with FLO-2D

The FLO-2D system consists of processor programs to facilitate graphical editing and mapping and components that simulation channel and floodplain detail. The Grid Developer System (GDS) generates a grid system that represents the topography as a series of small tiles. The FLO-2D model has components for rainfall, channel flow, overland flow, street flow, infiltration, levees and other physical features. The GDS and the FLOENVIR processor programs are used to spatially edit the grid system attributes. The PROFILES program edits channel slope and cross section shape. Flood routing results can be viewed graphically in the MAXPLOT, MAPPER and HYDROG (plot hydrograph) programs.

FLO-2D is an effective tool for delineating flood hazards or designing flood mitigation. The model utility is discovered through its application to diverse flooding problems. Starting with a basic overland flood scenario, details can added to the simulation by turning on or off switches for the various components shown in Figure 1. Multiple flood hydrographs can be introduced to the system either as a floodplain or channel inflow. As the floodwave moves over the floodplain or down channels or streets, flow over adverse slopes, floodwave attenuation, ponding and backwater effects can be simulated. In urban areas, buildings and flow obstructions can be simulated to account for the loss of storage and redirection of the flow path. The levee component can be used to test mitigation alternatives.

Channel flow is one-dimensional with the channel geometry represented by either by natural, rectangular or trapezoidal cross sections. Street flow is modeled as a rectangular channel. Overland flow is modeled two-dimensionally as either sheet flow or flow in multiple channels (rills and gullies). Channel overbank flow is computed when the channel capacity is exceeded. An interface routine calculates the channel to floodplain flow exchange including return flow to the channel. Similarly, the interface routine also calculates flow exchange between the streets and overland areas within a grid element (Figure 2). Once the flow overtops the channel, it will disperse to other overland grid elements based on topography, roughness and obstructions. For flood projects with specific requirements, there are several unique components such as mud and debris flow routing, sediment transport, a floodway option, open water surface evaporation and others.

The user is encouraged to apply these components while understanding the contribution of each component to the overall flood distribution. It is important to assess the level of detail required on a given project. FLO-2D users have a tendency to put more detail into their models than is necessary for a large flood event. Preparation of channel flow, street flow, buildings and flow obstructions data files can be time consuming and should be tailored to meet the project needs. The desired accuracy of predicted water surface elevations should be consistent with the resolution of the mapping, survey and hydrologic data bases. Simulating large floods requires less detail than shallow flood or mitigation design models. Grid element sizes ranging from 25 ft (8 m) to 500 ft (150 m) is practically for most flood inundation projects.

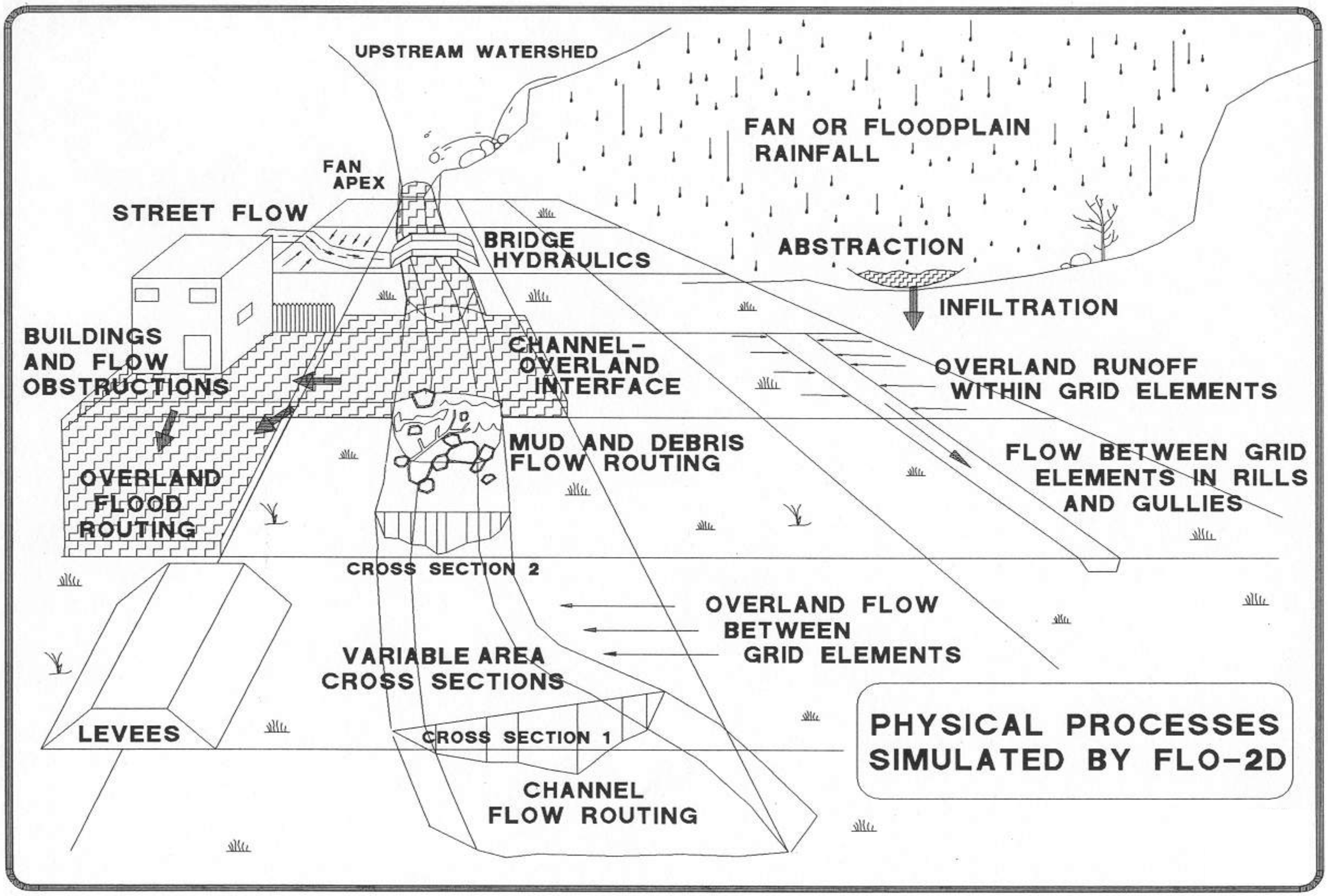

Figure 1. Physical Processes Simulated by FLO-2D

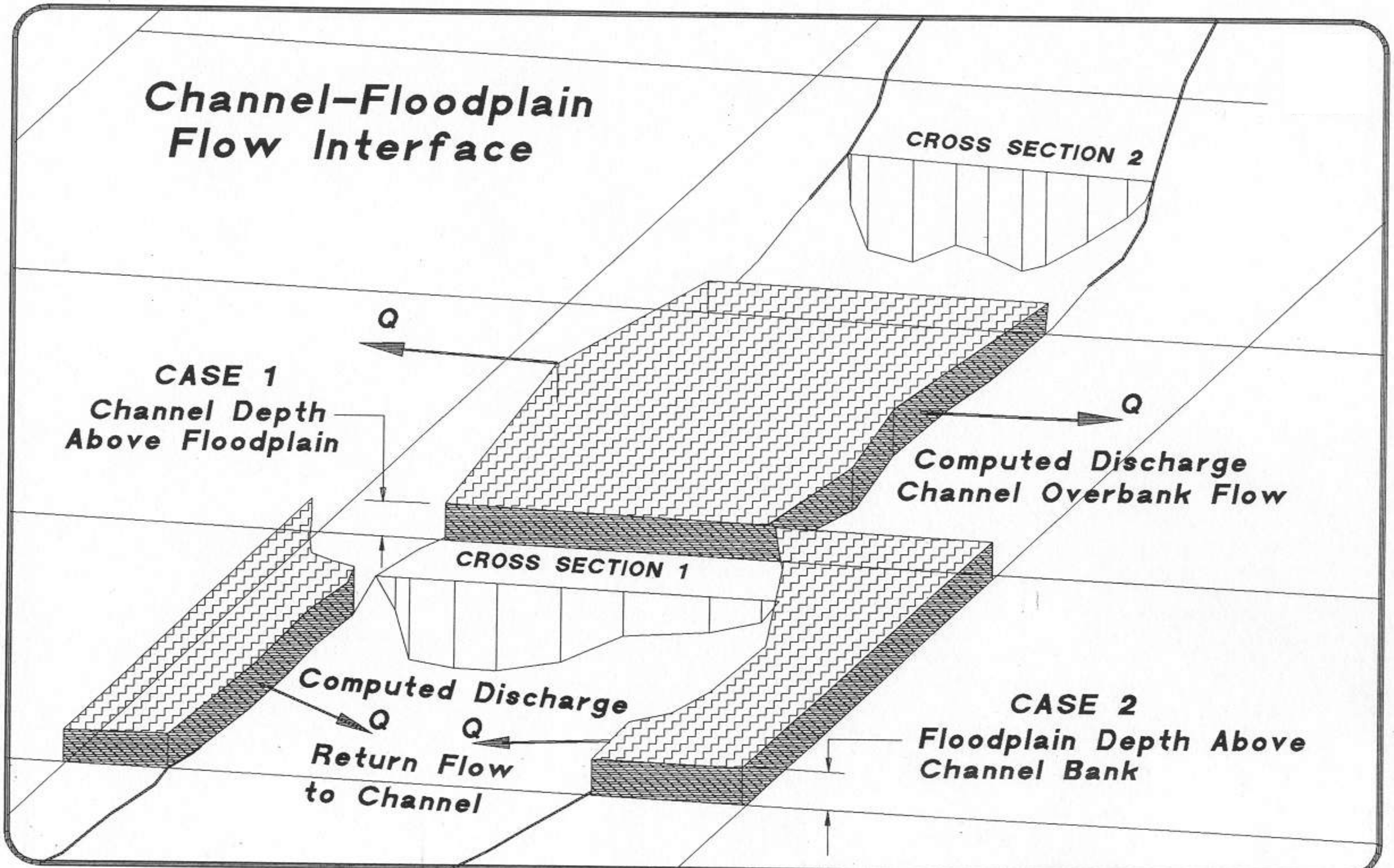

Figure 2. Channel – Floodplain Interface

1.3 Getting Started on a Project – A Brief Overview

There are two important steps to starting a flood simulation, obtaining the topographic data base and developing the flood hydrology. For the first step, a digital terrain model (DTM) has to be overlaid with a grid system. The Grid Developer System (GDS) processor program will overlay the grid system on a DTM data base and assign elevations to the grid elements. Aerial photography, detailed topographic maps, orthographic photos and digitized mapping can be used to locate important features with respect to the grid system such as streets, buildings, bridges, culverts or other flood conveyance or containment structures. Figure 3 is a flow chart that outlines how the various components interface with each other.

Each flood simulation requires either an inflow flood hydrograph or a rain storm. The discharge inflow points might include the alluvial fan apex or a known discharge location in a river system. FLO-2D can be used to generate the flood hydrograph at a specific location by modeling the rainfall-runoff in the upstream watershed. Another approach is to use an external hydrologic model to generate an inflow hydrograph for the FLO-2D model. Rainfall can also be simulated on the water surface as the flood progresses over the grid system. The model inflow flood volume is the primary factor that determines an area of flood inundation. For that reason, it is suggested that an appropriate effort be spent on the hydrology analysis to support the accuracy of the flood routing simulation.

Results from a FLO-2D flood simulation may include: outflow hydrographs from the grid system; hydrographs and flow hydraulics for each channel element; flood hydrographs and hydraulics for designated floodplain cross sections; maximum flow depths and velocities for all grid elements; changes in bed elevation; and a summary of the inflow, outflow, storage and volume losses in the system. The user can specify the temporal and spatial output detail including the outflow hydrograph locations, the output time intervals and the graphical display of the flood progression over the grid system. Starting with the preliminary FLO-2D runs, the user should test the output options to determine required level of output detail.

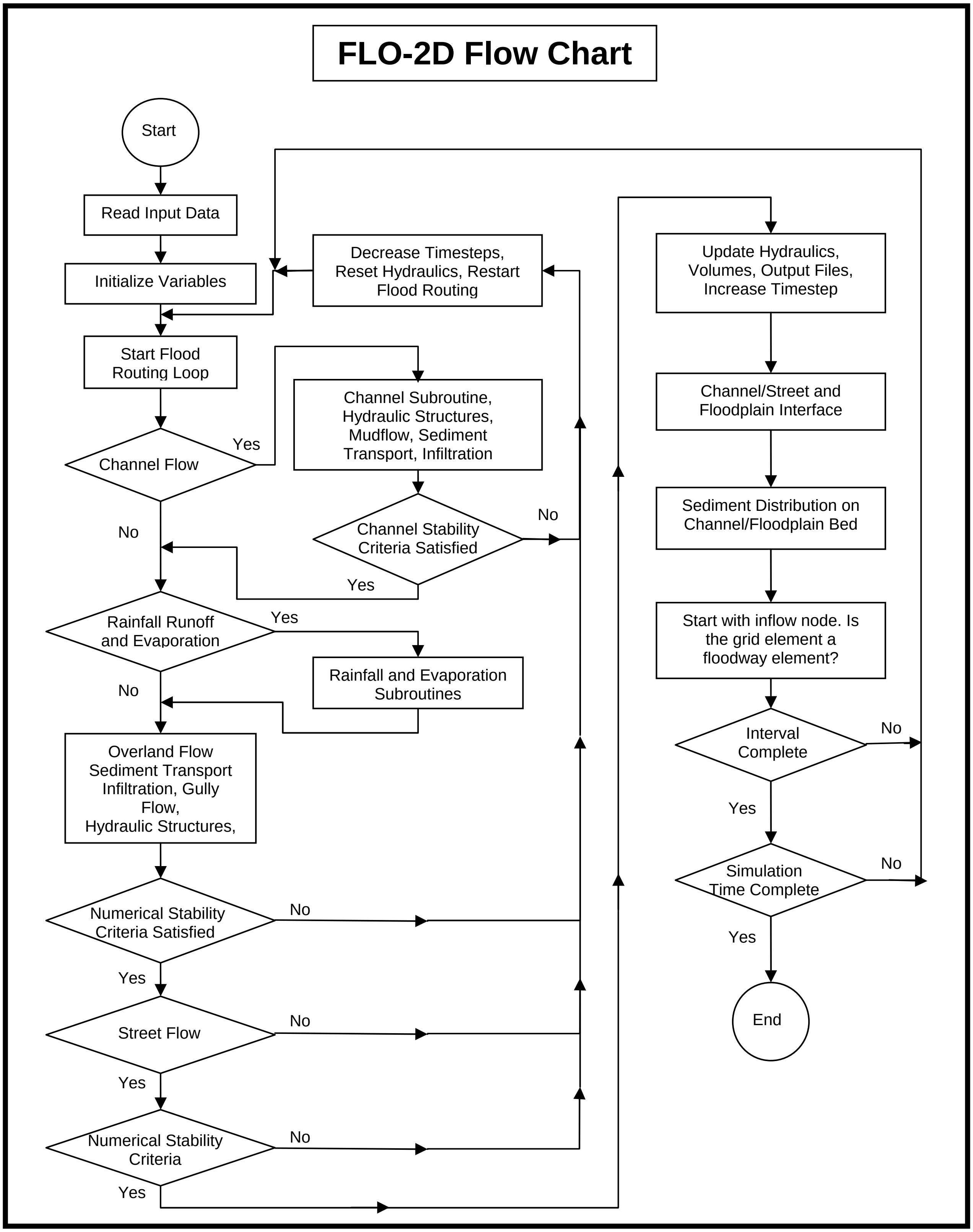

Figure 3. FLO-2D Flow Chart

II. FLO-2D MODEL THEORY

FLO-2D is a simple volume conservation model. It moves the flood volume around on a series of tiles for overland flow or through stream segments for channel routing. Floodwave progression over the flow domain is controlled by topography and resistance to flow. Flood routing in two dimensions is accomplished through a numerical integration of the equations of motion and the conservation of fluid volume for either a water flood or a hyperconcentrated sediment flow. A presentation of the governing equations is followed by a discussion on mud and debris flow modeling.

2.1 Governing Equations

The general constitutive fluid equations include the continuity equation, and the equation of motion (dynamic wave momentum equation):

$$\frac{\partial h}{\partial t} + \frac{\partial hV}{\partial x} = i$$

$$S_f = S_o - \frac{\partial h}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$$

where h is the flow depth and V is the depth-averaged velocity in one of the eight flow directions x. The excess rainfall intensity (i) may be nonzero on the flow surface. The friction slope component S_f is based on Manning's equation. The other terms include the bed slope S_o, pressure gradient and convective and local acceleration terms. This equation represents the one-dimensional depth averaged channel flow. For the floodplain, while FLO-2D is multi-direction flow model, the equations of motion in FLO-2D are applied by computing the average flow velocity across a grid element boundary one direction at time. There are eight potential flow directions, the four compass directions (north, east, south and west) and the four diagonal directions (northeast, southeast, southwest and northwest). Each velocity computation is essentially one-dimensional in nature and is solved independently of the other seven directions. The stability of this explicit numerical scheme is based on strict criteria to control the size of the variable computational timestep. The equations representing hyperconcentrated sediment flow are discussed later in the manual.

The relative magnitude of the acceleration components to the bed slope and pressure terms is important. Henderson (1966) computed the relative magnitude of momentum equation terms for a moderately steep alluvial channel and a fast rising hydrograph as follows:

	Bed Slope	Pressure Gradient	Convective Acceleration	Local Acceleration
Momentum Equation Term:	S_o	$\partial h/\partial x$	$V\partial V/g\partial x$	$\partial V/g\partial t$
Magnitude (ft/mi)	26	0.5	0.12 - 0.25	0.05

This illustrates that the application of the kinematic wave ($S_o = S_f$) on moderately steep slopes with relatively steady, uniform flow is sufficient to model floodwave progression and the contribution of the pressure gradient and the acceleration terms can be neglected. The addition of the pressure gradient term to create the diffusive wave equation will enhance overland flow simulation with complex topography. The diffusive wave equation with the pressure gradient is required for floodwave attenuation and change in storage on the floodplain. The local and convective acceleration terms are important to the flood routing for flat or adverse slopes or very steep slopes or unsteady flow conditions. Only the full dynamic wave equation is applied in FLO-2D model.

2.2 Solution Algorithm - How the Model Works

The differential form of the continuity and momentum equations in the FLO-2D model is solved with a central, finite difference numerical scheme. This explicit algorithm solves the momentum equation for the flow velocity across the grid element boundary one element at a time. The solution of the differential form of the momentum equation results from a discrete representation of the equation when applied at a single point. Explicit schemes are simple to formulate but usually are limited to small timesteps by strict numerical stability criteria. Finite difference schemes can require lengthy computer runs to simulate steep rising or very slow rising floodwaves, channels with highly variable cross sections, abrupt changes in slope, split flow and ponded flow areas.

The solution domain in the FLO-2D model is discretized into uniform, square grid elements. The computational procedure for overland flow involves calculating the discharge across each of the boundaries in the eight potential flow directions (Figure 4) and begins with a linear estimate of the flow depth at the grid element boundary. The estimated boundary flow depth is an average of the flow depths in the two grid elements that will be sharing discharge in one of the eight directions. Non-linear estimates of the boundary depth were attempted in previous versions of the model, but they did not significantly improve the results. Other hydraulic parameters are also averaged between the two grid elements to compute the flow velocity including flow resistance (Manning's n-value), flow area, slope, water surface elevation and wetted perimeter. The flow velocity (dependent variable) across the boundary is computed from the solution of the momentum equation (discussed below). Using the average flow area between two elements, the discharge for each timestep is determined by multiplying the velocity times flow area.

The full dynamic wave equation is a second order, non-linear, partial differential equation. To solve the equation for the flow velocity at a grid element boundary, initially the flow velocity is calculated with the diffusive wave equation using the average water surface slope (bed slope plus pressure head gradient). This velocity is then used as a first estimate (or a seed) in the second order Newton-Raphson tangent method to determine the roots of the full dynamic wave equation (James, et. al., 1977). Manning's equation is applied to compute the friction slope. If the Newton-Raphson solution fails to converge after 3 iterations, the algorithm defaults to the diffusive wave solution.

In the full dynamic wave momentum equation, the local acceleration term is the difference in the velocity for the given flow direction over the previous timestep. The convective acceleration term is evaluated as the difference in the flow velocity across the grid element from the previous timestep. For example, the local acceleration term ($1/g*\partial V/\partial t$) for grid element 251 in the east (2) direction converts to:

$$\Delta(V_t - V_{t-1})_{251} / (g * \Delta t)$$

where V_t is the velocity in the east direction for grid element 251 at time t, V_{t-1} is the velocity at the previous timestep (t-1) in the east direction, Δt is the timestep in seconds, and g is the acceleration due to gravity. A similar construct for the convective acceleration term ($V_x/g*\partial V/\partial x$) can be made where V_2 is the velocity in the east direction and V_4 is the velocity in the west direction for grid element 251:

$$V_2 * \Delta(V_2 - V_4)_{251} / (g * \Delta x)$$

The discharge across the grid element boundary is computed by multiplying the velocity times the cross sectional flow area. After the discharge is computed for all eight directions, the net change in discharge (sum of the discharge in the eight flow directions) in or out of the grid element is multiplied by the timestep to determine the net change in the grid element water volume (see Figure 4). This net change in volume is then divided by the available surface area (A_{surf} = storage area) on the grid element to obtain the increase or decrease in flow depth Δh for the timestep. The channel routing integration is performed essentially the same way except that the flow depth is a function of the channel cross section geometry and there are usually only one upstream and one downstream channel grid element for sharing discharge.

$$\sum Q_x^{i+1} = Q_n + Q_e + Q_s + Q_w + Q_{ne} + Q_{se} + Q_{sw} + Q_{nw} = A_{surf}\ \Delta h/\Delta t$$

where: Q_x = discharge across one boundary
A_{surf} = surface area of one grid element
$\Delta h/\Delta t$ = change in flow depth in a grid element during one timestep

To summarize, the solution algorithm incorporates the following steps:

1. The average flow geometry, roughness and slope between two grid elements are computed.
2. The flow depth d_x for computing the velocity across a grid boundary for the next timestep (i+1) is estimated from the previous timestep i using a linear estimate (the average depth between two elements).

$$d_x^{i+1} = d_x^i + d_{x+1}^i$$

3. The first estimate of the velocity is computed using the diffusive wave equation. The only unknown variable in the diffusive wave equation is the velocity for overland, channel or street flow.
4. The predicted diffusive wave velocity for the current timestep is used as a seed in the Newton-Raphson solution to solve the full dynamic wave equation for the solution velocity. It should be noted that for hyperconcentrated sediment flows such as mud and debris flows, the velocity calculations include the additional viscous and yield stress terms.
5. The discharge Q across the boundary is computed by multiplying the velocity by the cross sectional flow area. For overland flow, the flow width is adjusted by the width reduction factors (WRFs).
6. The incremental discharge for the timestep across the eight boundaries (or upstream and downstream channel elements) are summed,

$$\Delta Q_x^{i+1} = Q_n + Q_e + Q_s + Q_w + Q_{ne} + Q_{se} + Q_{sw} + Q_{nw}$$

   and the change in volume (net discharge x timestep) is distributed over the available storage area within the grid or channel element to determine an incremental increase in the flow depth.
   where ΔQ_x is the net change in discharge in the eight floodplain directions for the grid element for the

$$\Delta d_x^{i+1} = \Delta Q_x^{i+1} \Delta t / A_{surf}$$

   timestep Δt between time i and i + 1.
7. The numerical stability criteria is then checked for the new grid element flow depth. If any of the stability criteria are exceeded, the simulation time is reset to the previous simulation time, the timestep increment is reduced, all the previous timestep computations are discarded and the velocity computations begin again.
8. The simulation progresses with increasing timesteps until the stability criteria are exceeded.

In this computation sequence, the grid system inflow discharge and rainfall is computed first, then the channel flow is computed. Next, if streets are being simulated, the street discharge is computed and finally, overland flow in 8-directions is determined (Figure 5). After all the flow routing for these components has been completed, the numerical stability criteria are tested for every floodplain grid, channel or street element. If stability criteria of any element is exceeded, the timestep is reduced by various functions depending on the previous history of stability success and the computation sequence is restarted. If all the numerical stability criteria are successfully met, the timestep is increased for the next grid system computational sweep. During a sweep of the grid system for a timestep, discharge flux is added to the inflow elements, flow velocity and discharge between grid elements are computed and the change in storage volume in each grid element for both water and sediment are determined. All the inflow volume, outflow volume, change in storage or loss from the grid system area are summed at the end of each time step and the volume conservation is computed. Results are written to the output files or to the screen at user specified output time intervals.

The FLO-2D flood routing scheme proceeds on the basis that the timestep is sufficiently small to insure numerical stability (i.e. no numerical surging). The key to efficient finite difference flood routing is that numerical stability criteria limits the timestep to avoid surging and yet allows large enough timesteps to complete the simulation in a reasonable time. FLO-2D has a variable timestep that varies depending on whether the numerical stability criteria are not exceeded or not. The numerical stability criteria are checked for the every grid element on every timestep to ensure that the solution is stable. If the numerical stability criteria are exceeded, the timestep is decreased and all the previous hydraulic computations for that timestep are discarded. Most explicit schemes are subject to the Courant-Friedrich-Lewy (CFL) condition for numerical stability (Jin and Fread, 1997). The CFL condition relates the floodwave celerity to the model time and spatial increments. The physical interpretation of the CFL condition is that a particle of fluid should not travel more than one spatial increment Δx in one timestep Δt (Fletcher,1990). FLO-2D uses the CFL condition for the floodplain, channel and street routing. The timestep Δt is limited by:

$$\Delta t = C\ \Delta x\ /\ (\beta V + c)$$

where:

- C is the Courant number ($C \leq 1.0$)
- Δx is the square grid element width
- V is the computed average cross section velocity
- β is a coefficient (5/3 for a wide channel)
- c is the computed wave celerity

While the coefficient C can vary from 0.3 to 1.0 depending on the type of explicit routing algorithm, a value of 1.0 is employed in the FLO-2D model to allow the model to have the largest timestep. When C is set to 1.0, artificial or numerical diffusivity is theoretically zero for a linear convective equation (Fletcher, 1990).

For nonlinear equations, it is not possible to completely avoid the artificial diffusivity or numerical dispersion by setting C equal to 1.0 (Fletcher, 1990). For full dynamic wave routing, another set of the numerical stability criteria is applied that was developed by Ponce and Theurer (1982). This criteria is a function of bed slope, specific discharge and grid element size. It is expressed as:

$$\Delta t \ < \ \zeta\, S_o\, \Delta x^2 / q_o$$

where q_o is the unit discharge, S_o is the bed slope and ζ is an empirical coefficient. The coefficient ζ was created as a variable unique to the grid element and is adjusted by the model during runtime within a minimum and maximum range set by the user. Similar to the CFS criteria, when this numerical stability is exceeded, the hydraulic computations for that timestep are dumped and the timestep is decreased.

Before the CFL and the full dynamic wave equation numerical stability criteria are evaluated during a FLO-2D simulation, the percent change in depth from the previous timestep for a given grid element is checked. This percent change in depth is used to preclude the need for any additional numerical stability analysis. If the percent change in depth is greater than that specified by the user, the timestep is decreased and all the hydraulic computations for that timestep are voided.

Timesteps generally range from 0.1 second to 30 seconds. The model starts with the a minimum timestep equal to 1 second and increases it until one of the three numerical stability condition is exceeded, then the timestep is decreased. If the stability criteria continue to be exceeded, the timestep is decreased until a minimum timestep is reached. If the minimum timestep is not small enough to conserve volume or maintain numerical stability, then the minimum timestep can be reduced, the numerical stability coefficients can be adjusted or the input data can be modified. The timesteps are a function of the discharge flux for a given grid element and its size. Small grid elements with a steep rising hydrograph and large peak discharge require small timesteps. Accuracy is not compromised if small timesteps are used, but the computational time can be long if the grid system is large.

2.3 The Importance of Volume Conservation

A review of a model flood simulation results begins with volume conservation. Volume conservation is an indication numerical stability and accuracy. The inflow volume, outflow volume, change in storage and infiltration and evaporation losses from the grid system are summed at the end of each time step. The difference between the total inflow volume and the outflow volume plus the storage and losses is a measure of the volume conservation. Volume conservation results are written to the output files or to the screen at user specified output time intervals. Data errors, numerical instability, or poorly integrated components may cause a loss of volume conservation. Any simulation not conserving volume should be revised. It should be noted that volume conservation in any flood simulation is not exact. While some numerical error is introduced by rounding numbers, approximations or interpolations (such as with rating tables), volume should be conserved within a fraction of a percent of the inflow volume. The user must decide on an acceptable level of error in the volume conservation. Most simulations are accurate for volume conservation within a few millionths of a percent. Generally, volume conservation within 0.001 percent or less can be considerate as a successful flood simulation.

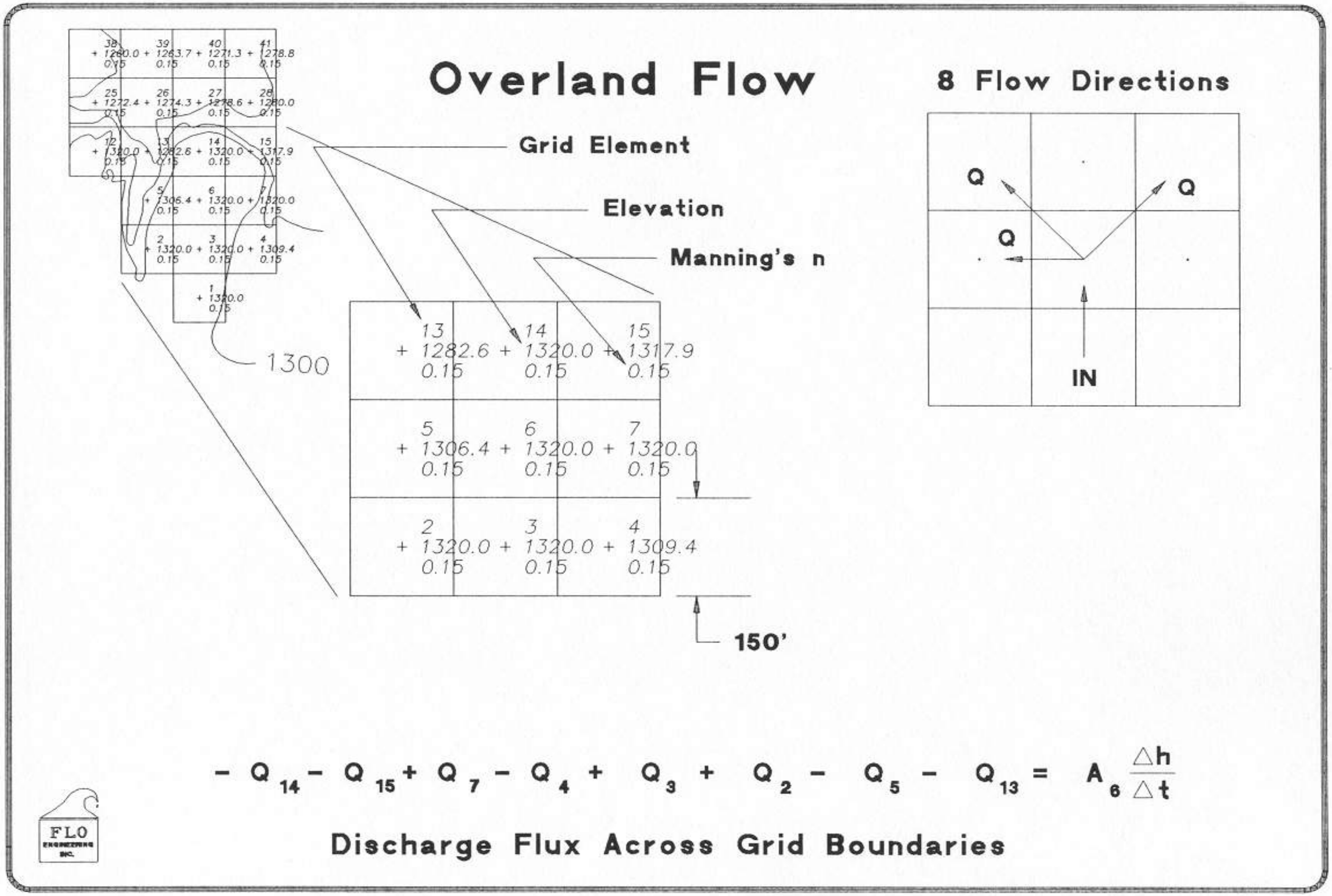

Figure 4. Discharge Flux across Grid Element Boundaries

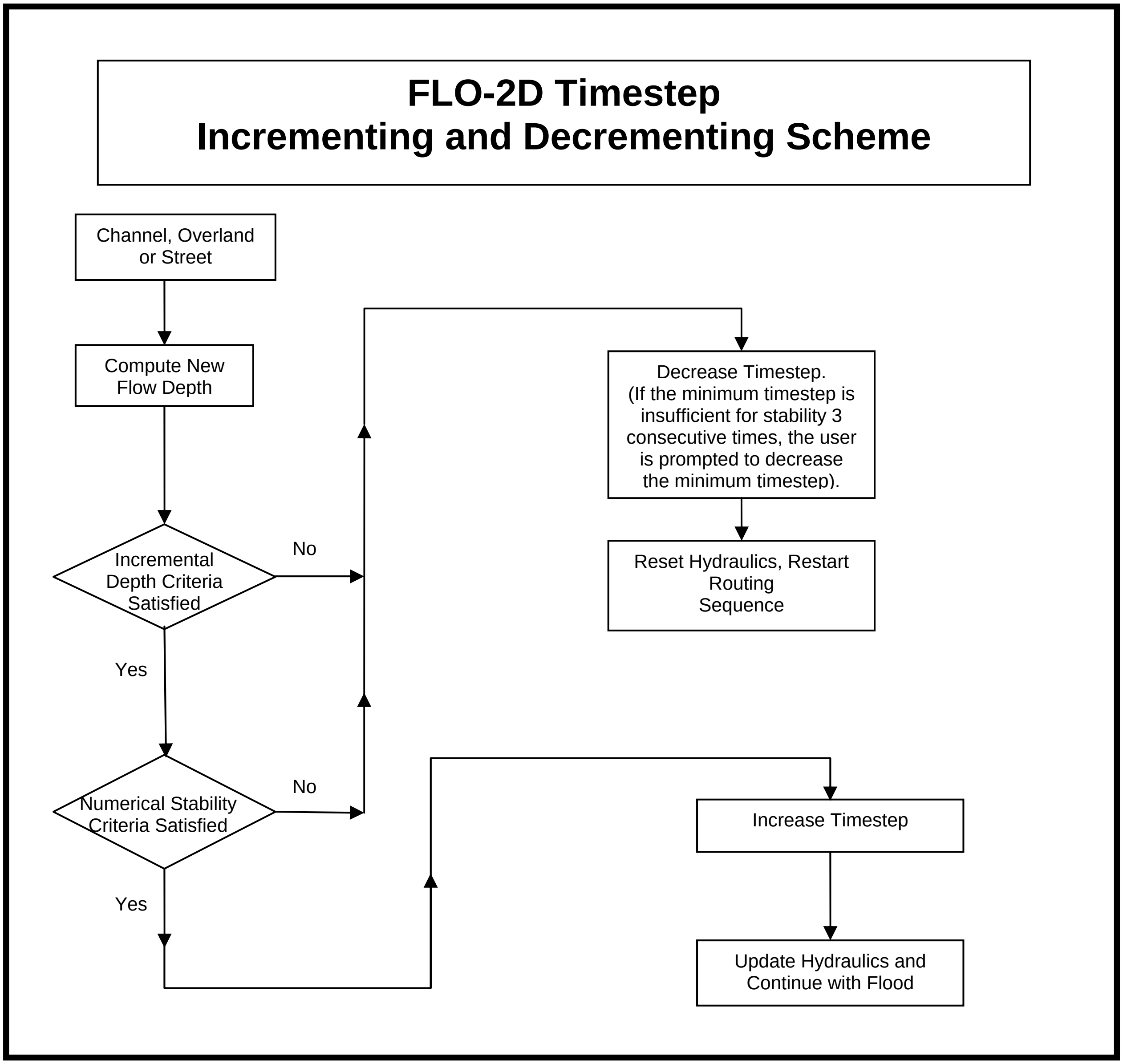

Figure 5. FLO-2D Stability Criteria Flow Chart

III. FLO-2D MODEL SYSTEM

3.1 Assumptions

Conceptualization

FLO-2D flood routing is analyzed using a volume and momentum conservation numerical scheme. The model moves around blocks of fluids on a discretized flow domain consisting of a system of tiles. FLO-2D numerically distributes the volume in finite fluid blocks to mimic the floodwave progression and timing over the discretized surface. Conceptually FLO-2D is not a Lagrangian particle dynamics model but rather a volume conservation model that moves blocks of volume around on the grid system in eight directions while controlled by numerical stability criteria.

Spatial Resolution

The spatial and temporal resolution of the FLO-2D model is dependent on the size of the grid elements and rate of rise in the hydrograph (discharge flux). The rate of change in flood discharge results in an incremental change in the flow depth when distributed over the available grid element surface area for a given timestep. Smaller grid elements may improve the resolution of the flood distribution at the cost of increased computational time, more extensive data files and boundary conditions. A balance must be struck between the number of grid elements and an acceptable computational time. A grid size of 50 ft (15 m) to 500 ft (150 m) is usually appropriate for most simulations. Smaller grid elements will not only significantly increase the number of grid elements (the number of grid elements is quadrupled each time the grid element size is divided by two), but the rate of discharge flux per unit area of the grid element increases.

FLO-2D was developed to simulate large flood events on unconfined surfaces. The discretization of the floodplain topography into a system of square grid elements to accommodate large discharges can obscure some topographic features such as mounds and depressions. This topographic variability will not affect the water surface when the entire valley is flooded. When simulating shallow flow due to steep slopes or small discharge, smaller grid elements should be used. Map resolution and accuracy should be considered when selecting the grid element size. Topographic contour resolution of plus or minus 1 ft (0.3 m) may not support grid elements less than 50 ft (15 m).

For one-dimensional channel flow, the spatial representation and variation in channel geometry is usually limited by the number of cross section surveys. Generally one cross section represents 5 to 10 grid elements. The relationship between flow area, slope and roughness can be distorted by having an insufficient number of cross section surveys. This can result in numerical surges which commonly occur in cases of abrupt channel transitions. The objective is to eliminate any discharge surges without substantially reducing the timestep so that the model runs as fast as possible. This can be accomplished by having gradual transitions between wide and narrow reaches.

Floodwave Attenuation and Discontinuities

Floodwave attenuation in the FLO-2D model occurs in response to flood storage (both channel and overbank). It is the most important feature of the FLO-2D model. Infiltration and evaporation losses can also contribute to floodwave attenuation. Floodwave attenuation represents the interaction of the friction and bed slope terms with the diffusive pressure gradient. While the application of the dynamic wave equation can reduce instabilities in the flood routing computations, rapidly varying flow is still limited by the grid element size. The model does not have the ability to simulate shock waves, rapidly varying flow or hydraulic jumps, and these discontinuities in the flow profile are smoothed out in the model’s calculations. Subcritical and supercritical flow transitions are assimilated into the average hydraulic conditions (flow depth and velocity) between two grid elements.

Simulating Ponded Water Conditions

Ponded water conditions may require special consideration. FLO-2D uses Manning's equation to assess hydraulic roughness. Manning's equation is based on uniform, fully developed turbulent flow. In a ponded water condition, the velocity profile may not represent uniform flow. Flow near the bed could be in one-direction and flow near the surface in another direction. A deep ponded water surface might have a very mild or flat slope, but using Manning's equation, high average velocities could still be computed because the velocity is a power function of the depth. It is possible to compute reasonable or accurate water surface elevations in a ponded water condition with FLO-2D, but very small timesteps must be applied. The simplest approach to forcing small timesteps is to set DEPTOL in the TOLER.DAT file to 0.10 or less.

Basic Assumptions

The inherent assumptions in a FLO-2D simulation are:

- Steady flow for the duration of the timestep;
- Hydrostatic pressure distribution;
- Hydraulic roughness is based on steady, uniform turbulent flow resistance;
- A channel element is represented by uniform channel geometry and roughness.

These assumptions are self-explanatory but they remind us that the flow conditions between grid elements are being averaged.

Rigid Bed versus Mobile Bed

When sediment transport is not simulated, a rigid bed is presumed for the flood simulation. Rigid boundary conditions are appropriate for flow over steep slopes, urban flooding and mudflow events. The area of inundation associated with extreme flood events are generally unaffected by bed changes. Channel bed changes generally deviate about a mean condition, and the portion of the flood volume stored in the channel can be small relative the volume on the floodplain. It is assumed in rigid bed simulations that the average flow hydraulics and water surface are not appreciably affected by the scour and deposition that might occur in an individual grid element. Simulating a mobile bed can be more important for smaller floods, for alluvial fan flows and where channel avulsion or sediment deposition might change the flow path.

3.2 Parameter Variability

Roughness Adjustments

For overland flow, there are two flow conditions that warrant special attention. Shallow overland flow where the flow depth is on the order of the roughness elements (>0.2 ft or 0.06 m) can be more effectively modeled by assigning the SHALLOWN parameter in the CONT.DAT file. Suggested n-values for the SHALLOWN parameter range from 0.10 to 0.20. For shallow overland flow less than 0.5 ft (0.15 m) but greater than 0.2 ft (0.06 m), 50% of the SHALLOWN n-value assigned. This roughness adjustment accounts for higher flow resistance associated with shallow flows through vegetation.

Depth variable n-values can be computed for both the channel and floodplain to control the floodwave timing. Roughness n-values to be increased for shallow flows based on the assignment of bankfull n-values for the channel and flows 3 ft (1 m) and higher for overland flooding. The ROUGHADJ variable in the CHAN.DAT file will enable the depth variable n-value adjustment for channel flow. The depth variable n-value is the default condition for floodplain flow and the AMANN variable in the CONT.DAT file will '**turn off**' this adjustment. The basic equation for the roughness n_d as function of flow depth is:

$$n_d = n_b\ r_c\ e^{-(r2\ depth/dmax)}$$

where:

n_b = bankfull discharge roughness
depth = flow depth
dmax = bankfull flow depth
r2 = roughness adjustment coefficient (fixed for overland flow)
$r_c = 1./e^{-r2}$

Ponded Water Conditions

For ponded water conditions with water surface slopes less than 0.001, Manning's open channel flow equation representing the friction slope has limited applicability. In this case, it may necessary to slow the model down by reducing the stability criteria in the TOLER.DAT file. It is recommended that you review the maximum velocities in MAXPLOT for any surging. If you have unreasonable velocities, reduce the stability criteria and/or increase n-values. The selected n-values should be in a range that represents actual flow resistance (see Table 2).

Flow Contraction and Expansion

Flow contraction and expansion between two channel elements is addressed by increasing the head loss as function of the ratio of the flow areas. The head loss coefficient is 0.0 for a ratio of 0.95 or higher. For a contraction of up to 60%, the head loss coefficient varies from 0.0 to 0.6. For flow expansion where the ratio of flows is 60% or less, the head loss coefficient varies from 0.0 to 1.0. The head loss is given by the velocity head $V^2/2g$ times the head loss coefficient and is expressed as slope between the two channel elements. The head loss reduces the available energy gradient between the channel elements. Variability of the contraction and expansion coefficient is automatically computed by the channel routing routine.

Limiting Froude Numbers

Limiting Froude numbers can be specified for overland flow, channel flow and street flow. As an introduction, limiting Froude numbers can be used to adjust the relationship between the flow area, slope and n-values. When the computed Froude number exceeds the limiting Froude number, the n-value is increased for that grid element by a small incremental value for the next timestep. In this manner, the flow can be forced to be subcritical if in reality, critical or supercritical flow is not possible. For example, in steep-slope sand bed channels, high energy flows may entrain more sediment to sustain subcritical flow. In this case, the limiting Froude number might be set to 0.9. For flow down steep streets, a maximum Froude number of 1.2 to 1.5 may be specified to limit the supercritical flow. Since FLO-2D does not simulate hydraulic jumps, the limiting Froude number should represent average flow conditions in a channel reach. During the falling limb of the hydrograph when the Froude decreases to a value less than 0.5, the flow resistance n-value decreases by a small incremental value until the original n-value is reached. The limiting Froude number will be discussed in more detail in Section 4.6.

Flood Parameter Variability

FLO-2D can simulate the many components of the hydrologic system including rainfall, infiltration, street flow, and flow through hydraulic structures. This level of detail requires a large number of variables. In terms of the channel and floodplain flood routing, the parameters having the greatest effect on the area of inundation or outflow hydrographs are as follows:

- Inflow hydrograph discharge and volume directly affect the area of inundation.
- The overland flow path is primarily a function of the topography.
- The floodplain roughness n-values range from 0.03 to 0.5 and control the overland floodwave speed.
- River channel n-values generally range from 0.020 to 0.085. Roughness adjustment will usually result in only minor variation of the water surface (~ 0.2 ft or 0.06 m).
- The relationship between the channel cross section flow area, bed slope and roughness controls the floodwave routing, attenuation and numerical stability. Flow area has the most important affect on channel routing stability. Changes in the cross section flow area between channel elements should be limited to 25% or less. More cross section surveys may be necessary to simulated rapidly changing flow geometry. Constructed rapid transitions in channel geometry can be modeled, but will require smaller timesteps and more channel detail.
- Floodplain storage loss (ARF values) due to buildings, trees or topography can be globally assigned for the entire grid system using the XARF parameter in the CONT.DAT file. Typically, an XARF value of 5% to 10% can be used to represent a small loss of storage over the entire grid system.
- Most watershed and alluvial fan flooding should be bulked for sediment loading. If the sediment loading will be relatively minor, the XCONC factor in the CONT.DAT file can be used to uniformly bulk all the inflow hydrograph volumes. Typically, watershed flooding that will not generate mudflows can be conservatively bulked using an XCONC value of 10% to 15% by volume. River flood sediment concentration will rarely exceed 5% by volume and setting XCONC = 5% will conservatively bulk the inflow hydrograph volume by 1.05. Mudflow should be simulated by assigning concentrations by volume to the inflow hydrographs and the XCONC factor should not be used.

3.3 Inflow and Outflow Control

A discretized flood hydrograph from an upstream basin can be inflow either to the floodplain, channel or both. More than one grid element can have an inflow hydrograph. Hydrographs can be assigned as either direct inflow or outflow (diversions) from a channel. This could be a simple constant diversion of 100 cfs or a variable hydrograph over the course of the simulation. If mudflows are being simulating then a volumetric sediment concentration or sediment volume must be assigned to each water discharge increment.

For flow out of the grid system, outflow grid elements must be specified for either the floodplain or channel or both. The discharge from outflow elements is equal to sum of the inflows and a flow depth is then assigned to the outflow element based on a weighted average of the upstream flow depths. In this manner, normal flow is approximated at the outflow element. The outflow discharge is totally removed from the system and is accounted to the outflow volume. It is possible to specify outflow from elements that are not on the boundary of the grid system, but outflow elements should be treated as sinks (all the inflow to them is lost from the flow system). Outflow elements should not be modified with ARF's or WRF's, levees, streets, etc. Channel outflow can also be established by a stage-discharge. This option can be used when channel outflow occurs at a hydraulic structure or when a known discharge relationship is available.

Stage-time relationships can be specified for either the floodplain or channel. These relationships can be assigned for outflow elements or for any elements in the system. When a stage-time relationship is specified, volume conservation is accounted for when the discharge enters or leaves the stage-time designed grid element. Stage-time relationships provide opportunity to simulate coastal flooding related to ocean storm surge, hurricane surges or tsunamis (Figure 6). In addition, the backwater effects of tidal variation on river and estuary flooding can be model.

Figure 6. Overland Tsunami Wave Progression in an Urban Area (Waikiki Beach, Hawaii)

3.4 Floodplain Cross Sections

A floodplain cross section analysis can be conducted by specifying grid elements in a cross section in the FPXSEC.DAT file. The grid elements must be contiguous and in a straight line to constitute a cross section across a floodplain or alluvial fan. By designating one or more cross sections, the user can track floodwave attenuation across unconfined surfaces. Both the flood hydrograph and flow hydraulics can be analyzed at cross sections. The average cross section hydraulics as well as the individual grid element hydraulics in the cross section are summarized in cross section output files.

3.5 Graphical User Interface

A graphical user interface (GUI) facilitates the data input. The GUI creates the ASCII text files used by the FLO-2D model. Specific instructions for the GUI are presented in the Data Input Manual. The GUI is series of forms that represent the individual FLO-2D data files. Each form consists of data dialog boxes, radio switch buttons or grid entry tables. After the data is entered in the GUI dialog boxes, the resulting ASCII text file can be viewed from the GUI or from any other ASCII editor such as MS WordPad®. You can run the model or any of the processor programs from the GUI, but the model doesn't need the GUI to run a simulation.

3.6 Grid Developer System (GDS)

The Grid Developer System (GDS) create and edit the FLO-2D grid system and data files and provides a platform for running the other pre- and post-processor programs. The GDS is a pre-processor program that will overlay the grid system on the DTM points, interpolate and assign elevations to the grid elements. The GDS will then automatically prepare the basic input files for the FLO-2D model. Geo-referenced aerial photos, shape file images or maps can be imported as background images to support the graphical editing.

In addition to developing the FLO-2D grid system, the GDS also provides important editorial features including the assignment of spatially variable grid element attributes such channels, levees, streets, infiltration, area and width reduction factors, floodplain elevation and roughness, inflow and outflow nodes and rill and gully geometry. It allows selection of individual elements or large groups of node using the mouse. Rainfall can also be spatially varied. Detailed instructions are presented in the GDS Manual.

3.7 Graphical Output Options

A graphical display of the flow depths can be viewed on the screen during a FLO-2D simulation to visualize the progression of the floodwave over the potential flow surface. In addition to the predicted flow depths, an inflow hydrograph will be plotted. For rainfall simulation, the cumulative precipitation can also be plotted. The grid element results for floodplain, channel and street flow can be reviewed in a post-processor program MAXPLOT or flood contours can be generated in MAPPER.

Graphical displays are provided in the HYDROG, PROFILES and MAPPER post-processor programs. HYDROG will plot the hydrograph for every channel element. HYDROG can also be used to evaluate the average channel hydraulics in a given reach. The user can select the upstream and downstream channel elements and the program will compute the average of the hydraulics for all the channel elements in the reach including: velocity, depth, discharge, flow area, hydraulic radius, wetted perimeter, top width, width to depth ratio, energy slope, and bed shear stress. The PROFILES program plots channel water surface and bed slopes.

MAPPPER is the primary program for displaying the FLO-2D results. It can create high resolution color contour plots. Several map combinations can be created: grid element or DTM point plots, line contour maps and shaded contour maps. Maps can be created for ground surface elevations, maximum water surface elevations, maximum floodplain flow depths, maximum velocities, maximum static and dynamic pressure, specific energy, and floodway delineation. One of the most important features of MAPPER is its capability to create flood depth plots using the DTM topographic points. When the user activates the feature, MAPPER will subtract each DTM ground point elevation from the grid element floodplain water surface elevation. The resultant DTM point flow depths can then be interpolated and plotted as color contours. Some of the MAPPER features include:

- Multiple geo-referenced aerial photos in various graphic formats can be imported such as TIFF, BMP, JPG, etc.
- Multiple layer capability including control of layer properties is available.
- Cut and view flow depth and topography profiles.
- Flood damage assessment component to compute the flood damage as function of the FLO-2D predicted maximum depths, building shape files and building value tables (dbf file).
- Flood animation. The floodwave progression over the grid system can be viewed.
- Flood maximum deposition and scour can be plotted.
- Maximum flow velocity vectors can be viewed.
- Hazard maps based on flood intensity and frequency can be created.
- GIS shape files (*.shp) are automatically created with any plotted results. This GIS shape files can be then be imported into ArcView or other GIS programs.
- FEMA Digital Flood Insurance Rate Map (DFIRM) optional tool.

The MAPPER features and functions are described in its own manual.

3.8 Data Output Options

The FLO-2D model has a number of output files to help the user organize the results. Floodplain, channel and street hydraulics are written to file. Hydraulic data include water surface elevation, flow depth and velocities in the eight flow directions. Discharge for specified output intervals (hydrographs) are written to various files. A mass conservation summary table comparing the inflow, outflow and storage in the system is presented in the SUMMARY.OUT file. A complete description of all the output files are presented in the Data Input Manual.

IV. MODEL COMPONENTS

4.1 Model Features

The primary features of the FLO-2D model are:

- Floodwave attenuation can be analyzed with hydrograph routing.
- Overland flow on unconfined surfaces is modeled in eight directions.
- Floodplain flows can be simulated over complex topography and roughness including split flow, shallow flow and flow in multiple channels.
- Channel, street and overland flow and the flow exchange between them can be simulated.
- Channel flow is routed with either a rectangular or trapezoidal geometry or natural cross section data.
- Streets are modeled as shallow rectangular channels.
- The flow regime can vary between subcritical and supercritical.
- Flow over adverse slopes and backwater effects can be simulated.
- Rainfall, infiltration losses and runoff on the alluvial fan or floodplain can be modeled.
- Viscous mudflows can be simulated.
- The effects of flow obstructions such as buildings, walls and levees that limit storage or modify flow paths can be modeled.
- The outflow from bridges and culverts is estimated by user defined rating curves.
- The number of grid and channel elements and most array components is unlimited.

Data file preparation and computer run times vary according to the number and size of the grid elements, the inflow discharge flux and the duration of the inflow flood hydrograph being simulated. Most flood simulations can be accurately performed with square grid elements ranging from 100 ft (30 m) to 500 ft (150 m). Projects have been undertaken with grid elements as small as 10 ft (3 m), although models with grid elements this small tend to be slow. It is important to balance the project detail and the number of model components applied with the mapping resolution and anticipated level of accuracy in the results. It is often more valuable from a project perspective to have a model that runs quickly enabling many simulation scenarios to be performed from which the user can learn about how the project responds to flooding. Model component selection should focus on those physical features that will significantly effect the volume distribution and area of inundation. A brief description of the FLO-2D components follows.

4.2 Overland Flow

The simplest FLO-2D model is overland flow on an alluvial fan or floodplain. The floodplain element attributes can be modified to add detail to the predicted area of inundation. The surface storage area or flow path on grid elements can be adjusted for buildings or other obstructions. Using the area reduction factors (ARFs), a grid element can be completely removed from receiving any inflow. Any of the eight flow directions can be partially or completely blocked to represent flow obstruction. The area of inundation can also be affected by levees, channel breakout flows, flow constriction at bridges and culverts, or street flow in urban areas. Rainfall and infiltration losses can add or subtract from the flow volume on the floodplain surface. These overland flow components are shown in a computational flow chart in Figure 7.

Overland flow velocities and depths vary with topography and the grid element roughness. Spatial variation in floodplain roughness can be assigned through the GDS or FLOENVIR processor. The assignment of overland flow roughness must account for vegetation, surface irregularity, non-uniform and unsteady flow. It is also a function of flow depth. Typical roughness values (Manning's n coefficients) for overland flow are shown in Table 1.

Table 1. Overland Flow Manning's n Roughness Values[1]

Surface	n-value
Dense turf	0.17 - 0.80
Bermuda and dense grass, dense vegetation	0.17 - 0.48
Shrubs and forest litter, pasture	0.30 - 0.40
Average grass cover	0.20 - 0.40
Poor grass cover on rough surface	0.20 - 0.30
Short prairie grass	0.10 - 0.20
Sparse vegetation	0.05 - 0.13
Sparse rangeland with debris	
0% cover	0.09 - 0.34
20 % cover	0.05 - 0.25
Plowed or tilled fields	
Fallow - no residue	0.008 - 0.012
Conventional tillage	0.06 - 0.22
Chisel plow	0.06 - 0.16
Fall disking	0.30 - 0.50
No till - no residue	0.04 - 0.10
No till (20 - 40% residue cover)	0.07 - 0.17
No till (60 - 100% residue cover)	0.17 - 0.47
Open ground with debris	0.10 - 0.20
Shallow glow on asphalt or concrete (0.25" to 1.0")	0.10 - 0.15
Fallow fields	0.08 - 0.12
Open ground, no debris	0.04 - 0.10
Asphalt or concrete	0.02 - 0.05

[1]Adapted from COE, HEC-1 Manual, 1990 and the COE, Technical Engineering and Design Guide, No. 19, 1997 with modifications.

Some FLO-2D projects have been model grid elements inside of the channel. In this case, the channel component is not used and instead the FLO-2D grid system is draped over the channel portion of the topography. While these projects have been conducted with some success, there are several modeling concerns that should be addressed. The FLO-2D model was developed to be able to exchange 1-D channel overbank discharge with the floodplain grid elements. For this reason, the model works well on large flood events and large grid elements. When small grid elements are used inside of a channel with confined flow and large discharges and flow depths, the model may run slow. In addition, there will be zero water surface slope between some grid elements. It should be noted that the application of the Manning's equation for uniform channel to compute the friction slope is no longer valid as the velocity approaches zero (ponded flow condition). The resulting water surface elevations can be accurately predicted but will display some small variation across the channel.

For overland flow, the specific energy, impact pressure and static pressure are computed and reported to file on an output interval basis. The specific energy is computed by adding the flow depth velocity head ($V^2/2g$) to the flow depth. The maximum specific energy is reported to the file SPECENERGY.OUT by grid element. You can use MAPPER to plot the specific energy contours.

The impact pressure P_i for a floodplain grid element is reported as a force per unit length (impact pressure x flow depth). The user can then multiply the impact pressure by the structure length within the grid element to get a maximum impact force on the structure. Impact force is a function of fluid density, structure materials, angle of impact, and a number of other variables. To conservatively estimate the impact pressure, the equation for water taken from Deng (1996):

$$P_i = k \rho_f V^2$$

where P_i is the impact pressure, coefficient k is 1.28 for both both English and SI units, ρ_f = water density and V is the maximum velocity regardless of direction. For hyperconcentrated sediment flows such as mud floods and mudflows, the fluid density ρ_f and coefficient k is a function of sediment concentration by volume. The coefficient k is based on a regressed relationship as a function of sediment concentration from the data presented in Deng (1996). This relationship is given by,

$$k = 1.261\ e^{Cw}$$

where Cw = sediment concentration by weight. The impact pressure is reported in the file IMPACT.OUT.

The static pressure P_s for each grid element is also expressed as a force per unit length. It is given by the maximum flow depth to the center of gravity $\hat{h}$ times the specific weight of the fluid. The static pressure is then multiplied by the flow depth to compute the static force per unit length of structure (assumes surface area A = l x d). The maximum static pressure is written to the STATICPRESS.OUT file.

$$P_s = \gamma\ \hat{h}$$

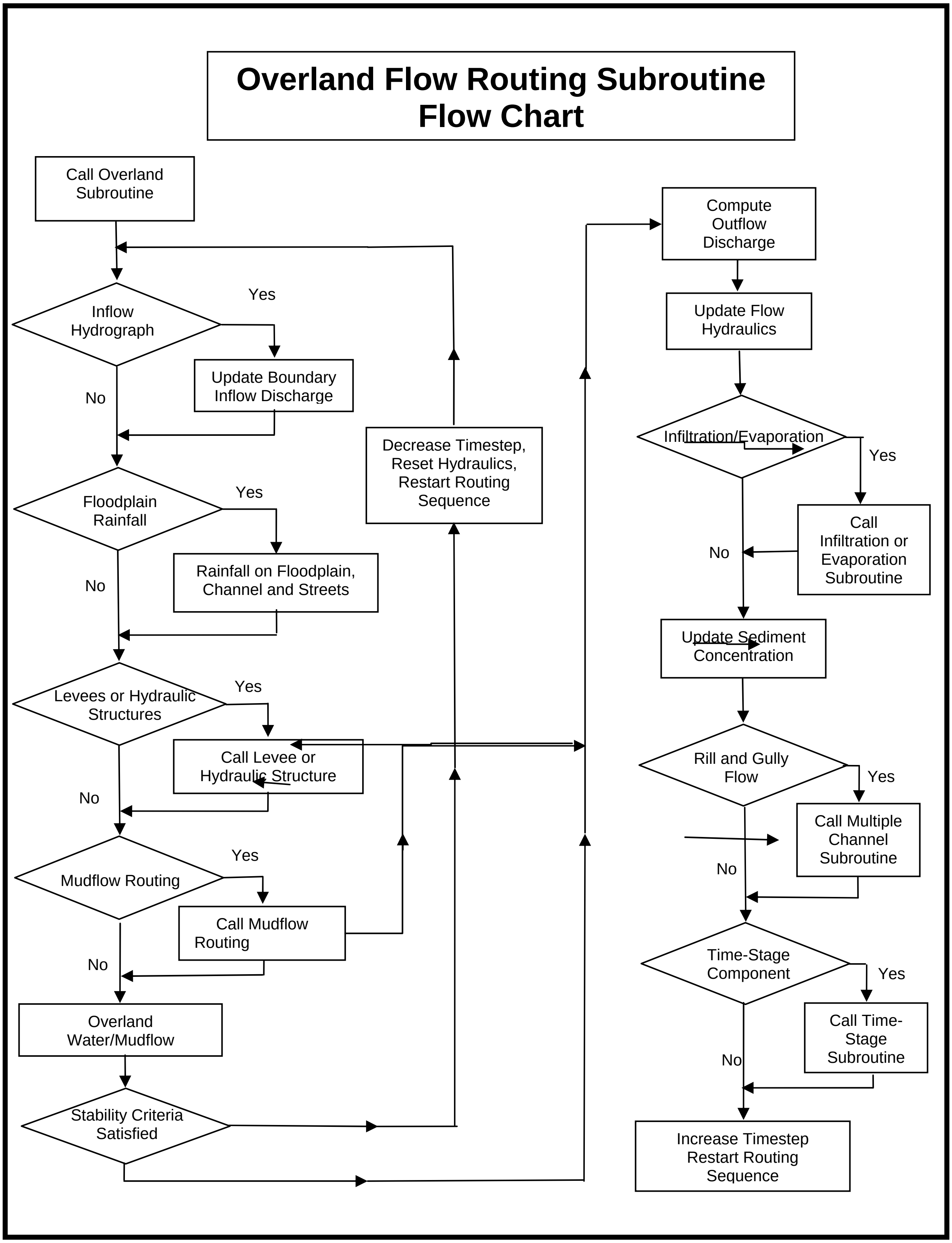

Figure 7. Overland Flow Routing Subroutine Flow Chart

4.3 Channel Flow

Flow in channels is simulated as one-dimensionally. Average flow hydraulics of velocity and depth define the discharge between channel grid elements. Secondary currents, dispersion and superelevation in channel bends are not modeled with the 1-D channel component. The governing equations of continuity and momentum were present in Section 2.1. The average flow path length between two channel elements is on the order of the length of the grid element and this precludes the simulation of hydraulic jumps over a short distance. The flow transition between subcritical and supercritical flow is based on the average conditions between two channel elements.

River channel flow is simulated with either rectangular or trapezoidal or surveyed cross sections and is routed with the dynamic wave approximation to the momentum equation. The channels are represented in the CHAN.DAT by a grid element, cross section geometry that defines the relationship between the thalweg elevation and the bank elevations, average cross section roughness, and the length of channel within the grid element. Channel slope is computed as the difference between the channel element thalweg elevation divided by the half the sum of the channel lengths within the channel elements. Channel elements must be contiguous to be able to share discharge.

The channel width can be larger than the grid element and may encompass several elements (Figure 9). If the channel width is greater than the grid element width, the model extends the channel into neighboring grid elements. A channel may be 1000 ft (300 m) wide and the grid element only 300 ft (100 m) square. The model also makes sure that there is sufficient floodplain surface area after extension. The channel interacts with the right and left bank floodplain elements to share discharge. Each bank can have a unique elevation. If the two bank elevations are different in the CHAN.DAT file, the model automatically splits the channel into two elements even if the channel would fit into one grid element.

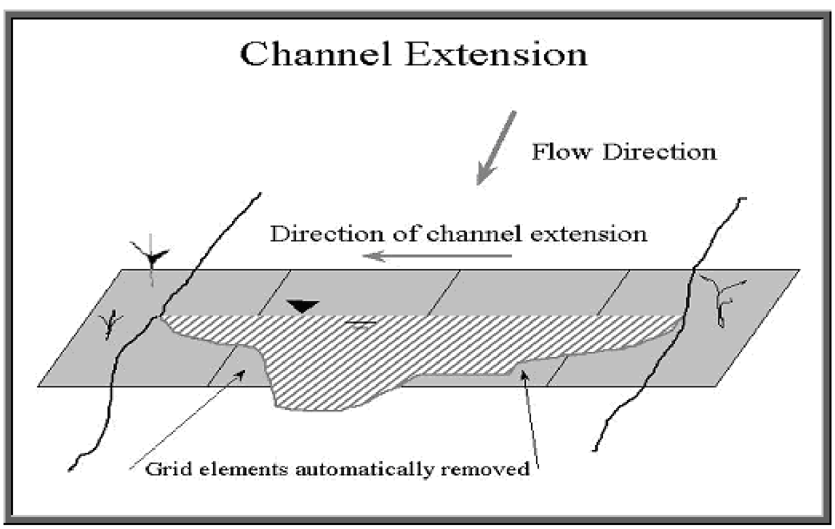

Figure 9. Channel Extension over Several Grid Elements

There are two options for establishing the bank elevation in relationship to the channel bed elevation (thalweg) and the floodplain elevation in the CHAN.DAT file:

1. The channel grid element bed elevation is determined by subtracting the assigned channel thalweg depth from the floodplain elevation.
2. A bank elevation is assigned in the CHAN.DAT file and the channel bed elevation is computed by subtracting the thalweg depth from the lowest bank elevation.

When using cross section data for the channel geometry, option 2 should be applied.

In river simulations, the important components include channel routing, the channel-floodplain interaction, hydraulic structures and levees. These components are described in more detail in the following sections. The basic procedure for creating a FLO-2D river simulation is as follows:

Select Channel Cross Sections. Surveyed river cross sections should be spaced to represent a uniform river reach that may encompass a number of channel elements, say 5 to 10 elements. Geo-referenced surveyed cross section station and elevation data can be entered directly into the model data files or the data can be defined by setting the highest bank to an arbitrary elevation. For channel design purposes, a rectangular or trapezoidal cross section may be selected. To use surveyed cross section data, an XSEC.DAT file has to be created with all cross section station and elevation data. The cross sections are then assigned to a channel element in the CHAN.DAT. The relationship between the flow depth and channel geometry (flow area and wetted perimeter) is based on an interpolation of depth and flow area between vertical slices that constitute a channel geometry rating table for each cross section.

Locate the Channel Element with Respect to the Grid System. Using the GDS and an aerial photo, the channels can be assigned to a grid element. For channel flow to occur through a reach of river, the channel elements must be neighbors.

Adjust the Channel Bed Slope and Interpolate the Cross Sections. Each channel element is assigned a cross section in the CHAN.DAT file. Typically, there are only a few cross sections and many channel elements, so each cross section will be assigned to several channel elements. When the cross sections have all been assigned the channel profile looks like a stair case because the channel elements with the same cross section have identical bed elevations. The channel slope and cross section shape can then be interpolated by using a command in the GDS or in the PROFILES program that adjusts and assigns a cross section with a linear bed slope for each channel element. The interpolated cross section is a weighted flow area adjustment of the cross section to achieve a more uniform rate of change in the flow area.

The user has several other options for setting up the channel data file including grouping the channel elements into segments, specifying initial flow depths, identifying contiguous channel elements that do not share discharge, assigning limiting Froude numbers and depth variable n-value adjustments.

IMPORTANT NOTE: Manning's equation is an empirical formula that was developed on the basis of laboratory and field measurements on steady, uniform, fully developed turbulent flow. Its application, however has become universal for all flow conditions. In a FLO-2D flood simulation the flow is neither steady nor uniform. Channel backwater and ponded flow conditions are two instances when Manning's equation may not be appropriate. The flow resistance should be represented by a composite n-value that includes adjustments to the basic n value for bed irregularities, obstructions, vegetation, variation in channel geometry, channel expansion and contraction, potential rapidly varying flow and variable river planform. Poor selection of n-values or failure to provide spatial variation in roughness can result in numerical surging. Avoid using n-values for natural channels that represent prismatic channel flow.

4.4 Channel-Floodplain Interface

Channel flow is exchanged with the floodplain grid elements in a separate routine after the channel, street and floodplain flow subroutines have been completed. When the channel conveyance capacity is exceeded, an overbank discharge is computed. If the channel flow is less than bankfull discharge and there is no flow on the floodplain, then the channel-floodplain interface routine is not accessed. The channel-floodplain flow exchange is limited by the available exchange volume in the channel or by the available storage volume on the floodplain. The interface routine is internal to the model and there are no data requirements for its application. This subroutine also computes the flow exchange between the street and the floodplain.

The channel-floodplain exchange is computed for each channel bank element and is based on the potential water surface elevation difference between the channel and the floodplain grid element containing either channel bank (Figure 2). The computed velocity of either the outflow from the channel or the return flow to the channel is computed using the diffusive wave momentum equation. It is assumed that the overbank flow velocity is relatively small and thus the acceleration terms are negligible. The channel bank elevation is established by the surveyed channel geometry and the channel water surface and floodplain water surface is known in relationship to the channel top of bank. For return flow to the channel, if the channel water surface is less than the bank elevation, the bank elevation is used to compute the return flow velocity. Overbank discharge or return flow to the channel is computed using the floodplain assigned roughness. The overland flow can enter a previously dry channel.

4.5 Limiting Froude Numbers

The Froude number represents several physical implications; it delineates subcritical and supercritical flow, it is the ratio of average flow velocity to shallow wave celerity and it relates the movement of a translational wave to the stream flow. Jia (1990) suggested that the trend towards the minimum Froude number is a mechanism that controls the channel adjustment. An alluvial channel system tends to lower its potential energy and attain higher stability as it evolves. This indicates that the greater the bed material movement, the lower the channel stability. It follows therefore that a channel with low bed material movement and high stability will also have minimum hydraulic values. As alluvial channels approach equilibrium conditions, the Froude number will seek a minimum value to reflect minimum bed material motion and maximum channel stability. Since the Froude number identifies a hydraulic state, the most stable condition for sand-bed channel equilibrium may be directly related to a minimum Froude number (Jia, 1990).

Establishing a limiting Froude number in a flood routing model can help sustain the numerical stability. In alluvial channels, the practical range of Froude numbers at bankfull discharge is 0.4 to 0.6. Overland flow on steep alluvial fans can approach critical flow (a Froude number of 1.0). In general, supercritical flow on alluvial fans is suppressed by high rates of sediment transport. High velocities and shallow depths on alluvial surfaces will dissipate energy with sediment entrainment. Supercritical flow is more prevalent on hard surfaces such as bedrock. Jia (1990) provides a relationship to estimate a minimum Froude number (Fr_{min}) for stable alluvial channels at equilibrium:

$$Fr_{(min)} = 4.49\, d^{-0.186}\, (VS)^{0.377}$$

where d = representative sediment size, V = velocity and S = bed slope.

When a limiting Froude is assigned for either floodplain flow (FROUDL in CONT.DAT), street flow (STRFNO in STREET.DAT) or channel flow (FROUDC in CHAN.DAT), the model computes the grid element flow direction Froude number for each timestep. If the limiting Froude number is exceeded, the Manning's n-value for hydraulic flow resistance is increased according to the following criteria.

Percent change from the original n-value	n-value increment increase
< 0.20	0.0002
0.20 < % < 0.50	0.0001
0.50 < % < 1.00	0.00002
1.00 < % < 2.00	0.000002

On the recessional limb, when the limiting Froude number is not exceeded the n-value is decreased by 0.0001. This increase in flow resistance mimics increasing energy loss as the flow accelerates. When the limiting Froude is exceeded, the changes in the n-value are reported in the ROUGH.OUT file. When the simulation is finished the maximum n-values in the ROUGH.OUT file are written to FPLAIN.RGH, CHAN.RGH or STREET.RGH depending on the component utilized. After reviewing the maximum n-value changes in ROUGH.OUT and making any necessary changes in the *.RGH files, these files can be renamed to *.DAT for the next simulation. In this manner, you are spatially calibrating the channel, street and floodplain roughness to a reasonable Froude number.

There is a unique relationship that exists between slope, flow area and roughness. If fact, the Froude number (Fr) is related to the flow resistance K and the energy slope S as given by:

$$Fr = (KS)^{0.5}$$

If there is a mismatch between these physical variables in a flood routing model, then high velocities can occur that may result in flow surging. Assigning a limiting Froude number has several practical advantages. First, it helps to maintain the average flow velocity within a reasonable range. Secondly, a review of the increased n-values in ROUGH.OUT will identify any trouble spots where the velocity exceeds a reasonable value. In this case, the roughness value is increased to offset an inappropriate flow area and slope relationship. When the adjusted n-values in CHAN.RGH and FPLAIN.RGH are used for the next simulation, the effect of the mismatched variables is reduced and numerical surging is dampened. In addition, the increased n-values can prevent oversteepening of the frontal wave. As is the case for any routing model, the best estimate of parameters are not only dependant on the calibration method, but also are governed by the uniqueness and stability of the optimization process. The final n-values used in a simulation should be carefully reviewed for reasonableness. The limiting Froude numbers can be set to "0" for the final simulation to avoid any additional adjustments in the n-values.

4.6 Levees

The FLO-2D levee component confines flow on the floodplain surface by blocking one of the eight flow directions. Levees are designated at the grid element boundaries (Figure 9). If a levee runs through the center of a grid element, the model levee position is represented by one or more of the eight grid element boundaries. Levees often follow the boundaries along a series of consecutive elements. A levee crest elevation can be assigned for each of the eight flow directions in a given grid element. The model will predict levee overtopping. When the flow depth exceeds the levee height, the discharge over the levee is computed using the broadcrested weir flow equation with a 2.85 coefficient. Weir flow occurs until the tailwater depth is 85% of the headwater depth and then at higher flows, the water is exchanged across the levees using the difference in water surface elevation. Levee overtopping will not cause levee failure unless the failure or breach option is invoked.

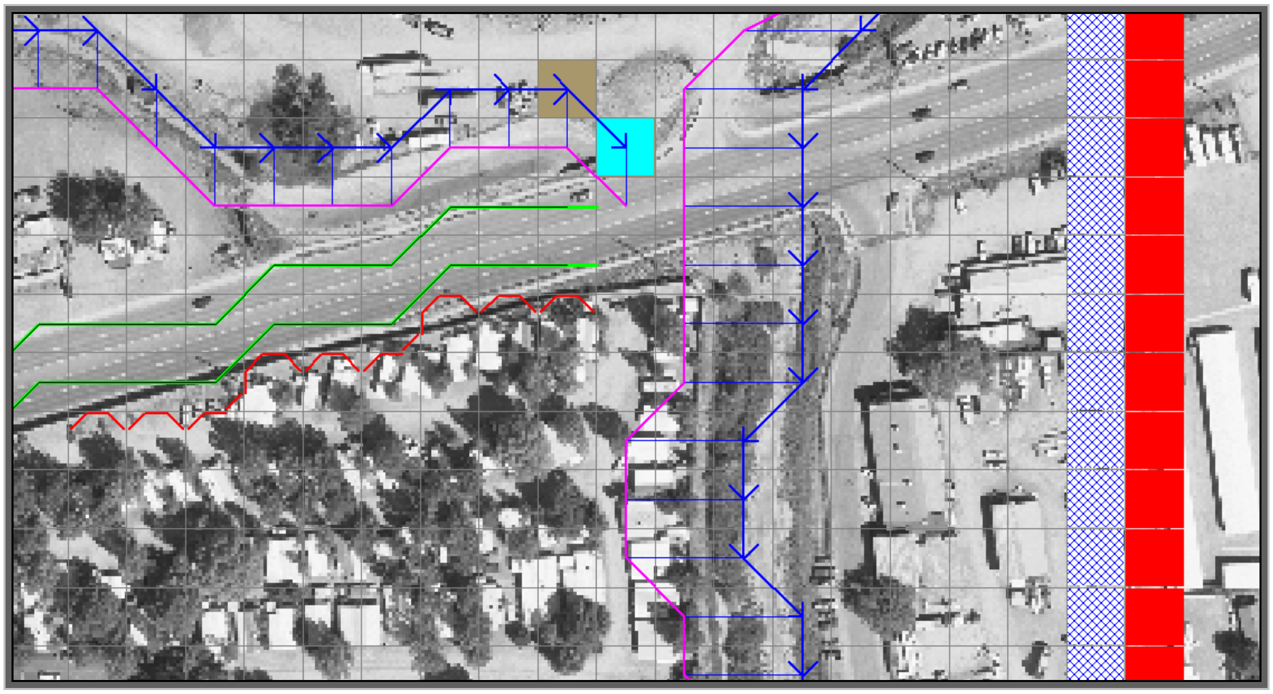

Figure 9. Levees are depicted in Red and the River in Blue in the GDS Program

The levee output files include LEVEE.OUT, LEVOVERTOP.OUT and LEVEEDEFIC.OUT. LEVEE.OUT contains the levee elements that failed. Failure width, failure elevation, discharge from the levee breach and the time of failure occurrence are listed. A discharge hydrograph overtopping the levee element is reported in LEVOVERTOP.OUT. The discharge is combined for all the levee directions that are being overtopped. Finally the LEVEEDIFIC.OUT file lists the levee elements with loss of freeboard during the flood event. Five levels of freeboard deficit are reported:

0 = freeboard > 3 ft (0.9 m)

1 = 2 ft (0.6 m) < freeboard < 3 ft (0.9 m)

2 = 1 ft (0.3 m) < freeboard < 2 ft (0.6 m)

3 = freeboard < 1 ft (0.3 m)

4 = levee is overtopped by flow.

The levee deficit can be displayed graphically in both MAXPLOT and MAPPER.

Figure 10. Levee Freeboard Deficit Plot in Mapper

4.7 Levee and Dam Breach Failures

FLO-2D can simulate levee and dam breach failures (Figures 11 and 12). There are two failure modes; one is a simple uniform rate of breach expansion and the other predicts the breach erosion. For both cases, the breach timestep is controlled by the flood routing model. FLO-2D computes the discharge through the breach, the change in upstream storage, the tailwater and backwater effects, and the downstream flood routing. Each failure option generates a series of output files to assist the user in analyzing the response to the dam or levee breach. The model reports of the time of breach or overtopping, the breach hydrograph, peak discharge through the breach, and breach parameters as a function of time. Additional output files that define the breach hazard include the time-to-flow-depth output files that report the time to the maximum flow depth, the time to one foot flow depth and time to two foot flow depth which are useful for delineating evacuation routes.

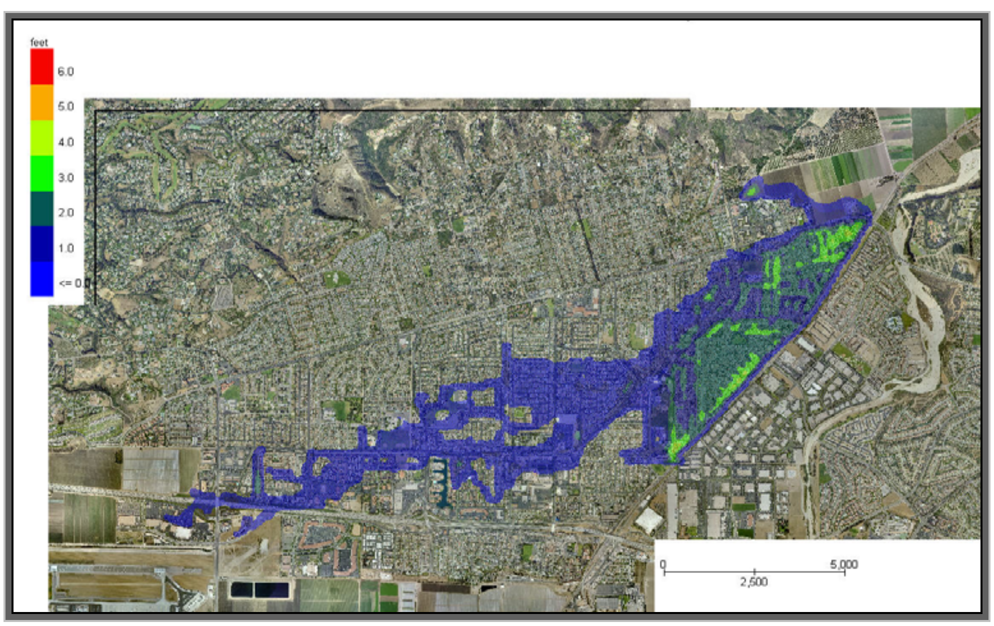

Figure 11. Example of Levee Breach Urban Flooding

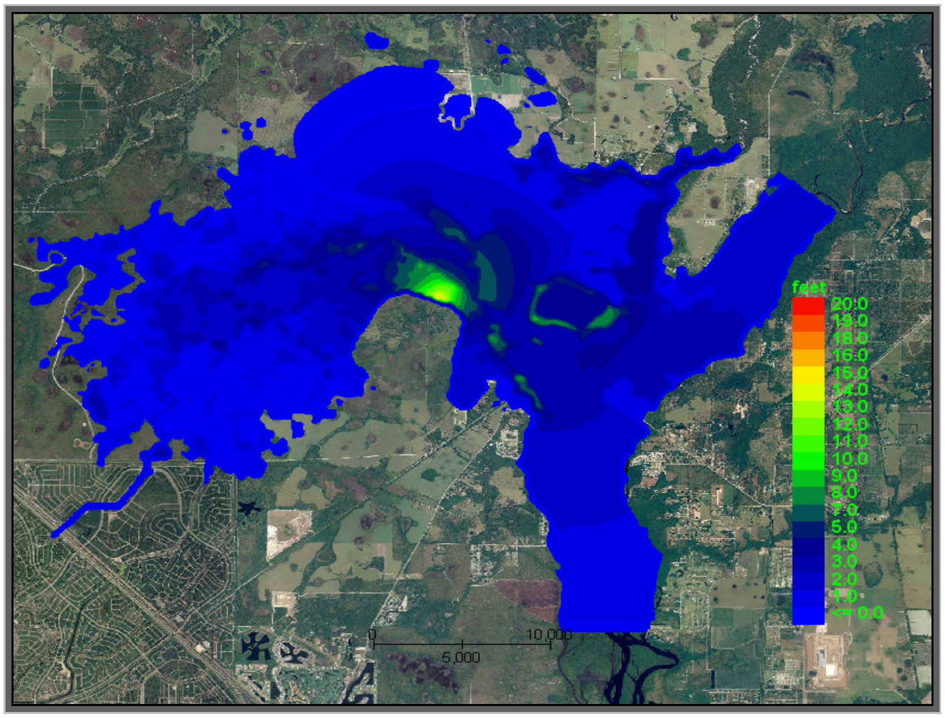

Figure 12. Example of a Proposed Domestic Water Supply Reservoir Breach Failure

For the simplified levee failure method, the breach can enlarge vertically or horizontally. Rates of breach expansion in feet or meters per hour can be specified for both the horizontal and vertical failure modes. A final levee base elevation that is higher than the floodplain elevation can also be specified. The levee failure can occur for the entire grid element width for a given flow direction. Discharge through the breach is based on the breach width and the difference in water surface elevations on the two sides of the levee. Levee failure can also be initiated by a prescribed specified water surface elevation for a given duration. The flow through the breach or overtop the levee is computed as broadcrested weir flow using a weir coefficient of 2.85.

The breach erosion component was added to the FLO-2D model to combine the river-floodplain exchange and unconfined flooding components with a realistic assessment of a levee or dam failure. The BREACH model by Fread (1988) was the basis for the breach component. The BREACH model code was obtained from the National Weather Service and extensively revised. There were a number of code errors in the original Breach model that were corrected.

The basic mechanisms of dam or levee breach failure are overtopping, piping and slope stability failure by sliding, slumping or collapse. In FLO-2D, a dam or levee breach can fail as follows:

- Overtopping and development of a breach channel;
- Piping failure;
- Piping failure and roof collapse and development of a breach channel;
- Breach channel enlargement through side slope slumping;
- Breach enlargement by wedge collapse.

The user has the option to specify the breach element and breach elevation or to assign global parameters and the model will determine which grid element is breached. During a flood simulation, water ponds against the levee or dam until the water surface elevation is higher than the structures and overtops it or exceeds a prescribed elevation for the breach. The global breach elevation can be specified as a depth below the crest elevation. When the water elevation exceeds the breach elevation for a given duration, piping is initiated. If the pipe roof collapse, then the discharge is computed through the resultant breach channel. A breach channel is also simulated if the levee is overtopped. A description of the breach enlargement routine follows.

If the user specifies a breach elevation, then piping will be initiated first when the upstream water surface exceeds the pipe bottom elevation. The breach discharge is computed as weir flow with a user specified weir coefficient. The discharge is then used to compute velocity and depth in a rectangular pipe channel. With the channel hydraulics and dam or levee embankment material parameters, sediment transport capacity is computed using a modified Meyer-Peter Mueller bedload equation (Fread, 1988). The sediment discharge is assumed to erode uniformly from the walls, bed and rood of the pipe (Figure 13). When the pipe height is larger than the material remaining in the embankment of above, the roof of the pipe collapses and breach channel flow ensues. The channel discharge is also calculated by the weir equation and similar to the pipe failure the eroded sediment is distributed on the walls and bed of the rectangular channel (see Figure 14). As the channel width and depth increases, the slope stability is checked and if the stability criteria is exceeded, the sides of the channel slump and the rectangular breach transitions to a trapezoidal channel. The breach continues to wide until the top width of the channel equals or exceeds the octagon width of the grid element. At this point the breach is assumed to be stable.

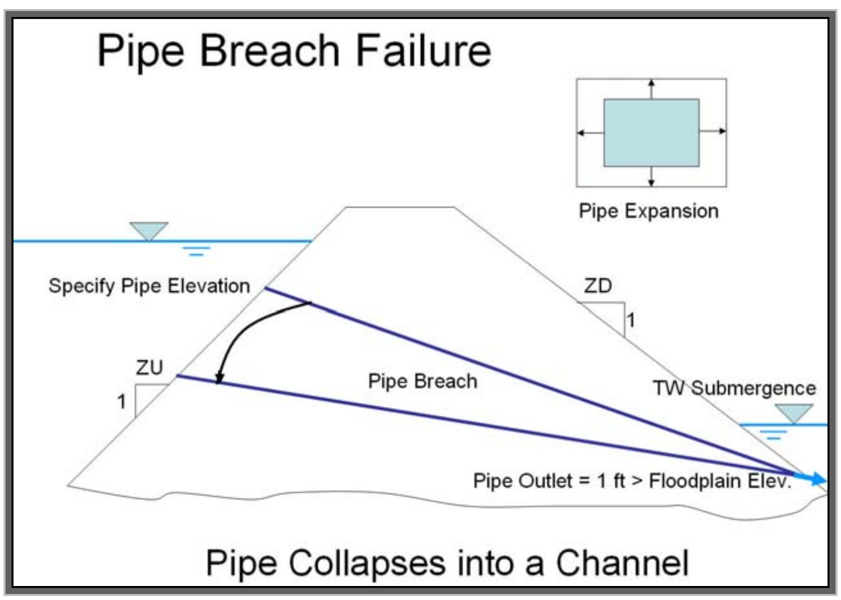

Figure 13. Pipe Breach Failure

Breach enlargement is also possible by sudden collapse of the upper portion of the dam. The collapse would consist of a wedge shaped mass of embankment material. This collapse is caused by the water pressure on the upstream side of the wedge exceeding the friction forces of shear and cohesion that resist sliding. When the breach collapse occurs, it is assumed that the breach enlargement ceases until all the wedge material is transported downstream. A flow chart of the basic computation scheme for the breach component is shown in Figure 15.

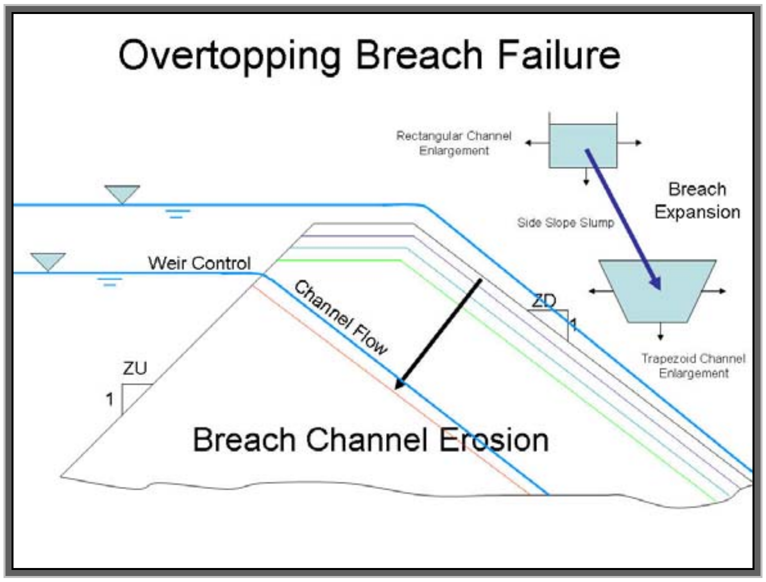

Figure 14. Overtopping and Channel Breach Erosion

Water routed through the breach is accounted by the volume conservation routines in the FLO-2D model that tracks the storage along with the discharge in and out of every grid element according to the FLO-2D timesteps. These timesteps are significantly smaller (5 to 10 times smaller) than the timesteps used in the original BREACH model. The breach component also assesses the sediment volume conservation and the water discharge through the breach is bulked by the sediment eroded during the breach failure. Routing water thru the breach continues until the water surface elevation no longer exceeds the bottom breach elevations or until all the ponded water is gone.

One of the reasons for selecting the BREACH model is that the program had sufficient geotechnical detail to mathematical represent the physical process of dam breach failure. Refer to Fread (1988) for a presentation of the equations and more discussion of the breach theory. The breach model includes the following features:

- The embankment can have an impervious core and a non-cohesive shell with different materials;
- Embankment material properties include sediment size, specific weight, cohesive strength, internal friction angle, porosity and Manning's n-value;
- Breach channel initiation through piping failure;
- Enlargement of the breach through sudden structural collapse or slope instability;
- Riprap material or grass on the downstream face;
- Sediment transport for different size sediment in the embankment core or shell.

There are several important assumptions have been hardwired into the breach model. These are:

- Initial breach width to depth ratio (BRATIO) – if the assigned breach width to depth ration is 0., then BRATIO = 2.
- The initial piping width is assumed to be 0.5 ft (0.15 m).
- The minimum and maximum Manning's n-values permitted for the breach flow resistance are 0.02 and 0.25, respectively.
- The downstream pipe outlet at the toe of the dam or levee is the grid element floodplain elevation plus 1 ft (0.3 m).

- Breach discharge is computed if the upstream water surface elevation exceeds the upstream breach pipe or channel bottom elevation plus the tolerance value (TOL ~ 0.1 ft or 0.3 m).
- If the specified initial breach elevation in the BREACHDATA.DAT file is less than 10.0 ft (3.0 m), then the initial piping breach elevation is assumed to be the dam or levee crest elevation minus the assigned breach elevation (Initial Breach Elevation = Levee Crest – BRBOTTOMEL).

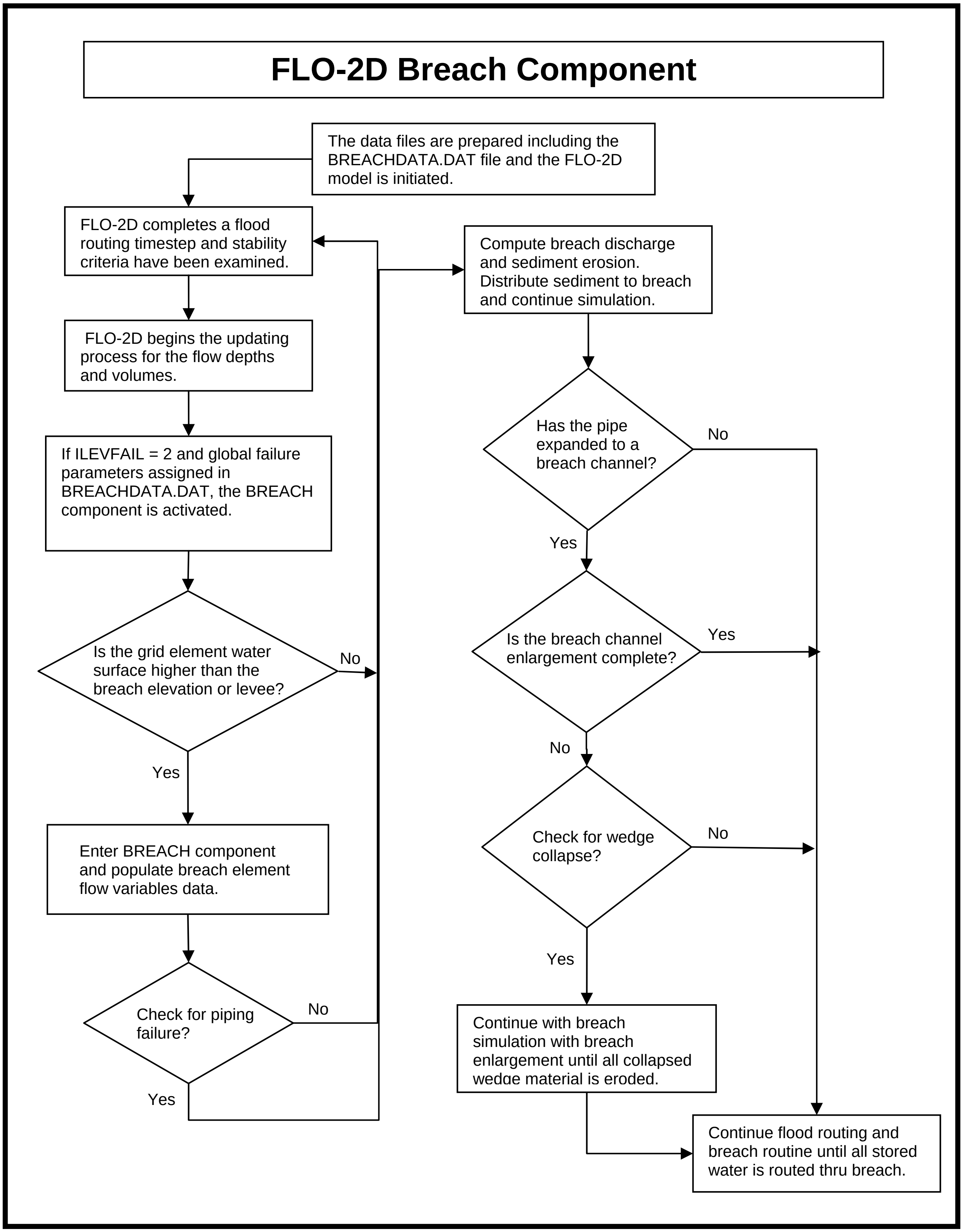

Figure 15. Breach Schematic Flow Chart

4.8 Hydraulic Structures

Hydraulic structures are simulated by specifying either discharge rating curves or rating tables. Hydraulic structures can include bridges, culverts, weirs, spillways or any hydraulic facility that controls conveyance and whose discharge can be specifying by a rating curve or tables. Backwater effects upstream of bridges or culverts as well as blockage of a culvert or overtopping of a bridge can be simulated. A hydraulic structure can control the discharge between channel or floodplain grid elements that do not have to be contiguous but may be separated by several grid elements. For example, a culvert under an interstate highway may span several grid elements.

A hydraulic structure rating curve equation specifies discharge as a function of the headwater depth h:

$$Q = a\, h^b$$

where: (a) is a regression coefficient and (b) is a regression exponent. More than one power regression relationship may be used for a hydraulic structure by specifying the maximum depth for which the relationship is valid. For example, one depth relationship can represent culvert inlet control and a second relationship can be used for the outlet control. In the case of bridge flow, blockage can simulated with a second regression that has a zero coefficient for the height of the bridge low chord.

By specifying a hydraulic structure rating table, the model interpolates between the depth and discharge increments to calculate the discharge. A typical rating curve will start with zero depth and zero discharge and increase in non-uniform increments to the maximum expected discharge. The rating table may be more accurate than the regression relationship if the regression is nonlinear on a log-log plot of the depth and discharge. Flow blockage by debris can be simulated by setting the discharge equal to zero corresponding to a prescribed depth. This blockage option may useful in simulating worst case mud and debris flow scenarios where bridges or culverts are located on alluvial fans. Each bridge on an alluvial fan channel can have simulated blockage forcing all the discharge to flow overland on the fan surface.

4.9 Street Flow

Street flow is simulated as flow in shallow rectangular channels with a curb height using the same routing algorithm as channels. The flow direction, street width and roughness are specified for each street section within the grid element. Street and overland flow exchanges are computed in the channel-floodplain flow exchange subroutine. When the curb height is exceeded, the discharge to floodplain portion of the grid element is computed. Return flow to the streets is also simulated.

Streets are assumed to emanate from the center of the grid element to the element boundary in the eight flow directions (Figure 16). For example, an east-west street across a grid element would be assigned two street sections. Each section has a length of one-half the grid element side or diagonal. A given grid element may contain one or more streets and the streets may intersect. Street roughness values, street widths, elevations and curb heights can be modified on a grid element or street section basis in the GDS program.

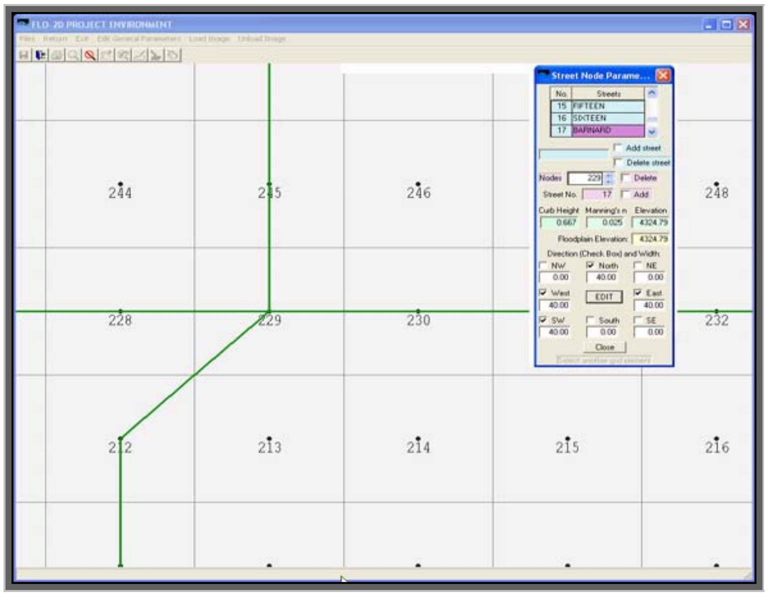

Figure 16. Streets Depicted in Green in the FLOENVIR Program.

4.10 Floodplain Surface Storage Area Modification and Flow Obstruction

One of the unique features the FLO-2D model is its ability to simulate flow problems associated with flow obstructions or loss of flood storage. Area reduction factors (ARFs) and width reduction factors (WRFs) are coefficients that modify the individual grid element surface area storage and flow width. ARFs can be used to reduce the flood volume storage on grid elements due to buildings or topography. WRFs can be assigned to any of the eight flow directions in a grid element and can partially or completely obstruct flow paths in all eight directions simulating floodwalls, buildings or berms.

These factors can greatly enhance the detail of the flood simulation through an urban area. Area reduction factors are specified as a percentage of the total grid element surface area (less than or equal to 1.0). Width reduction factors are specified as a percentage of the grid element side (less than or equal to 1.0). For example, a wall might obstruct 40% of the flow width of a grid element side and a building could cover 75% of the same grid element (Figure 17).

It is usually sufficient to estimate the area or width reduction on a map by visual inspection without measurement. Visualizing the area or width reduction can be facilitated by plotting the grid system over the digitized maps or importing an image in the GDS to locate the buildings and obstructions with respect to the grid system. As a guideline, the area or width reduction factors should be estimated within 10% to 20%. It should be noted that only four width reduction factors need to be specified for the eight possible flow directions. The other four flow directions are assigned automatically by grid element correlation. Two of the specified width reduction factors are for flow across the diagonals. It is possible to specify individual grid elements that are totally blocked from receiving any flow in the ARF.DAT file.

Figure 17. Area and Width Reduction Factors

4.11 Rainfall and Runoff

Rainfall and runoff can be routed to the channel system and then the river flood hydraulics can be computed in the same flood simulation. Either the watershed hydrology or the river hydraulics can be modeled separately with FLO-2D. Alluvial fan or floodplain rainfall can make a substantial contribution to the flood volume and peak discharge. Some fan or floodplain surface areas are similar in size as their upstream watershed areas. In these cases excess rainfall on the fan or floodplain may be equivalent to the volume of inflow hydrograph from the watershed. The rainfall and runoff on the fan or floodplain may precede or lag the arrival of the floodwave from the upstream watershed. It would also dilute the mudflows from the upstream basin.

The storm rainfall is discretized as a cumulative percent of the total. This discretization of the storm hyetograph is established through local rainfall data or through regional drainage criteria that defines storm duration, intensity and distribution. Often in a FLO-2D simulation the first upstream flood inflow hydrograph timestep corresponds to the first rainfall incremental timestep. By altering the storm time distribution on the fan or floodplain, the rainfall can lag or precede the rainfall in the upstream basin depending on the direction of the storm movement over the basin. The storm can also have more or less total rainfall than that occurring in the upstream basin.

There are a number of options to simulate variable rainfall including a moving storm, spatially variable depth area reduction assignment, or even a grid based rain gage data from an actual storm event. Storms can be varied spatially over the grid system with areas of intense or light rainfall. Storms can also move over the grid system by assigning storm speed and direction. A rainfall distribution can be selected from a number of predefined distributions.

Historical storms can be assigned on a grid element basis using real rainfall data. If calibrated Next-Generation Radar (NEXRAD) data is available, the rainfall on the NEXRAD pixels for a given time interval can be automatically interpolated to the FLO-2D grid system using the GDS. Each grid element will be assigned a rainfall total for the NEXRAD time interval and the rainfall is then interpolated by the model for each computational timestep. The result is spatially and temporally variable rainfall-runoff from the grid system. As example of the application of NEXRAD rainfall on an alluvial fan and watershed near Tucson. Arizona is shown in Figure 18. You can accomplish the same result with gridded network data from a system of rain gages. After the GDS interpolation, each FLO-2D grid element will have a rainfall hyetograph to represent the storm. This is the ultimate temporal and spatial discretization of a storm event and the flood replication has proven to be very accurate.

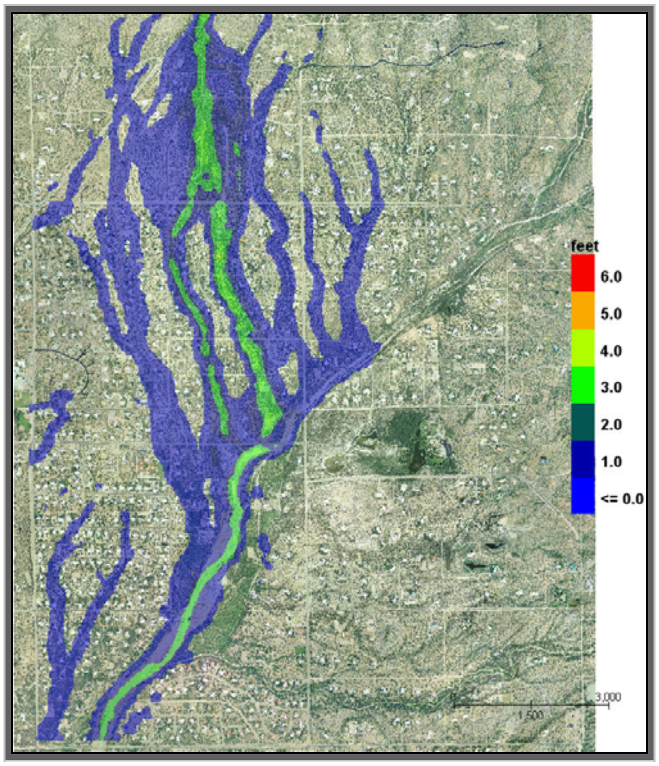

Figure 18. Flooding Replicated from NEXRAD Data near Tucson, Arizona

4.12 Infiltration and Abstraction

Precipitation losses, abstraction (interception) and infiltration are simulated in the FLO-2D model. The initial abstraction is filled prior to simulating infiltration and typical initial abstraction values are presented in Table 2. Infiltration is simulated using either the Green-Ampt infiltration model or the SCS curve number method. The infiltration parameters can be assigned global or the spatial variation of infiltration over the grid system can be modeled by assigning unique hydraulic conductivity and soil suction values to each grid element with the GDS. No infiltration is calculated for assigned streets, buildings or impervious surfaces in the grid elements. Channel infiltration can be also be simulated. Although channel bank seepage is usually only minor portion of the total infiltration losses in the system, it can affect the floodwave progression in an ephemeral channel. The surface area of a natural channel is used to approximate the wetted perimeter to compute the infiltration volume.

The Green-Ampt (1911) equation was selected to compute infiltration losses in the FLO-2D model because it is sensitive to rainfall intensity. When the rainfall exceeds the potential infiltration, then runoff is generated. The infiltration continues after the rainfall has ceased until all the available water has run off or has been infiltrated. The Green-Ampt equation is based on the following assumptions:

- Air displacement from the soil has a negligible effect on the infiltration process;
- Infiltration is a vertical process represented by a distinct piston wetting front;
- Soil compaction due to raindrop impact is insignificant;

- Hysteresis effects of the saturation and desaturation process are neglected;
- Flow depth has limited effect on the infiltration processes.

Table 2. Initial Abstraction

Surface Cover	Abstraction (inches)
Natural[1]	
Desert and rangeland	0.35
Hillslopes Sonoran desert	0.15
Mountain with vegetation	0.25
Developed – Residential[1]	
Lawns	0.20
Desert landscape	0.10
Pavement	0.05
Agricultural fields and pasture	0.50
Conifers[2]	0.01 - 0.36
Hardwoods[2]	0.001 - 0.08
Shrubs[2]	0.01 - 0.08
Grass[2]	0.04 - 0.06
Forest floor[2]	0.02 - 0.44

[1]Maricopa County Drainage Design Manual, 1992.
[2]W. T. Fullerton, Masters Thesis, CSU, 1983

A derivation of the Green-Ampt infiltration modeling procedure can be found in Fullerton (1983). To utilize the Green-Ampt model, hydraulic conductivity, soil suction, volumetric moisture deficiency and the percent impervious area must be specified. Typical hydraulic conductivity, porosity and soil suction parameters are presented in Tables 3 and 4. The volumetric moisture deficiency is evaluated as the difference between the initial and final soil saturation conditions (See Table 5). Depression storage is an initial loss from the potential surface flow (TOL value in TOLER.DAT). This is the amount of water stored in small surface depressions that does not become part of the overland runoff or infiltration.

Table 3. Green Ampt Infiltration - Hydraulic Conductivity and Porosity

Classification	(in/hr)[1]	(in/hr)[2]	(in/hr)[3]	Porosity[4]
sand and loamy sand	1.20	1.21 - 4.14	2.41 - 8.27	0.437
sandy loam	0.40	0.51	1.02	0.437
loam	0.25	0.26	0.52	0.463
silty loam	0.15	0.14	0.27	0.501
silt	0.10			
sandy clay loam	0.06	0.09	0.17	0.398
clay loam	0.04	0.05	0.09	0.464
silty clay loam	0.04	0.03	0.06	0.471
sandy clay	0.02	0.03	0.05	0.430
silty clay	0.02	0.02	0.04	0.479
clay	0.01	0.01	0.02	0.475
very slow			< 0.06[3]	
slow			0.06-.20[3]	
moderately slow			0.20-0.63[3]	
moderate			0.63-2.0[3]	
rapid			2.0-6.3[3]	
very rapid			> 6.3[3]	

[1]Maricopa County Drainage Design Manual, 1992.
[2]James, et. al., Water Resources Bulletin Vol. 28, 1992.
[3]W. T. Fullerton, Masters Thesis, CSU, 1983.
[4]COE Technical Engineering and Design Guide, No. 19, 1997

Table 4. Green Ampt Infiltration - Soil Suction			
Classification	(in)[1]	(in)[2]	(in)[3]
sand and loamy sand	2.4	1.9-2.4	
sandy loam	4.3	4.3	
Loam	3.5	3.5	
silty loam	6.6	6.6	
Silt	7.5		
sandy clay loam	8.6	8.6	
clay loam	8.2	8.2	
silty clay loam	10.8	10.8	
sandy clay	9.4	9.4	
silty clay	11.5	11.5	
Clay	12.4	12.5	
Nickel gravel-sand loam			2.0 - 4.5
Ida silt loam			2.0 - 3.5
Poudre fine sand			2.0 - 4.5
Plainfield sand			3.5 - 5.0
Yolo light clay			5.5 - 10.0
Columbia sandy loam			8.0 - 9.5
Guelph loam			8.0 - 13.0
Muren fine clay			15.0 - 20.0

[1]Maricopa County Drainage Design Manual, 1992.
[2]James, W.P., Warinner, J., Reedy, M., Water Resources Bulletin Vol. 28, 1992.
[3]W. T. Fullerton, Masters Thesis, CSU, 1983.

Table 5. Green Ampt Infiltration -Volumetric Moisture Deficiency		
Classification	Dry (% Diff)	Normal (% Diff)
sand and loamy sand[1]	35	30
sandy loam	35	25
loam	35	25
silty loam	40	25
silt	35	15
sandy clay loam	25	15
clay loam	25	15
silty clay loam	30	15
sandy clay	20	10
silty clay	20	10
clay	15	5

[1]Maricopa County Drainage Design Manual, 1992.

The SCS runoff curve number (CN) loss method is a function of the total rainfall depth and the empirical curve number parameter which ranges from 1 to 100. The rainfall loss is a function of hydrologic soil type, land use and treatment, surface condition and antecedent moisture condition. The method was developed on 24 hour hydrograph data on mild slope eastern rural watersheds in the United

States. Runoff curve numbers have been calibrated or estimated for a wide range of urban areas, agricultural lands and semi-arid range lands. The SCS CN method does not account for variation in rainfall intensity. The method was developed for predicting rainfall runoff from ungaged watersheds and its attractiveness lies in its simplicity. For large basins (especially semi-arid basins) which have unique or variable infiltration characteristics such as channels, the method tends to over-predict runoff (Ponce, 1989).

The SCS curve number parameters can be assigned graphically in the GDS to allow for spatially variable rainfall runoff. Shape files can used to interpolate SCS-CNs from ground cover and soil attributes. The SCS-CN method can be combined with the Green-Ampt infiltration method to compute both rainfall-runoff and overland flow transmission losses. The SCS-CN method will be applied to grid elements with rainfall during the model computational timestep and the Green-Ampt method will compute infiltration for grid elements that do have rainfall during the timestep. This enables transmission losses to be computed with Green-Ampt on alluvial fans and floodplains while the SCS-CN is used to compute the rainfall loss in the watershed basin.

4.13 Evaporation

An open water surface evaporation routine accounts for evaporation losses for long duration floods in large river systems. This component was implemented for the 173 mile Middle Rio Grande model from Cochiti Dam to Elephant Butte Reservoir in New Mexico. The open water surface evaporation computation is based on a total monthly evaporation that is prorated for the number of flood days in the given month. The user must input the total monthly evaporation in inches or mm for each month along with the presumed diurnal hourly percentage of the daily evaporation and the clock time at the start of the flood simulation. The total evaporation is then computed by summing the wetted surface area on both the floodplain and channel grid elements for each timestep. The floodplain wetted surface area excludes the area defined by ARF area reduction factors. The evaporation loss does not include evapotranspiration from floodplain vegetation. The total evaporation loss is reported in the SUMMARY.OUT file and should be compared with the infiltration loss for reasonableness.

4.14 Overland Multiple Channel Flow

The purpose of the multiple channel flow component is to simulate the overland flow in rills and gullies rather than as overland sheet flow. Surface water is often conveyed in small channels, even though they occupy only a fraction of the potential flow area. Simulating rill and gully flow concentrates the discharge and may improve the timing of the runoff routing. The multiple channel routine calculates overland flow as sheet flow within the grid element and flow between the grid elements is computed as rill and gully flow. No overland sheet flow is exchanged between grid elements if both elements have assigned multiple channels. The gully geometry is defined by a maximum depth, width and flow roughness. The multiple channel attributes can be spatially variable on the grid system and can be edited with the GDS program.

If the gully flow exceeds the specified gully depth, the multiple channel can be expanded by a specified incremental width. This channel widening process assumes these gullies are alluvial channels and will widen to accept more flow as the flow reaches bankfull discharge. There is no gully overbank discharge to the overland surface area within the grid element. The gully will continue to widen until the gully width exceeds the width of the grid element, then the flow routing between grid elements will revert to sheet flow. This enables the grid element to be overwhelmed by flood flows. During the falling limb of the hydrograph when the flow depth is less than 1 ft (0.3 m), the gully width will decrease to confine the discharge until the original width is again attained.

4.15 Sediment Transport – Total Load

When a channel rigid bed analysis is performed, any potential cross section changes associated with sediment transport are assumed to have a negligible effect on the predicted water surface. The volume of storage in the channel associated with scour or deposition is relatively small compared to the entire flood volume. This is a reasonable assumption for large river floods on the order of a 100-year flood. For large rivers, the change is flow area associated with scour or deposition will negligible effect on the water surface elevation for flows exceeding the bankfull discharge. On steep alluvial fans, several feet of scour or deposition will usually have a minimal effect on the flow paths of large flood events. For small flood events, the potential effects of channel incision, avulsion, blockage, bank or levee failure and sediment deposition on the flow path should be considered.

To address mobile bed issues, FLO-2D has a sediment transport component that can compute sediment scour or deposition. Within a grid element, sediment transport capacity is computed for either channel, street or overland flow based on the flow hydraulics. The sediment transport capacity is then compared with the sediment supply and the resulting sediment excess or deficit is uniformly distributed over the grid element potential flow surface using the bed porosity based on the dry weight of sediment. For surveyed channel cross sections, a non-uniform sediment distribution relationship is used. There nine sediment transport capacity that can be applied in the FLO-2D model which are discussed below. Each sediment transport formula was derived for unique fluvial geomorphic conditions and the user is encouraged to research the applicability of a selected equation for a particular project. Sediment routing by size fraction and armoring are also options. Sediment continuity is tracked on a grid element basis.

During a FLO-2D flood simulation, the sediment transport capacity is based on the predicted flow hydraulics between floodplain or channel elements, but the sediment transport computation is uncoupled from flow hydraulics. Initially the flow hydraulics are computed for all the grid and channel elements for the given time step and then the sediment transport is computed based on the completed flow hydraulics for that timestep. This assumes that the change in channel geometry resulting from deposition or scour will not have a significant effect on the average flow hydraulics for that timestep. If the scour or deposition is less than 0.10 ft, the sediment storage volume is not distributed on the bed, but is accumulated. Generally it takes several timesteps on the order of 1 to10 seconds to accumulate enough sediment so that the resulting deposition or scour will exceed 0.10 ft (0.03 m). This justifies the uncoupled sediment transport approach.

Sediment routing by size fraction requires a sediment size distribution. A geometric mean sediment diameter is estimated for each sediment interval represented as a percentage of the total sediment sample. Generally, a six or more sediment sizes and the corresponding percentages are determined from a sieve analysis. Each size fraction is routed in the model and the volumes in the bed (floodplain, channel or street) are tracked. The sediment supply to a reach can also be entered in sediment size fractions. An example of sediment data for routing by size fraction is presented below:

Sediment Diameter (mm)	Percent Finer
0.074	0.058
0.149	0.099
0.297	0.156
0.59	0.230
1.19	0.336
2.38	0.492
4.76	0.693
9.53	0.808
19.05	0.913
38.10	1.000

Bed armoring is automatically computed for sediment routing by size fraction. There are no switches to initiate armoring. The armoring process occurs when the upper bed layers of sediment become coarser as the finer sediment is transported out of the bed. An armor layer is complete when the coarse bed material covers the bed and protects the fine sediment below it. To assess armoring, the FLO-2D model tracks the sediment size distribution and volumes in an exchange layer defined by three times the D_{90} grain size of the bed material (Yang, 1996; O'Brien, 1984). The potential armor layer is evaluated each timestep for each element by assessing the volume of each size fraction in the exchange layer (Figure 19).

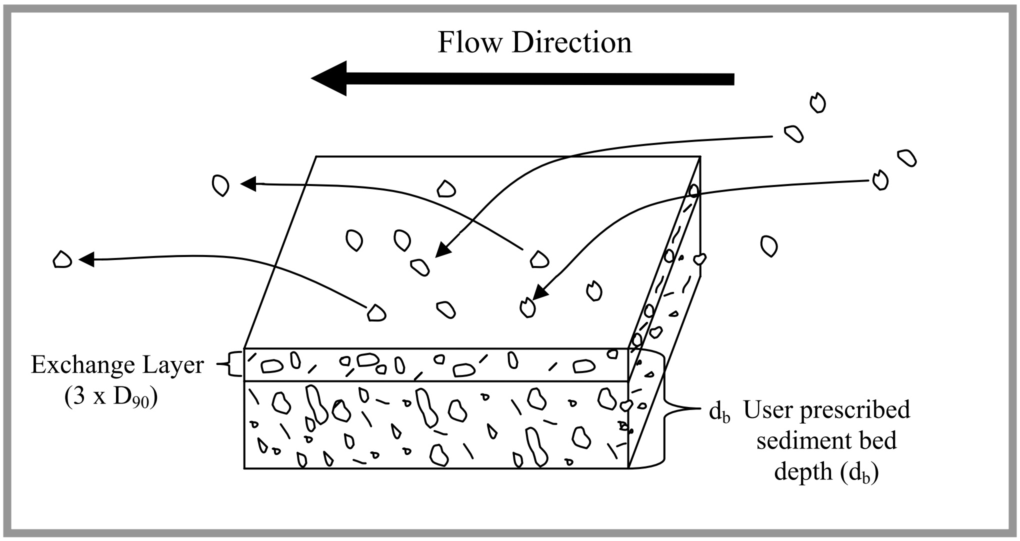

Figure 19. Sediment Transport Bed Exchange Layer

The size fraction percentage is tracked separately in the exchange layer and the rest of the channel bed. When the exchange layer has less than 33% of the original exchange layer volume, the exchange layer is replenished with sediment from the rest of the channel bed using the initial bed material size distribution. This effectively creates an armor layer that is 2 times the D_{90} size of the bed material. As sediment is removed from the exchange layer, the bed coarsens and the size fraction percentage is recomputed. If all smaller sediment size fractions in the exchange layer are removed leaving only the coarse size fraction that the flow cannot transport and the exchange layer thickness is greater than 33% of the original exchange layer thickness, then the bed is armored and no sediment is removed from the bed for that timestep. Sediment deposition can still occur on an armored bed if the supply of a given size fraction to the element exceeds the sediment transport capacity out of the element. The user can specific the total depth of the channel bed available for sediment transport. Sediment scour is limited for adverse slopes to essentially the average reach slope.

FLO-2D calculates the sediment transport capacity using each equation for each grid element and timestep. The user selects only one equation for use in the flood simulation, but can designate one floodplain or channel element to view the sediment transport capacity results for all the equations based on the output interval. The computed sediment transport capacity for each of the nine equations can then be compared by output interval in the SEDTRAN.OUT file. From this file, the range of sediment transport capacity and those equations that appear to be overestimating or underestimated the sediment load can be determined.

Each sediment transport equation is briefly described in the following paragraphs. The user is encouraged to do further research to determine which equation is most appropriate for a specific project channel morphology and hydraulics. When reviewing the SEDTRANS.OUT file, it might be observed that generally the Ackers-White and Engelund-Hansen equations compute the highest sediment transport capacity; Yang and Zeller-Fullerton result in a moderate sediment transport quantities; and Laursen and Toffaleti calculate the lowest sediment transport capacity. This correlation however varies according to project conditions. A brief discussion of each sediment transport equation in the FLO-2D model follows:

Ackers-White Method. Ackers and White (1973) expressed sediment transport in terms of dimensionless parameters, based on Bagnold's stream power concept. They proposed that only a portion of the bed shear stress is effective in moving coarse sediment. Conversely for fine sediment, the total bed shear stress contributes to the suspended sediment transport. The series of dimensionless parameters are required include a mobility number, representative sediment number and sediment transport function. The various coefficients were determined by best-fit curves of laboratory data involving sediment size greater than 0.04 mm and Froude numbers less than 0.8. The condition for coarse sediment incipient motion agrees well with Sheild's criteria. The Ackers-White approach tends to overestimate the fine sand transport (Julien, 1995) as shown in the above example output.

Engelund-Hansen Method. Bagnold's stream power concept was applied with the similarity principle to derive a sediment transport function. The method involves the energy slope, velocity, bed shear stress, median particle diameter, specific weight of sediment and water, and gravitational acceleration. In accordance with the similarity principle, the method should be applied only to flow over dune bed forms, but Engelund and Hansen (1967) determined that it could be effectively used in both dune bed forms and upper regime sediment transport (plane bed) for particle sizes greater than 0.15 mm.

Karim-Kennedy Equation. The simplified Karim-Kennedy equation (F. Karim, 1998) is used in the FLO-2D model. It is a nonlinear multiple regression equation based on velocity, bed form, sediment size and friction factor using a large number of river flume data sets. The data includes sediment sizes ranging from 0.08 mm to 0.40 mm (river) and 0.18 mm to 29 mm (flume), slope ranging from 0.0008 to 0.0017 (river) and 0.00032 to 0.0243 (flume) and sediment concentrations by volume up to 50,000 ppm. This equation can be used over non-uniform river bed conditions for typical large sand and gravel bed rivers. It will yield results similar to Laursen's and Toffaleti's equations.

Laursen's Transport Function. The Laursen (1958) formula was developed for sediments with a specific gravity of 2.65 and had good agreement with field data from small rivers such as the Niobrara River near Cody, Nebraska. For larger rivers the correlation between measured data and predicted sediment transport was poor (Graf, 1971). This set of equations involved a functional relationship between the flow hydraulics and sediment discharge. The bed shear stress arises from the application of the Manning-Strickler formula. The relationship between shear velocity and sediment particle fall velocity was based on flume data for sediment sizes less than 0.2 mm. The shear velocity and fall velocity ratio expresses the effectiveness of the turbulence in mixing suspended sediments. The critical tractive force in the sediment concentration equation is given by the Shields diagram.

MPM-Smart Equation. This is a modified Meyer-Peter-Mueller (MPM) sediment transport equation (Smart, 1984) for steep channels ranging from 3% to 20%. The original MPM equation underestimated sediment transport capacity because of deficiencies in the roughness values. This equation can be used for sediment sizes greater than 0.4 mm. It was modified to incorporate the effects of nonuniform sediment distributions. It will generate sediment transport rates approaching Englund-Hansen on steep slopes.

MPM-Woo Relationship. For computing the bed material load in steep sloped, sand bed channels such as arroyos, washes and alluvial fans, Mussetter, et al. (1994) linked Woo's relationship for computing the suspended sediment concentration with the Meyer-Peter-Mueller bed-load equation. Woo et al. (1988) developed an equation to account for the variation in fluid properties associated with high sediment concentration. By estimating the bed material transport capacity for a range of hydraulic and bed conditions typical of the Albuquerque, New Mexico area, Mussetter et al. (1994) derived a multiple regression relationship to compute the bed material load as a function of velocity, depth, slope, sediment size and concentration of fine sediment. The equation requires estimates of exponents and a coefficient and is applicable for velocities up to 20 fps (6 mps), a bed slope < 0.04, a D_{50} < 4.0 mm, and a sediment concentration of less than 60,000 ppm. This equation provides a method for estimating high bed material load in steep, sand bed channels that are beyond the hydraulic conditions for which the other sediment transport equations are applicable.

Toffeleti's Approach. Toffaleti (1969) develop a procedure to calculate the total sediment load by estimating the unmeasured load. Following the Einstein approach, the bed material load is given by the sum of the bedload discharge and the suspended load in three separate zones. Toffaleti computed the bedload concentration from his empirical equation for the lower-zone suspended load discharge and then computed the bedload. The Toffaleti approach requires the average velocity in the water column, hydraulic radius, water temperature, stream width, D_{65} sediment size, energy slope and settling velocity. Simons and Senturk (1976) reported that Toffaleti's total load estimated compared well with 339 river and 282 laboratory data sets.

Yang's Method. Yang (1973) determined that the total sediment concentration was a function of the potential energy dissipation per unit weight of water (stream power) and the stream power was expressed as a function of velocity and slope. In this equation, the total sediment concentration is expressed as a series of dimensionless regression relationships. The equations were based on measured field and flume data with sediment particles ranging from 0.137 mm to 1.71 mm and flows depths from 0.037 ft to 49.9 ft. The majority of the data was limited to medium to coarse sands and flow depths less than 3 ft (Julien, 1995). Yang's equations in the FLO-2D model can be applied to sand and gravel.

Zeller-Fullerton Equation. Zeller-Fullerton is a multiple regression sediment transport equation for a range of channel bed and alluvial floodplain conditions. This empirical equation is a computer generated solution of the Meyer-Peter, Muller bed-load equation combined with Einstein's suspended load to generate a bed material load (Zeller and Fullerton, 1983). For a range of bed material from 0.1 mm to 5.0 mm and a gradation coefficient from 1.0 to 4.0, Julien (1995) reported that this equation should be accurate with 10% of the combined Meyer-Peter Muller and Einstein equations. The Zeller-Fullerton equation assumes that all sediment sizes are available for transport (no armoring). The original Einstein method is assumed to work best when the bedload constitutes a significant portion of the total load (Yang, 1996).

In summary, Yang (1996) made several recommendations for the application of total load sediment transport formulas in the absence of measured data. These recommendations for natural rivers are slightly edited and presented below:

- Use Zeller and Fullerton equation when the bedload is a significant portion of the total load.
- Use Toffaleti's method or the Karim-Kennedy equation for large sand-bed rivers.
- Use Yang's equation for sand and gravel transport in natural rivers.
- Use Ackers-White or Engelund-Hansen equations for subcritical flow in lower sediment transport regime.
- Use Lausen's formula for shallow rivers with silt and fine sand.
- Use MPM-Woo's or MPM-Smart relationships for steep slope, arroyo sand bed channels and alluvial fans.

Yang (1996) reported that ASCE ranked the equations (not including Toffaleti, MPM-Woo, Karin-Kennedy) in 1982 based on 40 field tests and 165 flume measurements in terms of the best overall predictions as follows with Yang ranking the highest: Yang, Laursen, Ackers-White, Engelund-Hansen, and combined Meyer-Peter, Muller and Einstein.

It is important to note that in applying these equations, the wash load is not included in the computations. The wash load should be subtracted from any field data before comparing the field measurements with the predicted sediment transport results from the equations. It is also important to recognize if the field measurements are sediment supply limited. If this is case, any comparison with the sediment transport capacity equations would be inappropriate.

There are two other sediment transport options available in the FLO-2D model; assignment of rigid bed element and a limitation on the scour depth. Rigid bed element can be used would simulate a concrete apron in a channel below a culvert outlet, channel bed rock or a concrete lined channel reach. The scour depth limitation is a control that can be invoked for sediment routing.

4.16 Mud and Debris Flow Simulation

Very viscous, hyperconcentrated sediment flows are generally referred to as either mud or debris flows. Mudflows are nonhomogeneous, nonNewtonian, transient flood events whose fluid properties change significantly as they flow down steep watershed channels or across alluvial fans. Mudflow behavior is a function of the fluid matrix properties, channel geometry, slope and roughness. The fluid matrix consists of water and fine sediments. At sufficiently high concentrations, the fine sediments alter the properties of the fluid including density, viscosity and yield stress.

There are several important sediment concentration relationships that help to define the nature of hyperconcentrated sediment flows. These relationships relate the sediment concentration by volume, sediment concentration by weight, the sediment density, the mudflow mixture density and the bulking factor. When examining parameters related to mudflows, it is important to identify the sediment concentration as a measure of weight or volume. The sediment concentration by volume C_v is given by:

$$C_v = \text{volume of the sediment/(volume of water plus sediment)}$$

C_v is related to the sediment concentration by weight C_w by:

$$C_v = C_w\gamma / \{\gamma_s - C_w(\gamma_s - \gamma)\}$$

where γ = specific weight of the water and γ_s = specific weight of the sediment. The sediment concentration can also be expressed in parts per million (ppm) by dividing the concentration by weight C_w by 10^6. The specific weight of the mudflow mixture γ_m is a function of the sediment concentration by volume:

$$\gamma_m = \gamma + C_v(\gamma_s - \gamma)$$

Similarly the density of the mudflow mixture ρ_m is given by:

$$\rho_m = \rho + C_v (\rho_s - \rho)$$

and

$$\rho_m = \gamma_m / g$$

where g is gravitational acceleration. Finally, the volume of the total mixture of water and sediment in a mudflow can be determined by multiplying the water volume by the bulking factor. The bulking factor is simply:

$$BF = 1/(1 - C_v)$$

The bulking factor is 2.0 for a sediment concentration by volume of 50%. A sediment concentration of 7% by volume for a conventional river bedload and suspended results in a bulking factor of 1.075 indicating that the flood volume is 7.5% greater than if the flood was considered to be only water.

These basic relationships will be valuable when analyzing mudflow simulations. Most mudflow studies require estimates of the sediment concentration by volume and the bulking factor to describe the magnitude of the event. Average and peak sediment concentrations for the flood hydrograph are important variables for mitigation design.

The full range of sediment flows span from water flooding to mud floods, mudflows and landslides. The distinction between these flood events depends on sediment concentration measured either by weight or volume (Figure 20). Sediment concentration by volume expressed as a percentage is the most commonly used measure. Table 6 lists the four different categories of hyperconcentrated sediment flows and their dominant flow characteristics. This table was developed from the laboratory data using actual mudflow deposits. Some variation in the delineation of the different flow classifications should be expected on the basis of the geology.

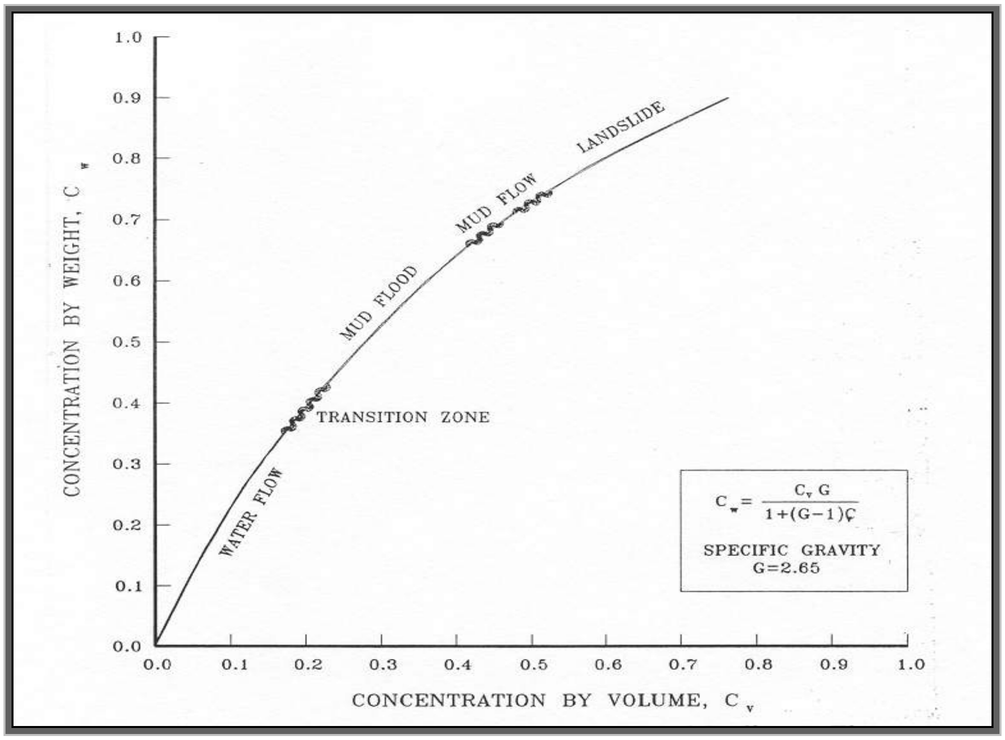

Figure 20. Classification of Hyperconcentrated Sediment Flows

Initial attempts to simulate debris flows were accomplished with one-dimensional flow routing models. DeLeon and Jeppson (1982) modeled laminar water flows with enhanced friction factors. Spatially varied, steady-state Newtonian flow was assumed and flow cessation could not be simulated. Schamber and MacArthur (1985) created a one-dimensional finite element model for mudflows using the Bingham rheological model to evaluate the shear stresses of a nonNewtonian fluid. O'Brien (1986) designed a one-dimensional mudflow model for watershed channels that also utilized the Bingham model. In 1986, MacArthur and Schamber presented a two-dimensional finite element model for application to simplified overland topography (Corps, 1988). The fluid properties were modeled as a Bingham fluid whose shear stress is a function of the fluid viscosity and yield strength.

Takahashi and Tsujimoto (1985) proposed a two-dimensional finite difference model for debris flows based a dilatant fluid model coupled with Coulomb flow resistance. The dilatant fluid model was derived from Bagnold's dispersive stress theory (1954) that describes the stress resulting from the collision of sediment particles. Later, Takahashi and Nakagawa (1989) modified the debris flow model to include turbulence.

Table 6. Mudflow Behavior as a Function of Sediment Concentration			
	Sediment Concentration		Flow Characteristics
	by Volume	by Weight	
Landslide	0.65 - 0.80	0.83 - 0.91	Will not flow; failure by block sliding
	0.55 - 0.65	0.76 - 0.83	Block sliding failure with internal deformation during the slide; slow creep prior to failure
Mudflow	0.48 - 0.55	0.72 - 0.76	Flow evident; slow creep sustained mudflow; plastic deformation under its own weight; cohesive; will not spread on level surface
	0.45 - 0.48	0.69 - 0.72	Flow spreading on level surface; cohesive flow; some mixing
Mud Flood	0.40 - 0.45	0.65 - 0.69	Flow mixes easily; shows fluid properties in deformation; spreads on horizontal surface but maintains an inclined fluid surface; large particle (boulder) setting; waves appear but dissipate rapidly
	0.35 - 0.40	0.59 - 0.65	Marked settling of gravels and cobbles; spreading nearly complete on horizontal surface; liquid surface with two fluid phases appears; waves travel on surface
	0.30 - 0.35	0.54 - 0.59	Separation of water on surface; waves travel easily; most sand and gravel has settled out and moves as bedload
	0.20 - 0.30	0.41 - 0.54	Distinct wave action; fluid surface; all particles resting on bed in quiescent fluid condition
Water Flood	< 0.20	< 0.41	Water flood with conventional suspended load and bedload

O'Brien and Julien (1988), Julien and Lan (1991), and Major and Pierson (1992) investigated mudflows with high concentrations of fine sediment in the fluid matrix. These studies showed that mudflows behave as Bingham fluids with low shear rates ($<10\ s^{-1}$). In fluid matricies with low sediment concentrations, turbulent stresses dominate in the core flow. High concentrations of non-cohesive particles combined with low concentrations of fine particles are required to generate dispersive stress. The quadratic shear stress model proposed by O'Brien and Julien (1985) describes the continuum of flow regimes from viscous to turbulent/dispersive flow.

Hyperconcentrated sediment flows involve the complex interaction of fluid and sediment processes including turbulence, viscous shear, fluid-sediment particle momentum exchange, and sediment particle collision. Sediment particles can collide, grind, and rotate in their movement past each other. Fine sediment cohesion controls the nonNewtonian behavior of the fluid matrix. This cohesion contributes to the yield stress τ_y which must be exceeded by an applied stress in order to initiate fluid motion. By combining the yield stress and viscous stress components, the well-known Bingham rheological model is prescribed.

For large rates of shear such as might occur on steep alluvial fans ($10\ s^{-1}$ to $50\ s^{-1}$), turbulent stresses may be generated. In turbulent flow an additional shear stress component, the dispersive stress, can arise from the collision of sediment particles. Dispersive stress occurs when non-cohesive sediment particles dominate the flow and the percentage of cohesive fine sediment (silts and clays) is small. With increasing high concentrations of fine sediment, fluid turbulence and particle impact will be suppressed and the flow will approach being laminar. Sediment concentration in a given flood event can vary dramatically and as a result viscous and turbulent stresses may alternately dominate, producing flow surges.

FLO-2D routes mudflows as a fluid continuum by predicting viscous fluid motion as function of sediment concentration. A quadratic rheologic model for predicting viscous and yield stresses as function of sediment concentration is employed and sediment continuity is observed. As sediment concentration changes for a given grid element, dilution effects, mudflow cessation and the remobilization of deposits are simulated. Mudflows are dominated by viscous and dispersive stresses and constitute a very different phenomenon than those processes of suspended sediment load and bedload in conventional sediment transport. In should be noted that the sediment transport and mudflow components **cannot** be used together in a FLO-2D simulation.

The shear stress in hyperconcentrated sediment flows, including those described as debris flows, mudflows and mud floods, can be calculated from the summation of five shear stress components. The total shear stress τ depends on the cohesive yield stress τ_c, the Mohr-Coulomb shear τ_{mc}, the viscous shear stress τ_v (η dv/dy), the turbulent shear stress τ_t, and the dispersive shear stress τ_d.

$$\tau = \tau_c + \tau_{mc} + \tau_v + \tau_t + \tau_d$$

When written in terms of shear rates (dv/dy), the following quadratic rheological model can be defined (O'Brien and Julien, 1985):

$$\tau = \tau_y + \eta \left(\frac{dv}{dy}\right) + C \left(\frac{dv}{dy}\right)^2$$

where

$$\tau_y = \tau_c + \tau_{mc}$$

and

$$C = \rho_m\ l^2 + f\ (\rho_m, C_v)\ d_s^2$$

In these equations η is the dynamic viscosity; τ_c is the cohesive yield strength; the Mohr Coulomb stress $\tau_{mc} = p_s \tan\varphi$ depends on the intergranular pressure p_s and the angle of repose φ of the material; C denotes the inertial shear stress coefficient, which depends on the mass density of the mixture ρ_m, the Prandtl mixing length l, the sediment size d_s and a function of the volumetric sediment concentration C_v. Bagnold (1954) defined the function relationship $f(\rho_m, C_v)$ as:

$$f(\rho_m, C_v) = a_i\ \rho_m \left[\left(\frac{C_*}{C_v}\right)^{1/3} - 1\right]$$

where a_i (~ 0.01) is an empirical coefficient and C_* is the maximum static volume concentration for the sediment particles. It should be noted that Takahashi (1979) found that the coefficient a_i may vary over several orders of magnitude. Egashira et al. (1989) revised this relationship and suggested the following:

$$f(\rho_s, C_v) = \frac{\pi}{12}\left(\frac{6}{\pi}\right)^{1/3} \sin^2 \alpha_I \;\; \rho_s (1 - e_n^2)\, C_v^{1/3}$$

where the energy restitution coefficient e_n after impact ranges $0.70 < e_n < 0.85$ for sands, α_I is the average particle impact angle and ρ_s is the mass density of sediment particles.

The first two stress terms in the quadratic rheological model are referred to as the Bingham shear stresses (Figure 21). The sum of the yield stress and viscous stress define the total shear stress of a cohesive, mudflow in a viscous flow regime. The last term is the sum of the dispersive and turbulent shear stresses and defines an inertial flow regime for a mud flood. This term is a function of the square of the velocity gradient. A discussion of these stresses and their role in hyperconcentrated sediment flows can be found in Julien and O'Brien (1987, 1993).

A mudflow model that incorporates only the Bingham stresses and ignores the inertial stresses assumes that the simulated flow is dominated by viscous stresses. This assumption is not universally appropriate because all mud floods and some mudflows are very turbulent with velocities as high as 25 fps (8 m/s). Even mudflows with concentrations up to 40% by volume can be turbulent (O'Brien, 1986). Depending on the fluid matrix properties, the viscosity and yield stresses for high sediment concentrations can still be relatively small compared to the turbulent stresses. If the flow is controlled primarily by the viscous stress, it will result in lower velocities. Conversely, if the viscosity and yield stresses are small, the turbulent stress will dominate and the velocities will be higher.

To delineate the role of turbulent and dispersive forces in sand and water mixtures, Hashimoto (1997) developed simplified criteria involving only flow depth d and sediment size D_i. When $d/D_i < 30$, the intergranular forces are dominant. If $d/D_i > 100$, inertial forces dominate. In the range $30 < d/D_i < 100$ both forces play an important role in the momentum exchange. It should be noted, however, that sediment concentration is a critical factor that is not accounted for in this criteria.

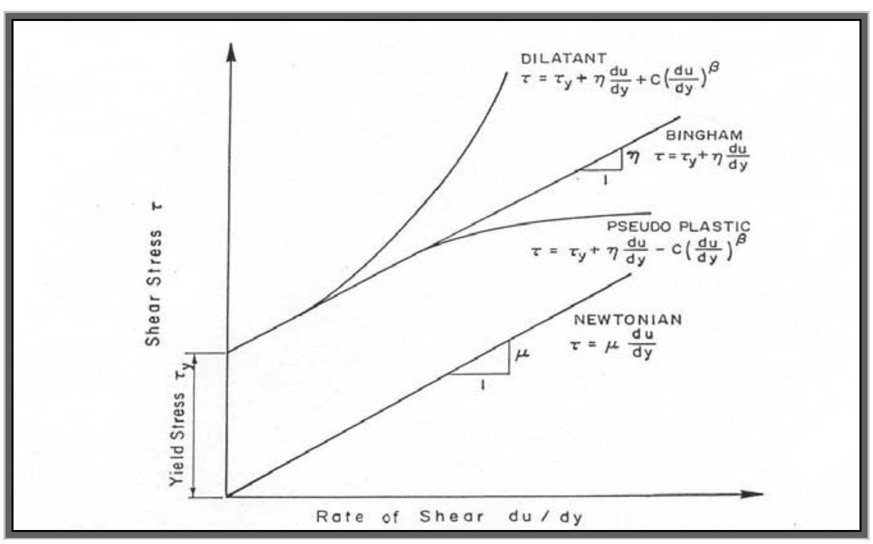

Figure 21. Shear Stress as a Function of Shear Rate for Fluid Deformation Models

To define all the shear stress terms for use in the FLO-2D model, the following approach was taken. By analogy, from the work of Meyer-Peter and Müller (1948) and Einstein (1950), the shear stress relationship is depth integrated and rewritten in the following form as a dimensionless slope:

$$S_f = S_y + S_v + S_{td}$$

where the total friction slope S_f is the sum of the yield slope S_y, the viscous slope S_v, and the turbulent-dispersive slope S_{td}. The viscous and turbulent-dispersive slope terms are written in terms of depth-averaged velocity V. The viscous slope can be written as:

$$S_v = \frac{K\ \eta}{8\ \gamma_m} \frac{V}{h^2}$$

where γ_m is the specific weight of the sediment mixture. The resistance parameter K for laminar flow equals 24 for smooth wide rectangular channels but increases significantly (~ 50,000) with roughness and irregular cross section geometry. In Table 7 for Kentucky Blue Grass with a slope of 0.01, K was estimated at 10,000 (Chen, 1976). A value of K = 2,285 was calibrated on the Rudd Creek, Utah mudflow for a residential area and has been used effectively for most urban studies. For laminar and transitional flows, turbulence is suppressed and the laminar flow resistance parameter K becomes important. In the FLO-2D model if K = 0 in the SED.DAT file, the value of K is automatically computed from the Manning's n-value.

Table 7. Resistance Parameters for Laminar Flow[1]

Surface	Range of K
Concrete/asphalt	24 -108
Bare sand	30 - 120
Graded surface	90 - 400
Bare clay - loam soil, eroded	100 - 500
Sparse vegetation	1,000 - 4,000
Short prairie grass	3,000 - 10,000
Bluegrass sod	7,000 - 50,000

[1] Woolhiser (1975)

The flow resistance n_{td} of the turbulent and dispersive shear stress components are combined into an equivalent Manning's n-value for the flow:

$$S_{td} = \frac{n_{td}^2 V^2}{h^{4/3}}$$

At very high concentrations, the dispersive stress arising from sediment particle contact increases the flow resistance n_{td} by transferring more momentum flux to the boundary. To estimate this increase in flow resistance, the conventional turbulent flow resistance n-value n_t is increased by an exponential function of the sediment concentration C_v:

$$n_{td} = n_t\ b\ e^{mC_v}$$

where: n_t is the turbulent n-value, b is a coefficient (0.0538) and m is an exponent (6.0896). This equation was based on unpublished paper by Julien and O'Brien (1998) that relates the dispersive and turbulent resistance in hyperconcentrated sediment flows as function of the ratio of the flow depth to the sediment grain size.

The friction slope components can then be combined in the following form:

$$S_f = \frac{\tau_y}{\gamma_m \ h} + \frac{K \ \eta \ V}{8 \gamma_m \ h^2} + \frac{n_{td}^2 \ V^2}{h^{4/3}}$$

A quadratic equation solution to the above friction slope equation has been formulated in the FLO-2D model to estimate the velocity for use in the momentum equation. The estimated velocity represents the flow velocity computed across the floodplain or channel element boundary using the average flow depth between the elements. Reasonable values of K and Manning's n-value can be assumed for the channel and overland flow resistance. The specific weight of the fluid matrix γ_m, yield stress τ_y and viscosity η vary principally with sediment concentration. Unless a rheological analysis of the mudflow site material is available, the following empirical relationships can be used to compute viscosity and yield stress:

$$\tau_y = \alpha_2 \ e^{\beta_2 C_v} \quad \text{and} \quad \eta = \alpha_1 \ e^{\beta_1 C_v}$$

where α_i and β_i are empirical coefficients defined by laboratory experiment (O'Brien and Julien, 1988). The viscosity (poises) and yield stress (dynes/cm^2) are shown to be functions of the volumetric sediment concentration C_v of silts, clays and in some cases, fine sands and do not include larger clastic material rafted along with the flow (Table 8 and Figures. 22 and 23).

Table 8. Yield Stress and Viscosity as a Function of Sediment Concentration

Source	$\tau_y = \alpha e^{\beta Cv}$ (dynes/cm^2)		$\eta = \alpha e^{\beta Cv}$ (poises)	
	α	β	α	β
Field Data				
Aspen Pit 1	0.181	25.7	0.0360	22.1
Aspen Pit 2	2.72	10.4	0.0538	14.5
Aspen Natural Soil	0.152	18.7	0.00136	28.4
Aspen Mine Fill	0.0473	21.1	0.128	12.0
Aspen Watershed	0.0383	19.6	0.000495	27.1
Aspen Mine Source Area	0.291	14.3	0.000201	33.1
Glenwood 1	0.0345	20.1	0.00283	23.0
Glenwood 2	0.0765	16.9	0.0648	6.20
Glenwood 3	0.000707	29.8	0.00632	19.9
Glenwood 4	0.00172	29.5	0.000602	33.1
Relationships Available from the Literature				
Iida (1938)*	-	-	0.0000373	36.6
Dai et al. (1980)	2.60	17.48	0.00750	14.39
Kang and Zhang (1980)	1.75	7.82	0.0405	8.29
Qian et al. (1980)	0.00136	21.2	-	-
	0.050	15.48	-	-
Chien and Ma (1958)	0.0588	19.1-32.7	-	-
Fei (1981)	0.166	25.6	-	-
	0.00470	22.2	-	-

*See O'Brien (1986) for the references.

Conversion: Shear Stress: 1 Pascal (PA) = 10 dynes/cm^2
Viscosity: 1 PAs = 10 dynes-sec/cm^2 = 10 poises

The viscosity of the fluid matrix is also a function of the percent and type of silts and clays and fluid temperature. Very viscous mudflows have high sediment concentrations and correspondingly high yield stresses and may result in laminar flow although laminar flows in nature are extremely rare. Less viscous flows (mud floods) are always turbulent.

For a mudflow event, the average sediment concentration generally ranges between 20% and 35% by volume with peak concentrations approaching 50% (Table 7 and Figure 22). Large flood events such as the 100-year flood may contain too much water to produce a viscous mudflow event. Smaller rainfall events such as the 10- or 25-year return period storm may have a greater propensity to create viscous mudflows. Most watersheds with a history of mudflow events and will gradually develop a sediment supply in the channel bed such that small storms may generate mudflow surges. Most rainfall induced mudflows follow a pattern of flood response. Initially clear water flows from the basin rainfall-runoff may arrive at the fan apex. This may be followed by a surge or frontal wave of mud and debris (40 to 50% concentration by volume). When the peak arrives, the average sediment concentration generally decreases to the range of 30 to 40% by volume. On the falling limb of the hydrograph, surges of higher sediment concentration may occur.

To simulate mudflows with the FLO-2D model, the MUD switch in the CONT.DAT must be turned on (MUD = 1) and the viscosity and yield stress variables in SED.DAT file must be specified. It is recommended that the viscosity and yield stress exponents and coefficients from Table 9 be selected for inclusion in the SED.DAT file. The field sample Glenwood 4, for example, creates a very viscous mudflow. A volumetric sediment concentration or a sediment volume must then be assigned to the water discharge for a timestep in the discretized inflow hydrograph in the INFLOW.DAT file. The inflow sediment volume may represent channel scour, bank erosion or hillslope failure. The incremental sediment volume is tracked through the routing simulation and reported as a total sediment volume in the summary volume conservation tables. This total sediment volume should be reviewed to determine if this is a reasonable sediment supply or yield from the watershed.

When routing the mud flood or mudflow over an alluvial fan or floodplain, the FLO-2D model preserves continuity for both the water and sediment. For every grid element and timestep, the change in the water and sediment volumes and the corresponding change in sediment concentration are computed. At the end of the simulation, the model reports on the amount of water and sediment removed from the study area (outflow) and the amount and location of the water and sediment remaining on the fan or in the channel (storage). The areal extent of mudflow inundation and the maximum flow depths and velocities are a function of the available sediment volume and concentration which can be varied in the FLO-2D simulations. For further discussion on model hyperconcentrated sediment flows, refer to the FLO-2D document *"Simulating Mudflows_Guidelines.doc"*.

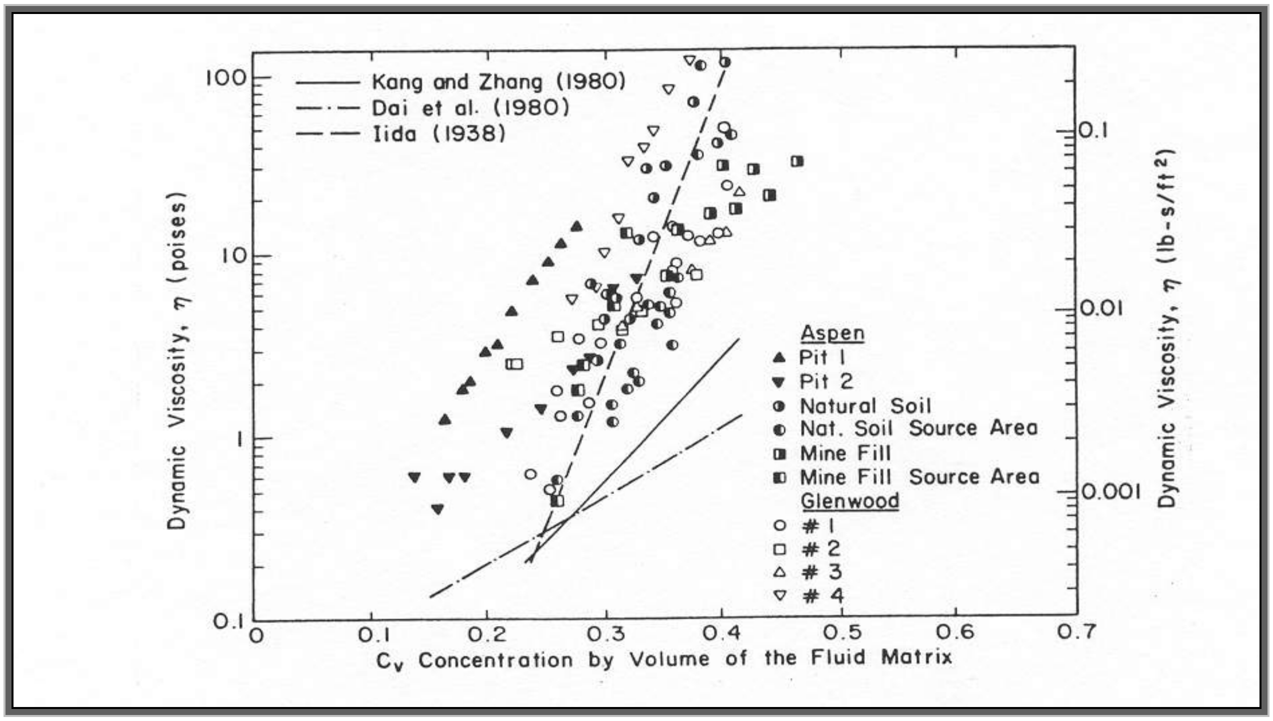

Figure 22. Dynamic Viscosity of Mudflow Samples versus Volumetric Concentration

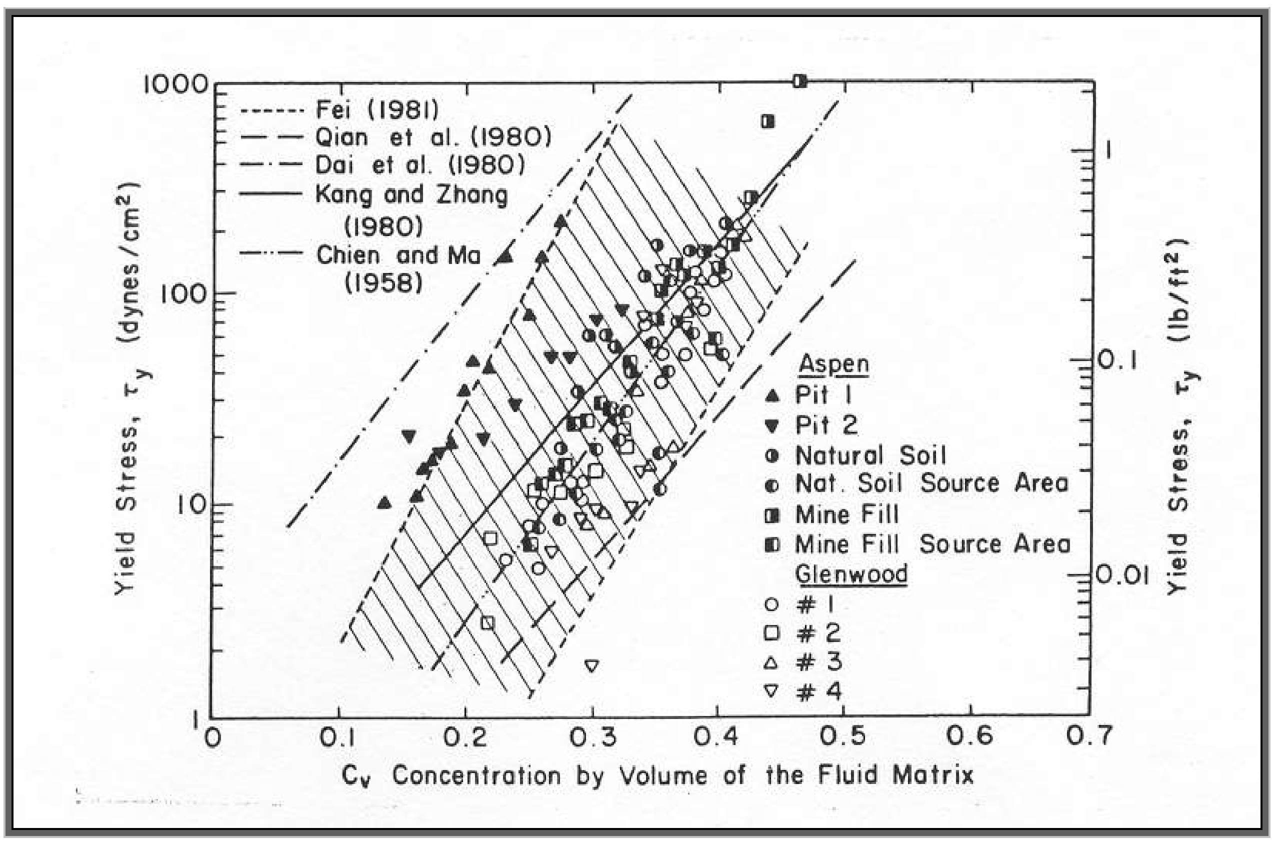

Figure 23. Yield Stress of Mudflow Samples versus Volumetric Concentration

V. FLO-2D APPLICATIONS AND METHODS

5.1 River Applications

Simulating river flow is one of the more common applications of the FLO-2D model (Figure 24). Abrupt cross section transitions, flat bed slopes, confluences and limited data bases are issues related to channel flow. The key to simulating river flooding is correctly assessing the relationship between the flood volume in the channel and the volume distributed on the floodplain. There are several considerations to defining channel volume and geometry. The surveyed channel cross sections should be appropriately spaced to model transitions between wide and narrow cross sections. The estimate of the total channel length (sum of the channel grid element lengths) is important to channel volume computation. Finally, surveyed water surface elevations at known discharges are needed to calibrate the channel roughness values. Channel routing with poorly matched channel geometry and estimated roughness can result in discharge surging.

When preparing a channel simulation, the available cross sections are distributed to the various channel elements based on reaches with similar geomorphic features. The bed elevation is then adjusted between channel elements with surveyed cross sections. The n-values are estimated from knowledge of the bed material, bed forms, vegetation or channel planform. The n-values may also serve to correct any mismatched channel flow area and slope. Roughness values can also be adjusted by specifying a maximum Froude number. Using this approach, the relationship between the channel flow area, bed slope and n-value can be adjusted to better represent the physical system, calibrate the water surface elevations, eliminate any numerical surging and speed-up the simulation.

The two most important FLO-2D results are the channel hydrograph at a downstream location and the floodplain area of inundation. Typically if the area of inundation is correct, then the channel flow depths and water surface elevations will be relatively accurate. Replicating the channel hydrograph and the floodplain inundation while conserving volume is a good indication that the volume distribution between the channel and the floodplain is reasonable.

Flood routing details related to channel flow include simulating hydraulic structures, levees, infiltration, sediment transport and hyperconcentrated sediment flows. Hydraulic structures may include bridges, culverts, weirs, diversions or any other channel hydraulic control. Levees are usually setback from the river on the floodplain, but can control the water surface in the channel if the flood is confined by the floodplain levees. Channel infiltration is based solely on the hydraulic conductivity and represents average bed and bank seepage conditions. Bed scour or deposition associated with a mobile analysis is non-uniformly distributed on the channel cross section. Finally, mudflows can be routed in channels.

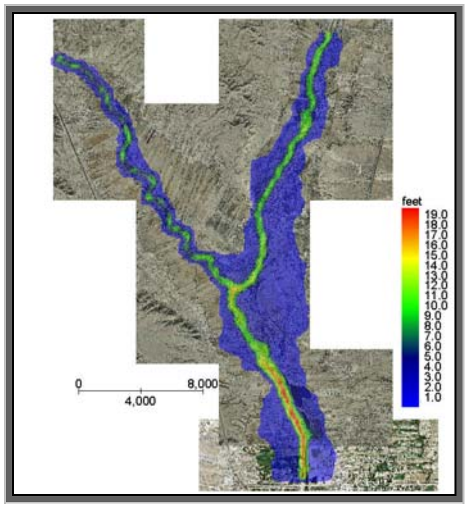

Figure 24. Middle Rio Grande and Rio Chama Confluence Model

5.2 Unconfined Overland and Alluvial Fan Floodimg

The primary focus of an unconfined flood simulation is how the volume is distributed over the floodplain surface. The flood volume controls the area of inundation (Figure 25). Important flood routing details include topography, spatial variation in infiltration and roughness, flow obstructions, levees, hydraulic structures and streets. The floodwave progression over the floodplain can be adjusted with the floodplain n-values. Street flow may control shallow flooding distribution in urban areas. Buildings and walls that obstruct flow paths and or eliminate floodplain storage (Figure 26). The levee routine can be used to simulate berms, elevated road fill, railroad embankments or other topographic features to confine the flow on the floodplain. Hydraulic conveyance facilities such as culverts, rainfall and gully flow may control the local water surface elevations.

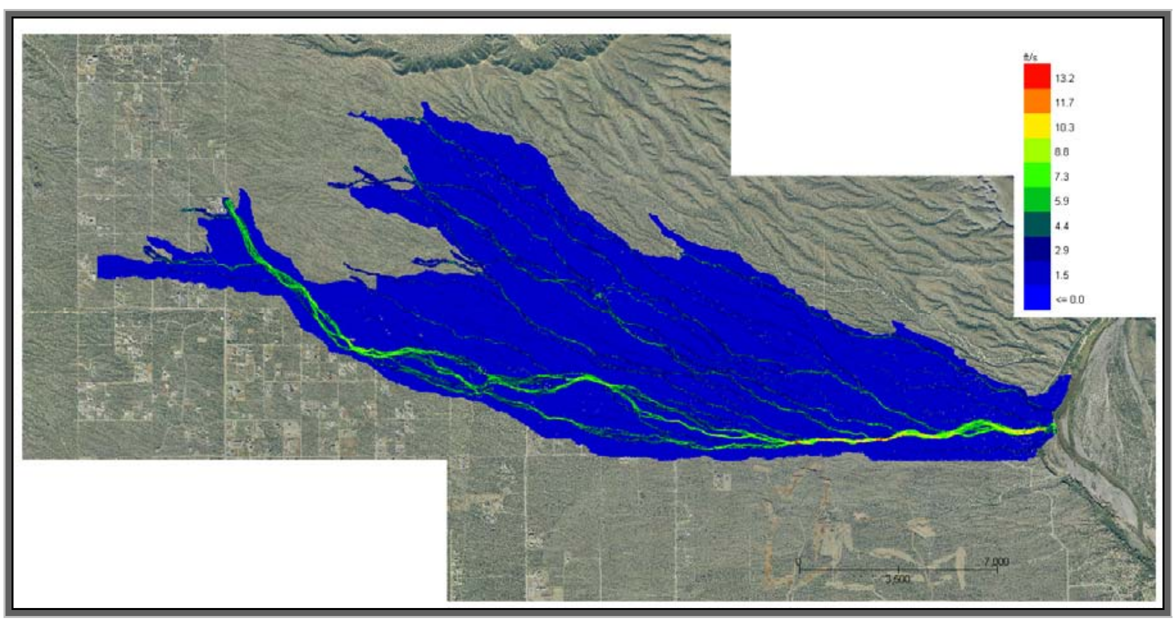

Figure 25. Unconfined Alluvial Fan Flooding

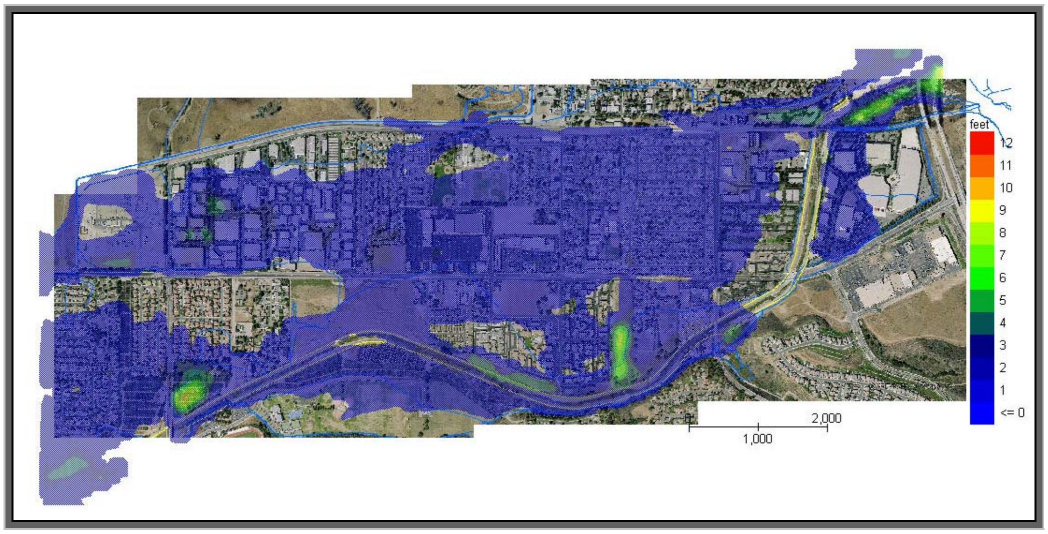

Figure 26. Urban flooding with Street Flow and Building Obstruction

FLO-2D can simulate an unconfined floodwave progression over a dry flow domain without specifying any boundary criteria. No hot starts or prescribed water surface elevations are required. It is possible to use the overland flow component to model various floodplain features such as detention basins, river channels or even streets. Flood retention basins have been modeled as part of the entire floodplain system using either the grid element elevation or levees to define the basin storage area. An appropriate grid element size should be selected to generate enough interior elements to adequately simulate the basin or channel. It should be noted that modeling the channel interior may require very small timesteps. Manning's open channel flow equation for the friction slope that is based on uniform, steady flow may not be appropriate if the water is ponded and the water surface is very flat.

If no inflow flood hydrograph data is available, FLO-2D can perform as a watershed model. Rainfall can occur on the floodplain surface resulting in sheet runoff after infiltration losses have been computed. It is possible to simulate rainfall while routing a flood event and have the rainfall occur on the inundated area. To improve concentration time, rill and gullies can be modeled to exchange flow between grid elements. This will reduce the travel time associated with sheet flow exchange between grid elements. Spatially variable rainfall distribution and a moving storm can be simulated. Real time rain gage data can also be modeled. The GDS will reformat the rain gage data for real time storm runoff and flood simulation.

Mud and debris flows can be simulated on alluvial fan surfaces. There are two methods for loading the hydrograph with sediment. A sediment concentration by volume is assigned to a discretized time interval of the inflow hydrograph. A second method is to load the inflow hydrograph with a volume of sediment. In this manner, spatially differential sediment loading in a watershed channel can be simulated. Once the hydrograph is bulked with sediment, the mudflow is routed as a water and sediment continuum over the hydrograph. The same water routing algorithm is used for mudflows but the momentum equation is solved with the additional viscous and yield stress terms. The bulked sediment hydrograph is tracked through system conserving volume for both water and sediment. Flow cessation and flow dilution are possible outcomes of the mudflow routing.

5.3 Model Results – What Constitutes a Successful Flood Simulation?

When a FLO-2D simulation is completed, how do you know if the simulation was successful or accurate? There are three keys to a successful project application:

- Volume conservation
- Area of inundation
- Maximum velocities and numerical surging.

Volume conservation must be conserved for both the overland flow and channel flow. If the volume was not conserved, then it will be necessary to conduct a more detailed review and determine where the volume conservation error occurred. If the volume was conserved, then the area of inundation can be quickly reviewed in either MAXPLOT or MAPPER programs. If the area of inundation seems reasonable and the flood appears to have progressed completely through the system, then the maximum velocities in the channel, on the floodplain or in the streets should be reviewed for discharge surging. By reviewing the results in MAXPLOT or MAPPER, the maximum floodplain velocities can be checked for unreasonably high velocities. The *Pocket Guide* and troubleshooting section in the Data Input Manual has more discussion on maximum velocities, numerical surging and how to resolve them including applications of the limiting Froude number.

Once the FLO-2D flood simulation is providing reasonable results, you can fine tune the model and speed it up. Review the TIME.OUT file to determine which channel, floodplain or street elements are causing the most timestep reductions. Model speed may not be critical if the simulation is accurate with respect to volume conservation, discharge surging and area of inundation.

VI. FLO-2D MODEL VALIDATION

The FLO-2D model has been applied on numerous projects by engineers and floodplain managers worldwide. Many users have performed validity tests including physical model studies. Users evaluate must whether the predicted hydraulics are reasonable and accurate for their projects. On occasion, a simulation may require some assistance to address a complex flow problem.

In January 1999, the Sacramento District Corps of Engineers conducted a review of several model applications, including a number of unconfined flood hazard projects, a California Aqueduct test case and replication model of the Arroyo Pasajero March 1995 alluvial fan flooding. Over a three-year period, the Corps actively engaged in model enhancement, code modification and model testing to expand the model applicability. In January 1999, the Sacramento District prepared a FLO-2D acceptance letter to FEMA. In early 2001, the Albuquerque District of the Corps of Engineers also completed a review of the FLO-2D model for riverine studies and submitted an acceptance letters to FEMA in support of using the FLO-2D for flood insurance studies. FLO-2D is on FEMA's list of approved hydraulic models for both riverine and overland flow (alluvial fan) flood studies.

Validation of hydraulic models with actual flood events is dependent on several factors including estimates of flow volume and area of inundation, appropriate estimates of flow resistance, representative conveyance geometry, accurate overland topography and measured flow hydraulics including water surface elevation, velocities and flow depths. The tools for validating hydraulic models include physical model (prototype) studies, comparison with other hydraulic numerical models or replication of past flood events. FLO-2D Software, Inc. maintains a series of validation tests. Ideally, the best model test involves the prediction of a flood event before it occurs; however, the probability of an actual flood having the similar volume to the predicted flood event is remote.

To confirm the accuracy of the FLO-2D model, several validation methods are maintained:

- Channel flow in the mild sloped California Aqueduct;
- Channel flow results compared to HEC-2 model results;
- Channel and floodplain flow routing for an actual river flood, Truckee River;
- Channel routing in a large river system (Green River) with a dam release floodwave;
- Comparison of floodplain inundation with mapped wetted acreage (Middle Rio Grande);
- Verification of mudflow hydraulics through replication of a know event (Rudd Creek);
- Flume discharge for steady, uniform flow using the overland flood routing component (compared with the analog results);
- Channel replication of measured river gaging discharge (Rio Grande, Figure 27).

In the last case, the replication of dam release discharge with highly unsteady flow 30 miles downstream reveals the robust nature of the solution algorithm. The results of these tests confirm that the FLO-2D computation algorithms are accurate for both channel and overland flood routing.

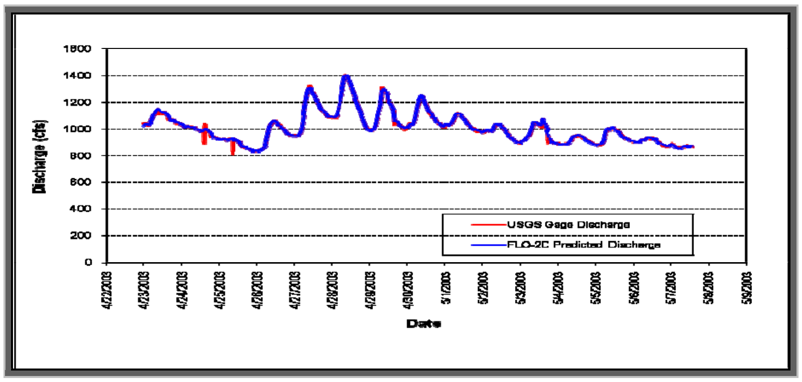

Figure 27. FLO-2D versus USGS Measured Gage Data

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APPENDIX 7-4: HAZUS Technical Manual

(Provided on attached CD in file Att7_SWF_TechJust_3of3)

APPENDIX 7-5: HAZUS Modeling Output

Overview of Hazus Output Data: Existing conditions (Without Project) - 25 year

	HAZUS value	Hazus output summary file
Area Flooded (acres)	204	no file (calculated in FLO2D)
Physical Damage		
# of structures affected (Hazus damaged)	3	structcount
# of structures in floodplain	985	structcount
value of structures affected($M)	$ 2.86	directloss (cap stock losses)
Loss of Function		
Lost business net income($M)	$ 0.14	directloss (cap related loss)
Lost Rental Income ($M)	$ 0.01	directloss
Loss of Wages ($M)	$ 0.33	directloss
Loss of Transportation/Utility Services ($M)	$ 0.001	transportation, utilities
Emergency Response/Clean-Up Costs		
Displacement/relocation costs ($M)	$ 0.08	directloss
Clean-Up		
debris (tons)	160	debris
truckloads (@25tons/truck)	6	debris
Displacement/Shelter		
# of displaced people	4285	displace_shelt
# of people needing short term shelter	3622	displace_shelt
Vehicles affected and value (day)		
car ($)	$ 249,074.00	vehicleday
light truck ($)	$ 145,980.00	vehicleday
heavy truck($)	$ 16,497.00	vehicleday
total loss ($)	$ 411,551.00	vehicleday

Overview of Hazus Output Data: Existing conditions (Without Project) - 50

	HAZUS value	
Area Flooded (acres)	610	
Physical Damage		
# of structures affected (Hazus damaged)	34	
# of structures in floodplain	2301	
value of structures affected($M)	$	17.55
Loss of Function		
Lost business net income($M)	$	0.52
Lost Rental Income ($M)	$	0.09
Loss of Wages ($M)	$	1.70
Loss of Transportation/Utility Services ($M)	$	0.002
Emergency Response/Clean-Up Costs		
Displacement costs ($M)	$	0.27
Clean-Up		
debris (tons)	868	
truckloads (@25tons/truck)	35	
Displacement/Shelter		
# of displaced people	10197	
# of people needing short term shelter	9074	
Vehicles affected and value (day)		
car ($)	$	1,155,402.00
light truck ($)	$	674,286.00
heavy truck($)	$	64,455.00
total loss ($)	$	1,894,143.00

year

Hazus output summary file
no file (calculated in ArcMap)
structcount
structcount
directloss (cap stock loss)
directloss (cap related loss)
directloss
directloss
transportation, utilities
displace_shelt
debris
debris
displace_shelt
displace_shelt
vehicleday
vehicleday
vehicleday
vehicleday

Overview of Hazus Output Data: Existing conditions (Without Project) - 100 year

	HAZUS value	Hazus output summary file
Area Flooded (acres)	950	no file (calculated in ArcMap)
Physical Damage		
# of structures affected (Hazus damaged)	104	structcount
# of structures in floodplain	3074	structcount
value of structures affected($M)	$ 50.70	directloss (cap stock losses)
Loss of Function		
Lost business net income($M)	$ 0.75	directloss (cap related loss)
Lost Rental Income ($M)	$ 0.14	directloss
Loss of Wages ($M)	$ 2.04	directloss
Loss of Transportation/Utility Services ($M)	$ 0.005	transportation, utilities
Emergency Response/Clean-Up Costs		
Displacement/relocation costs ($M)	$ 0.39	directloss
Clean-Up		
debris (tons)	2263	debris
truckloads (@25tons/truck)	91	debris
Displacement/Shelter		
# of displaced people	13717	displace_shelt
# of people needing short term shelter	12535	displace_shelt
Vehicles affected and value (day)		
car ($)	$ 2,479,398.00	vehicleday
light truck ($)	$ 1,416,639.00	vehicleday
heavy truck($)	$ 150,092.00	vehicleday
total loss ($)	$ 4,046,129.00	vehicleday

Overview of Hazus Output Data: Design Conditions (With Project) - 25 year

	HAZUS value	Hazus output summary file
Area Flooded (acres)	11	no file (calculated in ArcMap)
Physical Damage		
# of structures affected (Hazus damaged)	0	structcount
# of structures in floodplain	48	structcount
value of structures affected($M)	$ 0.02	directloss (cap stock losses)
Loss of Function		
Lost business net income($M)	$ -	directloss (cap related loss)
Lost Rental Income ($M)	$ -	directloss
Loss of Wages ($M)	$ -	directloss
Loss of Transportation/Utility Services ($M)	$ -	transportation, utilities
Emergency Response/Clean-Up Costs		
Displacement/relocation costs ($M)	$ 0.004	directloss
Clean-Up		
debris (tons)	1	debris
truckloads (@25tons/truck)	1	debris
Displacement/Shelter		
# of displaced people	147	displace_shelt
# of people needing short term shelter	111	displace_shelt
Vehicles affected and value (day)		
car ($)	$ 3,922.00	vehicleday
light truck ($)	$ 2,092.00	vehicleday
heavy truck($)	$ 173.00	vehicleday
total loss ($)	$ 6,187.00	vehicleday

Overview of Hazus Output Data: Design Conditions (With Project) - 50 year

	HAZUS value	Hazus output summary file
Area Flooded (acres)	14	no file (calculated in ArcMap)
Physical Damage		
# of structures affected (Hazus damaged)	0	structcount
# of structures in floodplain	61	structcount
value of structures affected($M)	$ 0.02	directloss (cap stock losses)
Loss of Function		
Lost business net income($M)	$ -	directloss (cap related loss)
Lost Rental Income ($M)	$ -	directloss
Loss of Wages ($M)	$ -	directloss
Loss of Transportation/Utility Services ($M)	$ -	transportation, utilities
Emergency Response/Clean-Up Costs		
Displacement/relocation costs ($M)	$ 0.004	directloss
Clean-Up		
debris (tons)	1	debris
truckloads (@25tons/truck)	1	debris
Displacement/Shelter		
# of displaced people	183	displace_shelt
# of people needing short term shelter	136	displace_shelt
Vehicles affected and value (day)		
car ($)	$ 6,257.00	vehicleday
light truck ($)	$ 3,430.00	vehicleday
heavy truck($)	$ 384.00	vehicleday
total loss ($)	$ 10,071.00	vehicleday

HAZUS-MH: Flood Event Report

Region Name: PermanentePDHale

Flood Scenario: exist25yr2

Print Date: Thursday, December 20, 2012

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social

Table of Contents

General Description of the Region

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- California

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 16 square miles and contains 691 census blocks. The region contains over 22 thousand households and has a total population of 51,912 people (2000 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 17,241 buildings in the region with a total building replacement value (excluding contents) of 6,611 million dollars (2006 dollars). Approximately 89.58% of the buildings (and 74.63% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 17,241 buildings in the region which have an aggregate total replacement value of 6,611 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,934,180	74.6%
Commercial	1,222,007	18.5%
Industrial	256,760	3.9%
Agricultural	66,649	1.0%
Religion	63,762	1.0%
Government	11,916	0.2%
Education	55,859	0.8%
Total	**6,611,133**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	1,246,093	84.0%
Commercial	136,557	9.2%
Industrial	22,958	1.5%
Agricultural	57,624	3.9%
Religion	10,540	0.7%
Government	1,000	0.1%
Education	8,758	0.6%
Total	**1,483,530**	**100.00%**

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 286 beds.
There are 23 schools, 5 fire stations, 1 police station and no emergency operation centers.

Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	PermanentePDHale
Scenario Name:	exist25yr2
Return Period Analyzed:	25
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

HAZUS estimates that about 3 buildings will be at least moderately damaged. This is over 0% of the total number of buildings in the scenario. There are an estimated 0 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS Flood technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	3	100.00	0	0.00	0	0.00	0	0.00
Total	**0**		**0**		**3**		**0**		**0**		**0**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	3	100.00	0	0.00	0	0.00	0	0.00

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 286 hospital beds available for use. On the day of the scenario flood event, the model estimates that 286 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	5	0	0	0
Hospitals	1	0	0	0
Police Stations	1	0	0	0
Schools	23	3	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 160 tons of debris will be generated. Of the total amount, Finishes comprises 100% of the total, Structure comprises 0% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 6 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 1,428 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 3,622 people (out of a total population of 51,912) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 13.70 million dollars, which represents 0.15 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 2.86 million dollars. 17% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 54.19% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	1.10	0.25	0.04	0.00	1.39
	Content	0.67	0.72	0.07	0.00	1.46
	Inventory	0.00	0.00	0.01	0.00	0.01
	Subtotal	**1.77**	**0.97**	**0.12**	**0.00**	**2.86**
Business Interruption						
	Income	0.00	0.06	0.00	0.08	0.14
	Relocation	0.07	0.01	0.00	0.00	0.08
	Rental Income	0.01	0.00	0.00	0.00	0.01
	Wage	0.00	0.09	0.00	0.24	0.33
	Subtotal	**0.09**	**0.16**	**0.00**	**0.32**	**0.57**
ALL	**Total**	**1.86**	**1.13**	**0.12**	**0.32**	**3.43**

Appendix A: County Listing for the Region

California

- Santa Clara

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
California				
Santa Clara	51,912	4,934,180	1,676,953	6,611,133
Total	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**
Total Study Region	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**

Debris Summary Report

January 10, 2013 *All values are in tons.*

	Finishes	Structures	Foundations	Total
California				
Santa Clara	160	0	0	160
Total	**160**	**0**	**0**	**160**
Scenario Total	**160**	**0**	**0**	**160**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Direct Economic Losses for Buildings

January 10, 2013

All values are in thousands of dollars

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
California									
Santa Clara	1,387	1,460	11	0.1	80	141	334	12	3,425
Total	**1,387**	**1,460**	**11**	**0.10**	**80**	**141**	**334**	**12**	**3,425**
Scenario Total	**1,387**	**1,460**	**11**	**0.10**	**80**	**141**	**334**	**12**	**3,425**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: exist25yr2
Return Period: 25

Shelter Summary Report

January 10, 2013

	# of Displaced People	# of People Needing Short Term Shelter
California		
Santa Clara	4,285	3,622
Total	**4,285**	**3,622**
Scenario Total	**4,285**	**3,622**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale

Scenario: exist25yr2

Return Period: 25

Income and Employment Impact (with outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.019	0.002	0.000	0.000	-0.001	-0.001	-0.001	0.000	0.018
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.012	0.001	-0.001	-0.001	-0.002	-0.004	-0.002	0.000	0.002
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.001	0.002	-0.001	0.004	-0.003	-0.006	-0.002	0.000	-0.007
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.001	0.002	-0.001	0.004	-0.003	-0.006	-0.002	0.000	-0.007

Income and Employment Impact (with outside aid)

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.001	0.002	-0.001	0.004	-0.003	-0.006	-0.002	0.000	-0.007

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (without outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.290	0.056	0.000	0.017	0.000	-0.001	0.000	0.000	0.363
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.130	0.027	0.000	0.008	0.000	0.000	0.000	0.000	0.165
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.003	0.000	0.007	0.000	0.000	0.000	0.000	0.010
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.003	0.000	0.007	0.000	0.000	0.000	0.000	0.010
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.003	0.000	0.007	0.000	0.000	0.000	0.000	0.010

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: exist25yr2
Return Period: 25

Building Damage Count by General Building Type

January 10, 2013

	Count of Buildings (#) by Range of Damage (%)							
	None	**1-10**	**11-20**	**21-30**	**31-40**	**41-50**	**Substantial**	**Total**
California								
Santa Clara								
Concrete	1	0	0	0	0	0	0	1
ManufHousing	1	0	0	0	0	0	0	1
Masonry	3	0	0	0	0	0	0	3
Steel	1	0	0	0	0	0	0	1
Wood	976	0	0	3	0	0	0	979
Total	**982**	**0**	**0**	**3**	**0**	**0**	**0**	**985**
Total	**982**	**0**	**0**	**3**	**0**	**0**	**0**	**985**
Scenario Total	**982**	**0**	**0**	**3**	**0**	**0**	**0**	**985**

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Direct Economic Loss For Transportation

January 10, 2013

All values are in thousands of dollars

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
California								
Santa Clara								
Segments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Bridges	$1.15	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1.15
Tunnels	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$1.15**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$1.15**
Total	**$1.15**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$1.15**
Scenario Total	**$1.15**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$1.15**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: exist25yr2
Return Period: 25

Direct Economic Losses for Utilities

January 10, 2013

All values are in thousands of dollars.

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
California							
Santa Clara							
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pipelines	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale

Scenario: exist25yr2

Return Period: 25

Direct Economic Losses For Vehicles (Day)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	249,074	145,980	16,497	411,551
Total	**249,074**	**145,980**	**16,497**	**411,551**
Scenario Total	**249,074**	**145,980**	**16,497**	**411,551**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: exist25yr2
Return Period: 25

Direct Economic Losses For Vehicles (Night)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	270,765	152,344	17,325	440,434
Total	**270,765**	**152,344**	**17,325**	**440,434**
Scenario Total	**270,765**	**152,344**	**17,325**	**440,434**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: exist25yr2
Return Period: 25

HAZUS-MH: Flood Event Report

Region Name: PermHalePD

Flood Scenario: Exist50yr

Print Date: Thursday, December 20, 2012

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social

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General Description of the Region

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- California

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 16 square miles and contains 691 census blocks. The region contains over 22 thousand households and has a total population of 51,912 people (2000 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 17,241 buildings in the region with a total building replacement value (excluding contents) of 6,611 million dollars (2006 dollars). Approximately 89.58% of the buildings (and 74.63% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 17,241 buildings in the region which have an aggregate total replacement value of 6,611 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,934,180	74.6%
Commercial	1,222,007	18.5%
Industrial	256,760	3.9%
Agricultural	66,649	1.0%
Religion	63,762	1.0%
Government	11,916	0.2%
Education	55,859	0.8%
Total	**6,611,133**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	2,441,567	79.4%
Commercial	458,015	14.9%
Industrial	61,754	2.0%
Agricultural	58,467	1.9%
Religion	29,600	1.0%
Government	9,975	0.3%
Education	16,183	0.5%
Total	**3,075,561**	**100.00%**

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 286 beds.
There are 23 schools, 5 fire stations, 1 police station and no emergency operation centers.

Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	PermHalePD
Scenario Name:	Exist50yr
Return Period Analyzed:	50
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

HAZUS estimates that about 36 buildings will be at least moderately damaged. This is over 2% of the total number of buildings in the scenario. There are an estimated 0 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS Flood technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	3	100.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	5	15.15	28	84.85	0	0.00	0	0.00	0	0.00
Total	**0**		**8**		**28**		**0**		**0**		**0**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	6	17.65	28	82.35	0	0.00	0	0.00	0	0.00

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 286 hospital beds available for use. On the day of the scenario flood event, the model estimates that 286 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	5	5	0	0
Hospitals	1	0	0	0
Police Stations	1	0	0	0
Schools	23	7	0	2

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 868 tons of debris will be generated. Of the total amount, Finishes comprises 99% of the total, Structure comprises 0% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 35 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 3,399 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 9,074 people (out of a total population of 51,912) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 60.38 million dollars, which represents 1.88 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 17.55 million dollars. 13% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 49.72% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	5.79	1.53	0.20	0.02	7.53
	Content	3.95	5.47	0.37	0.13	9.93
	Inventory	0.00	0.03	0.06	0.00	0.09
	Subtotal	**9.74**	**7.03**	**0.63**	**0.16**	**17.55**
Business Interruption						
	Income	0.01	0.40	0.00	0.11	0.52
	Relocation	0.18	0.08	0.00	0.00	0.27
	Rental Income	0.04	0.05	0.00	0.00	0.09
	Wage	0.04	0.46	0.00	1.21	1.70
	Subtotal	**0.27**	**0.99**	**0.00**	**1.32**	**2.58**
ALL	**Total**	**10.01**	**8.02**	**0.63**	**1.48**	**20.13**

Appendix A: County Listing for the Region

California

- Santa Clara

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
California				
Santa Clara	51,912	4,934,180	1,676,953	6,611,133
Total	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**
Total Study Region	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**

Debris Summary Report

January 08, 2013

All values are in tons.

	Finishes	Structures	Foundations	Total
California				
Santa Clara	861	3	4	868
Total	**861**	**3**	**4**	**868**
Scenario Total	**861**	**3**	**4**	**868**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Exist50yr
Return Period: 50

Direct Economic Losses for Buildings

January 08, 2013 | *All values are in thousands of dollars*

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
California									
Santa Clara	7,534	9,925	91	0.2	267	522	1,702	85	20,126
Total	**7,534**	**9,925**	**91**	**0.20**	**267**	**522**	**1,702**	**85**	**20,126**
Scenario Total	**7,534**	**9,925**	**91**	**0.20**	**267**	**522**	**1,702**	**85**	**20,126**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Shelter Summary Report

January 08, 2013

	# of Displaced People	# of People Needing Short Term Shelter
California		
Santa Clara	10,197	9,074
Total	**10,197**	**9,074**
Scenario Total	**10,197**	**9,074**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (with outside aid)

January 08, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.040	0.005	-0.001	0.001	-0.002	-0.003	-0.001	0.000	0.039
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.025	0.003	-0.002	-0.002	-0.005	-0.010	-0.004	0.000	0.005
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.001	0.004	-0.003	0.008	-0.006	-0.012	-0.005	0.000	-0.015
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.001	0.004	-0.003	0.008	-0.006	-0.012	-0.005	0.000	-0.015

Income and Employment Impact (with outside aid)

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.001	0.004	-0.003	0.008	-0.006	-0.012	-0.005	0.000	-0.015

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (without outside aid)

January 08, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.625	0.121	-0.001	0.038	0.000	-0.001	0.000	0.000	0.781
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.280	0.059	0.000	0.017	0.000	0.000	0.000	0.000	0.356
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.007	0.000	0.015	0.000	0.000	0.000	0.000	0.022
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.007	0.000	0.015	0.000	0.000	0.000	0.000	0.022
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.007	0.000	0.015	0.000	0.000	0.000	0.000	0.022

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Exist50yr
Return Period: 50

Building Damage Count by General Building Type

January 08, 2013

	Count of Buildings (#) by Range of Damage (%)							
	None	1-10	11-20	21-30	31-40	41-50	Substantial	Total
California								
Santa Clara								
Steel	6	0	0	0	0	0	0	6
Wood	2,218	0	6	28	0	0	0	2,252
Masonry	13	0	0	0	0	0	0	13
Concrete	5	0	0	0	0	0	0	5
ManufHousing	25	0	0	0	0	0	0	25
Total	**2,267**	**0**	**6**	**28**	**0**	**0**	**0**	**2,301**
Total	**2,267**	**0**	**6**	**28**	**0**	**0**	**0**	**2,301**
Scenario Total	**2,267**	**0**	**6**	**28**	**0**	**0**	**0**	**2,301**

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Exist50yr
Return Period: 50

Direct Economic Loss For Transportation

January 08, 2013

All values are in thousands of dollars

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
California								
Santa Clara								
Segments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Bridges	$2.29	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2.29
Tunnels	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$2.29**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$2.29**
Total	**$2.29**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$2.29**
Scenario Total	**$2.29**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$2.29**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Exist50yr
Return Period: 50

Direct Economic Losses for Utilities

January 08, 2013

All values are in thousands of dollars.

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
California							
Santa Clara							
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pipelines	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Direct Economic Losses For Vehicles (Day)

January 08, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	1,155,402	674,286	64,455	1,894,143
Total	**1,155,402**	**674,286**	**64,455**	**1,894,143**
Scenario Total	**1,155,402**	**674,286**	**64,455**	**1,894,143**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Exist50yr
Return Period: 50

Direct Economic Losses For Vehicles (Night)

January 08, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	1,112,974	623,967	68,683	1,805,624
Total	**1,112,974**	**623,967**	**68,683**	**1,805,624**
Scenario Total	**1,112,974**	**623,967**	**68,683**	**1,805,624**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Exist50yr
Return Period: 50

HAZUS-MH: Flood Event Report

Region Name: PermanentePDHale

Flood Scenario: PDHale100Exist

Print Date: Thursday, December 20, 2012

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social

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General Description of the Region

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- California

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 16 square miles and contains 691 census blocks. The region contains over 22 thousand households and has a total population of 51,912 people (2000 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 17,241 buildings in the region with a total building replacement value (excluding contents) of 6,611 million dollars (2006 dollars). Approximately 89.58% of the buildings (and 74.63% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 17,241 buildings in the region which have an aggregate total replacement value of 6,611 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,934,180	74.6%
Commercial	1,222,007	18.5%
Industrial	256,760	3.9%
Agricultural	66,649	1.0%
Religion	63,762	1.0%
Government	11,916	0.2%
Education	55,859	0.8%
Total	**6,611,133**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	2,781,420	77.1%
Commercial	587,459	16.3%
Industrial	119,112	3.3%
Agricultural	59,306	1.6%
Religion	32,841	0.9%
Government	10,972	0.3%
Education	17,505	0.5%
Total	**3,608,615**	**100.00%**

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 286 beds.
There are 23 schools, 5 fire stations, 1 police station and no emergency operation centers.

Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	PermanentePDHale
Scenario Name:	PDHale100Exist
Return Period Analyzed:	100
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

HAZUS estimates that about 105 buildings will be at least moderately damaged. This is over 3% of the total number of buildings in the scenario. There are an estimated 0 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS Flood technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	5	100.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	17	17.00	82	82.00	0	0.00	1	1.00	0	0.00
Total	**0**		**22**		**82**		**0**		**1**		**0**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	1	100.00	0	0.00
Masonry	0	0.00	1	100.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	1	100.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	19	18.81	82	81.19	0	0.00	0	0.00	0	0.00

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 286 hospital beds available for use. On the day of the scenario flood event, the model estimates that 286 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	5	5	0	0
Hospitals	1	0	0	0
Police Stations	1	0	0	0
Schools	23	9	0	3

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 2,263 tons of debris will be generated. Of the total amount, Finishes comprises 98% of the total, Structure comprises 1% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 91 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 4,572 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 12,535 people (out of a total population of 51,912) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 108.02 million dollars, which represents 2.53 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 50.69 million dollars. 6% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 46.08% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	14.84	5.10	1.47	0.04	21.44
	Content	9.68	15.54	3.26	0.25	28.73
	Inventory	0.00	0.14	0.35	0.04	0.52
	Subtotal	**24.52**	**20.77**	**5.08**	**0.33**	**50.69**
Business Interruption						
	Income	0.01	0.60	0.00	0.13	0.75
	Relocation	0.25	0.13	0.00	0.00	0.39
	Rental Income	0.06	0.08	0.00	0.00	0.14
	Wage	0.04	0.65	0.01	1.35	2.04
	Subtotal	**0.37**	**1.46**	**0.01**	**1.48**	**3.32**
ALL	**Total**	**24.89**	**22.22**	**5.09**	**1.81**	**54.01**

Appendix A: County Listing for the Region

California

- Santa Clara

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
California				
Santa Clara	51,912	4,934,180	1,676,953	6,611,133
Total	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**
Total Study Region	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**

Debris Summary Report

January 10, 2013 *All values are in tons.*

	Finishes	Structures	Foundations	Total
California				
Santa Clara	2,217	14	33	2,263
Total	**2,217**	**14**	**33**	**2,263**
Scenario Total	**2,217**	**14**	**33**	**2,263**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

Direct Economic Losses for Buildings

January 10, 2013

All values are in thousands of dollars

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
California									
Santa Clara	21,442	28,730	522	0.6	386	749	2,039	141	54,009
Total	**21,442**	**28,730**	**522**	**0.60**	**386**	**749**	**2,039**	**141**	**54,009**
Scenario Total	**21,442**	**28,730**	**522**	**0.60**	**386**	**749**	**2,039**	**141**	**54,009**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

Shelter Summary Report

January 10, 2013

	# of Displaced People	# of People Needing Short Term Shelter
California		
Santa Clara	13,717	12,535
Total	**13,717**	**12,535**
Scenario Total	**13,717**	**12,535**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

Income and Employment Impact (with outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.050	0.006	-0.001	0.001	-0.002	-0.004	-0.002	0.000	0.049
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.031	0.003	-0.002	-0.003	-0.006	-0.012	-0.005	0.000	0.007
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.002	0.005	-0.003	0.010	-0.007	-0.015	-0.006	0.000	-0.019
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.002	0.005	-0.003	0.010	-0.007	-0.015	-0.006	0.000	-0.019

Income and Employment Impact (with outside aid)

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	-0.002	0.005	-0.003	0.010	-0.007	-0.015	-0.006	0.000	-0.019

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (without outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.787	0.152	-0.001	0.047	0.000	-0.002	0.000	0.000	0.984
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.353	0.074	0.000	0.021	0.000	0.000	0.000	0.000	0.448
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.008	0.000	0.019	0.000	0.000	0.000	0.000	0.028
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.008	0.000	0.019	0.000	0.000	0.000	0.000	0.028
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.008	0.000	0.019	0.000	0.000	0.000	0.000	0.028

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

Building Damage Count by General Building Type

January 10, 2013

	Count of Buildings (#) by Range of Damage (%)							
	None	**1-10**	**11-20**	**21-30**	**31-40**	**41-50**	**Substantial**	**Total**
California								
Santa Clara								
ManufHousing	74	0	0	0	0	1	0	75
Concrete	8	0	0	0	0	0	0	8
Wood	2,863	0	19	82	0	0	0	2,964
Masonry	18	0	1	0	0	0	0	19
Steel	7	0	1	0	0	0	0	8
Total	**2,970**	**0**	**21**	**82**	**0**	**1**	**0**	**3,074**
Total	**2,970**	**0**	**21**	**82**	**0**	**1**	**0**	**3,074**
Scenario Total	**2,970**	**0**	**21**	**82**	**0**	**1**	**0**	**3,074**

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Direct Economic Loss For Transportation

January 10, 2013

All values are in thousands of dollars

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
California								
Santa Clara								
Segments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Bridges	$4.59	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4.59
Tunnels	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$4.59**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$4.59**
Total	**$4.59**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$4.59**
Scenario Total	**$4.59**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$4.59**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

Direct Economic Losses for Utilities

January 10, 2013

All values are in thousands of dollars.

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
California							
Santa Clara							
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pipelines	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

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Direct Economic Losses For Vehicles (Day)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	2,479,398	1,416,639	150,092	4,046,129
Total	**2,479,398**	**1,416,639**	**150,092**	**4,046,129**
Scenario Total	**2,479,398**	**1,416,639**	**150,092**	**4,046,129**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

Direct Economic Losses For Vehicles (Night)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	2,184,921	1,221,338	159,801	3,566,060
Total	**2,184,921**	**1,221,338**	**159,801**	**3,566,060**
Scenario Total	**2,184,921**	**1,221,338**	**159,801**	**3,566,060**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100Exist
Return Period: 100

HAZUS-MH: Flood Event Report

Region Name: PermHalePD

Flood Scenario: Design25yr

Print Date: Thursday, December 20, 2012

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

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HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- California

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 16 square miles and contains 691 census blocks. The region contains over 22 thousand households and has a total population of 51,912 people (2000 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 17,241 buildings in the region with a total building replacement value (excluding contents) of 6,611 million dollars (2006 dollars). Approximately 89.58% of the buildings (and 74.63% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 17,241 buildings in the region which have an aggregate total replacement value of 6,611 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,934,180	74.6%
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Industrial	256,760	3.9%
Agricultural	66,649	1.0%
Religion	63,762	1.0%
Government	11,916	0.2%
Education	55,859	0.8%
Total	**6,611,133**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	59,497	95.7%
Commercial	1,929	3.1%
Industrial	754	1.2%
Agricultural	0	0.0%
Religion	0	0.0%
Government	0	0.0%
Education	0	0.0%
Total	**62,180**	**100.00%**

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 286 beds.
There are 23 schools, 5 fire stations, 1 police station and no emergency operation centers.

Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	PermHalePD
Scenario Name:	Design25yr
Return Period Analyzed:	25
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

HAZUS estimates that about 0 buildings will be at least moderately damaged. This is over 0% of the total number of buildings in the scenario. There are an estimated 0 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS Flood technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	**0**		**0**		**0**		**0**		**0**		**0**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 286 hospital beds available for use. On the day of the scenario flood event, the model estimates that 286 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	5	0	0	0
Hospitals	1	0	0	0
Police Stations	1	0	0	0
Schools	23	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 1 tons of debris will be generated. Of the total amount, Finishes comprises 100% of the total, Structure comprises 0% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 0 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 49 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 111 people (out of a total population of 51,912) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 0.02 million dollars, which represents 0.03 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 0.02 million dollars. 20% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 70.00% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	0.01	0.00	0.00	0.00	0.01
	Content	0.00	0.01	0.00	0.00	0.01
	Inventory	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.01**	**0.01**	**0.00**	**0.00**	**0.02**
Business Interruption						
	Income	0.00	0.00	0.00	0.00	0.00
	Relocation	0.00	0.00	0.00	0.00	0.00
	Rental Income	0.00	0.00	0.00	0.00	0.00
	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
ALL	**Total**	**0.01**	**0.01**	**0.00**	**0.00**	**0.02**

Appendix A: County Listing for the Region

California

- Santa Clara

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
California				
Santa Clara	51,912	4,934,180	1,676,953	6,611,133
Total	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**
Total Study Region	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**

Debris Summary Report

January 10, 2013

All values are in tons.

	Finishes	Structures	Foundations	Total
California				
Santa Clara	1	0	0	1
Total	**1**	**0**	**0**	**1**
Scenario Total	**1**	**0**	**0**	**1**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Direct Economic Losses for Buildings

January 10, 2013

All values are in thousands of dollars

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
California									
Santa Clara	7	9	0	0.0	4	0	0	0	20
Total	**7**	**9**	**0**	**0.00**	**4**	**0**	**0**	**0**	**20**
Scenario Total	**7**	**9**	**0**	**0.00**	**4**	**0**	**0**	**0**	**20**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Shelter Summary Report

January 10, 2013

	# of Displaced People	# of People Needing Short Term Shelter
California		
Santa Clara	147	111
Total	**147**	**111**
Scenario Total	**147**	**111**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Income and Employment Impact (with outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Income and Employment Impact (with outside aid)

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (without outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Building Damage Count by General Building Type

January 10, 2013

	Count of Buildings (#) by Range of Damage (%)							
	None	**1-10**	**11-20**	**21-30**	**31-40**	**41-50**	**Substantial**	**Total**
California								
Santa Clara								
Concrete	0	0	0	0	0	0	0	0
ManufHousing	0	0	0	0	0	0	0	0
Masonry	0	0	0	0	0	0	0	0
Steel	0	0	0	0	0	0	0	0
Wood	48	0	0	0	0	0	0	48
Total	**48**	**0**	**0**	**0**	**0**	**0**	**0**	**48**
Total	**48**	**0**	**0**	**0**	**0**	**0**	**0**	**48**
Scenario Total	**48**	**0**	**0**	**0**	**0**	**0**	**0**	**48**

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Direct Economic Loss For Transportation

January 10, 2013

All values are in thousands of dollars

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
California								
Santa Clara								
Segments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Bridges	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Tunnels	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Direct Economic Losses for Utilities

January 10, 2013

All values are in thousands of dollars.

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
California							
Santa Clara							
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pipelines	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Direct Economic Losses For Vehicles (Day)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	3,922	2,092	173	6,187
Total	**3,922**	**2,092**	**173**	**6,187**
Scenario Total	**3,922**	**2,092**	**173**	**6,187**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

Direct Economic Losses For Vehicles (Night)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	7,250	3,915	196	11,361
Total	**7,250**	**3,915**	**196**	**11,361**
Scenario Total	**7,250**	**3,915**	**196**	**11,361**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design25yr
Return Period: 25

HAZUS-MH: Flood Event Report

Region Name: PermHalePD

Flood Scenario: Design50yr

Print Date: Thursday, December 20, 2012

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social

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General Description of the Region

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- California

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 16 square miles and contains 691 census blocks. The region contains over 22 thousand households and has a total population of 51,912 people (2000 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 17,241 buildings in the region with a total building replacement value (excluding contents) of 6,611 million dollars (2006 dollars). Approximately 89.58% of the buildings (and 74.63% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 17,241 buildings in the region which have an aggregate total replacement value of 6,611 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,934,180	74.6%
Commercial	1,222,007	18.5%
Industrial	256,760	3.9%
Agricultural	66,649	1.0%
Religion	63,762	1.0%
Government	11,916	0.2%
Education	55,859	0.8%
Total	**6,611,133**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	67,313	95.8%
Commercial	2,169	3.1%
Industrial	754	1.1%
Agricultural	0	0.0%
Religion	0	0.0%
Government	0	0.0%
Education	0	0.0%
Total	**70,236**	**100.00%**

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 286 beds.
There are 23 schools, 5 fire stations, 1 police station and no emergency operation centers.

Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	PermHalePD
Scenario Name:	Design50yr
Return Period Analyzed:	50
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

HAZUS estimates that about 0 buildings will be at least moderately damaged. This is over 0% of the total number of buildings in the scenario. There are an estimated 0 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS Flood technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	**0**		**0**		**0**		**0**		**0**		**0**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 286 hospital beds available for use. On the day of the scenario flood event, the model estimates that 286 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	5	0	0	0
Hospitals	1	0	0	0
Police Stations	1	0	0	0
Schools	23	0	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 1 tons of debris will be generated. Of the total amount, Finishes comprises 100% of the total, Structure comprises 0% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 0 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 61 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 136 people (out of a total population of 51,912) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 0.04 million dollars, which represents 0.03 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 0.02 million dollars. 20% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 70.00% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	0.01	0.00	0.00	0.00	0.01
	Content	0.00	0.01	0.00	0.00	0.01
	Inventory	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.01**	**0.01**	**0.00**	**0.00**	**0.02**
Business Interruption						
	Income	0.00	0.00	0.00	0.00	0.00
	Relocation	0.00	0.00	0.00	0.00	0.00
	Rental Income	0.00	0.00	0.00	0.00	0.00
	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
ALL	**Total**	**0.01**	**0.01**	**0.00**	**0.00**	**0.02**

Appendix A: County Listing for the Region

California

- Santa Clara

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
California				
Santa Clara	51,912	4,934,180	1,676,953	6,611,133
Total	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**
Total Study Region	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**

Debris Summary Report

January 10, 2013 *All values are in tons.*

	Finishes	Structures	Foundations	Total
California				
Santa Clara	1	0	0	1
Total	**1**	**0**	**0**	**1**
Scenario Total	**1**	**0**	**0**	**1**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

Direct Economic Losses for Buildings

January 10, 2013

All values are in thousands of dollars

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
California									
Santa Clara	7	9	0	0.0	4	0	0	0	20
Total	**7**	**9**	**0**	**0.00**	**4**	**0**	**0**	**0**	**20**
Scenario Total	**7**	**9**	**0**	**0.00**	**4**	**0**	**0**	**0**	**20**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Shelter Summary Report

January 10, 2013

	# of Displaced People	# of People Needing Short Term Shelter
California		
Santa Clara	183	136
Total	**183**	**136**
Scenario Total	**183**	**136**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

Income and Employment Impact (with outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Income and Employment Impact (with outside aid)

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (without outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

Building Damage Count by General Building Type

January 10, 2013

	Count of Buildings (#) by Range of Damage (%)							
	None	**1-10**	**11-20**	**21-30**	**31-40**	**41-50**	**Substantial**	**Total**
California								
Santa Clara								
Concrete	0	0	0	0	0	0	0	0
ManufHousing	0	0	0	0	0	0	0	0
Masonry	0	0	0	0	0	0	0	0
Steel	0	0	0	0	0	0	0	0
Wood	61	0	0	0	0	0	0	61
Total	**61**	**0**	**0**	**0**	**0**	**0**	**0**	**61**
Total	**61**	**0**	**0**	**0**	**0**	**0**	**0**	**61**
Scenario Total	**61**	**0**	**0**	**0**	**0**	**0**	**0**	**61**

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Direct Economic Loss For Transportation

January 10, 2013

All values are in thousands of dollars

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
California								
Santa Clara								
Segments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Bridges	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Tunnels	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

Direct Economic Losses for Utilities

January 10, 2013

All values are in thousands of dollars.

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
California							
Santa Clara							
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pipelines	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

Direct Economic Losses For Vehicles (Day)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	6,257	3,430	384	10,071
Total	**6,257**	**3,430**	**384**	**10,071**
Scenario Total	**6,257**	**3,430**	**384**	**10,071**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

Direct Economic Losses For Vehicles (Night)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	10,373	5,680	461	16,514
Total	**10,373**	**5,680**	**461**	**16,514**
Scenario Total	**10,373**	**5,680**	**461**	**16,514**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermHalePD
Scenario: Design50yr
Return Period: 50

HAZUS-MH: Flood Event Report

Region Name:	PermanentePDHale
Flood Scenario:	PDHale100design
Print Date:	Tuesday, December 18, 2012

Disclaimer:

Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social

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General Description of the Region

HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The flood loss estimates provided in this report were based on a region that included 1 county(ies) from the following state(s):

- California

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 16 square miles and contains 691 census blocks. The region contains over 22 thousand households and has a total population of 51,912 people (2000 Census Bureau data). The distribution of population by State and County for the study region is provided in Appendix B.

There are an estimated 17,241 buildings in the region with a total building replacement value (excluding contents) of 6,611 million dollars (2006 dollars). Approximately 89.58% of the buildings (and 74.63% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

HAZUS estimates that there are 17,241 buildings in the region which have an aggregate total replacement value of 6,611 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,934,180	74.6%
Commercial	1,222,007	18.5%
Industrial	256,760	3.9%
Agricultural	66,649	1.0%
Religion	63,762	1.0%
Government	11,916	0.2%
Education	55,859	0.8%
Total	**6,611,133**	**100.00%**

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	562,965	84.2%
Commercial	92,203	13.8%
Industrial	4,078	0.6%
Agricultural	469	0.1%
Religion	4,373	0.7%
Government	62	0.0%
Education	4,540	0.7%
Total	**668,690**	**100.00%**

Essential Facility Inventory

For essential facilities, there are 1 hospitals in the region with a total bed capacity of 286 beds.
There are 23 schools, 5 fire stations, 1 police station and no emergency operation centers.

Flood Scenario Parameters

HAZUS used the following set of information to define the flood parameters for the flood loss estimate provided in this report.

Study Region Name:	PermanentePDHale
Scenario Name:	PDHale100design
Return Period Analyzed:	100
Analysis Options Analyzed:	No What-Ifs

Building Damage

General Building Stock Damage

HAZUS estimates that about 0 buildings will be at least moderately damaged. This is over 0% of the total number of buildings in the scenario. There are an estimated 0 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS Flood technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	**0**		**0**		**0**		**0**		**0**		**0**	

Table 4: Expected Building Damage by Building Type

Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Masonry	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Steel	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Wood	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Essential Facility Damage

Before the flood analyzed in this scenario, the region had 286 hospital beds available for use. On the day of the scenario flood event, the model estimates that 286 hospital beds are available in the region.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	5	0	0	0
Hospitals	1	0	0	0
Police Stations	1	0	0	0
Schools	23	3	0	0

If this report displays all zeros or is blank, two possibilities can explain this.

(1) None of your facilities were flooded. This can be checked by mapping the inventory data on the depth grid.

(2) The analysis was not run. This can be tested by checking the run box on the Analysis Menu and seeing if a message box asks you to replace the existing results.

Induced Flood Damage

Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. The model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 95 tons of debris will be generated. Of the total amount, Finishes comprises 100% of the total, Structure comprises 0% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 4 truckloads (@25 tons/truck) to remove the debris generated by the flood.

Social Impact

Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 415 households will be displaced due to the flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 1,043 people (out of a total population of 51,912) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the flood is 2.98 million dollars, which represents 0.45 % of the total replacement value of the scenario buildings.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building-related losses were 2.69 million dollars. 10% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 35.86% of the total loss. Table 6 below provides a summary of the losses associated with the building damage.

Table 6: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	0.52	0.31	0.00	0.00	0.83
	Content	0.50	1.35	0.00	0.00	1.86
	Inventory	0.00	0.00	0.00	0.00	0.00
	Subtotal	**1.02**	**1.67**	**0.00**	**0.00**	**2.69**
Business Interruption						
	Income	0.00	0.06	0.00	0.01	0.07
	Relocation	0.03	0.01	0.00	0.00	0.05
	Rental Income	0.01	0.01	0.00	0.00	0.01
	Wage	0.01	0.13	0.00	0.03	0.17
	Subtotal	**0.05**	**0.21**	**0.00**	**0.04**	**0.29**
ALL	**Total**	**1.07**	**1.87**	**0.00**	**0.04**	**2.98**

Appendix A: County Listing for the Region

California

- Santa Clara

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars)		
		Residential	Non-Residential	Total
California				
Santa Clara	51,912	4,934,180	1,676,953	6,611,133
Total	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**
Total Study Region	**51,912**	**4,934,180**	**1,676,953**	**6,611,133**

Debris Summary Report

January 10, 2013 *All values are in tons.*

	Finishes	Structures	Foundations	Total
California				
Santa Clara	95	0	0	95
Total	**95**	**0**	**0**	**95**
Scenario Total	**95**	**0**	**0**	**95**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100design
Return Period: 100

Direct Economic Losses for Buildings

January 10, 2013

All values are in thousands of dollars

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
California									
Santa Clara	830	1,858	1	0.1	45	66	166	12	2,978
Total	**830**	**1,858**	**1**	**0.10**	**45**	**66**	**166**	**12**	**2,978**
Scenario Total	**830**	**1,858**	**1**	**0.10**	**45**	**66**	**166**	**12**	**2,978**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Shelter Summary Report

January 10, 2013

	# of Displaced People	# of People Needing Short Term Shelter
California		
Santa Clara	1,246	1,043
Total	**1,246**	**1,043**
Scenario Total	**1,246**	**1,043**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (with outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.005
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.003	0.000	0.000	0.000	-0.001	-0.001	-0.001	0.000	0.001
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.001	0.000	0.001	-0.001	-0.002	-0.001	0.000	-0.002
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.001	0.000	0.001	-0.001	-0.002	-0.001	0.000	-0.002

Income and Employment Impact (with outside aid)

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.001	0.000	0.001	-0.001	-0.002	-0.001	0.000	-0.002

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Income and Employment Impact (without outside aid)

January 10, 2013

Income impact in millions of dollars
Employment impact in number of employees
Positive values denote a gain, negative values denote a loss

	Agriculture	Mining	Construction	Manufacturing	Transportation	Trade	Finance	Services	Government	Miscellaneous	Total
First Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.087	0.017	0.000	0.005	0.000	0.000	0.000	0.000	0.109
Second Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.039	0.008	0.000	0.002	0.000	0.000	0.000	0.000	0.050
Third Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.003
Fourth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.003
Fifth Year											
Employment Impact	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income Impact	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.003

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100design
Return Period: 100

Building Damage Count by General Building Type

January 10, 2013

	Count of Buildings (#) by Range of Damage (%)							
	None	1-10	11-20	21-30	31-40	41-50	Substantial	Total
California								
Santa Clara								
Concrete	2	0	0	0	0	0	0	2
ManufHousing	0	0	0	0	0	0	0	0
Masonry	3	0	0	0	0	0	0	3
Steel	2	0	0	0	0	0	0	2
Wood	372	0	0	0	0	0	0	372
Total	**379**	**0**	**0**	**0**	**0**	**0**	**0**	**379**
Total	**379**	**0**	**0**	**0**	**0**	**0**	**0**	**379**
Scenario Total	**379**	**0**	**0**	**0**	**0**	**0**	**0**	**379**

Special Notice Regarding Building Count:

Unlike the earthquake and hurricane models, the flood model performs its analysis at the census block level. This means that the analysis starts with a small number of buildings within each census block and applies a series of distributions necessary for analyzing the potential damage. The application of these distributions and the small number of buildings make the flood model more sensitive to rounding errors that introduces uncertainty into the building count results. Please use these results with suitable caution.

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Direct Economic Loss For Transportation

January 10, 2013

All values are in thousands of dollars

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total
California								
Santa Clara								
Segments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Bridges	$4.59	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4.59
Tunnels	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$4.59**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$4.59**
Total	**$4.59**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$4.59**
Scenario Total	**$4.59**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$4.59**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100design
Return Period: 100

Direct Economic Losses for Utilities

January 10, 2013

All values are in thousands of dollars.

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
California							
Santa Clara							
Facilities	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pipelines	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
Scenario Total	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100design
Return Period: 100

Direct Economic Losses For Vehicles (Day)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	143,421	83,464	3,395	230,280
Total	**143,421**	**83,464**	**3,395**	**230,280**
Scenario Total	**143,421**	**83,464**	**3,395**	**230,280**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100design
Return Period: 100

Direct Economic Losses For Vehicles (Night)

January 10, 2013

All values are in dollars.

	Car	Light Truck	Heavy Truck	Total Loss
California				
Santa Clara	93,100	52,119	3,712	148,931
Total	**93,100**	**52,119**	**3,712**	**148,931**
Scenario Total	**93,100**	**52,119**	**3,712**	**148,931**

Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county/state only if all of the census blocks for that county/state were selected at the time of study region creation.

Study Region: PermanentePDHale
Scenario: PDHale100design
Return Period: 100

APPENDIX 7-6: Water Supply and Infrastructure Master Plan

Santa Clara Valley Water District
Water Supply and Infrastructure Master Plan

Prepared by:
Tracy Hemmeter, Senior Project Manager
Erin Baker, Senior Engineer

Under the Direction of:

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Frank Maitski, Deputy Operating Officer
Jim Fiedler, Chief Operating Officer

September 2012

Acknowledgments

Stakeholder Review Committee

Building Industry Association of the Bay Area – Crisand Giles
City of Milpitas – Fernando Bravo, Howard Salamanca
City of Morgan Hill – Tony Eulo, Jimmy Forbis
City of Palo Alto - Nico Procos
City of Santa Clara – Chris DeGroot
City of Sunnyvale – Mansour Nasser
Farm Bureau of Santa Clara County - Jennifer Williams
League of Women Voters – Sue Graham, Karen Sundback
San Francisco Public Utilities Commission – Molly Petrick
San Jose Water Company – George Belhumeur
Santa Clara Basin Watershed Management Initiative – Trish Mulvey
Santa Clara Valley Audubon Society – Shani Kleinhaus
Silicon Valley Leadership Group – Sai Amath
United Neighborhoods of Santa Clara County – Ken Kelly

Water Supply and Infrastructure Master Plan Summary

A reliable supply of safe, clean water is necessary for the social, economic, and environmental well-being of Santa Clara County. Additional water supply investments will be needed in the future to meet the county's water needs. The Water Supply and Infrastructure Master Plan (Water Master Plan) presents the Santa Clara Valley Water District's strategy for meeting those future needs. The activities and project to carry out this strategy have to be funded or committed to by the District, and may be influenced by other factors beyond the scope of this Water Master Plan. However, the Water Master Plan does provide a water supply strategy with which these activities and projects can be planned and provides a roadmap for future District investments in water supply reliability.

Water Supply Strategy

- Secure existing water supplies, including imported and local surface water supplies
- Improve and maintain dams, pump stations, treatment plants, and pipelines
- Increase water conservation savings by 46,000 acre-feet per year
- Develop a gray water reuse program
- Increase non-potable recycled water use by 15,000 acre-feet per year
- Develop the use of advanced treated recycled water for groundwater recharge
- Construct additional groundwater recharge facilities
- Revise imported water operations to maximize storage and economic value

The District's water supply strategy has three key elements: secure existing supplies and facilities, optimize the use of existing supplies and facilities, and expand water use efficiency efforts. The District must secure existing supplies and facilities for future generations because they are, and will continue to be, the foundation of our water supply system. In addition, the District has opportunities to make more effective use of its existing assets. Finally, the District is committed to working with the community to meet Silicon Valley's future increases in water demand through conservation and recycling.

The Water Master Plan strategy is phased to ensure timely, appropriate investments decisions. Over the next five years, the District will continue work on securing and restoring existing supplies and infrastructure, and begin foundational work on developing future supplies. This foundational work includes participating in regional recycled water strategic planning, conducting public outreach on potable reuse, performing demonstration projects for advanced recycled water treatment technologies, developing groundwater protection guidelines for gray water reuse, entering into partnership agreements for dry-year water options, and participating in the development of regulations and policies. These activities are critical to successful project implementation, and once completed, the District can begin project-specific planning, design, and construction of new facilities.

The Water Master Plan is the District's strategy for providing a reliable and sustainable future water supply for Santa Clara County and ensuring new supply investments are effective and efficient.

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Figures

Tables

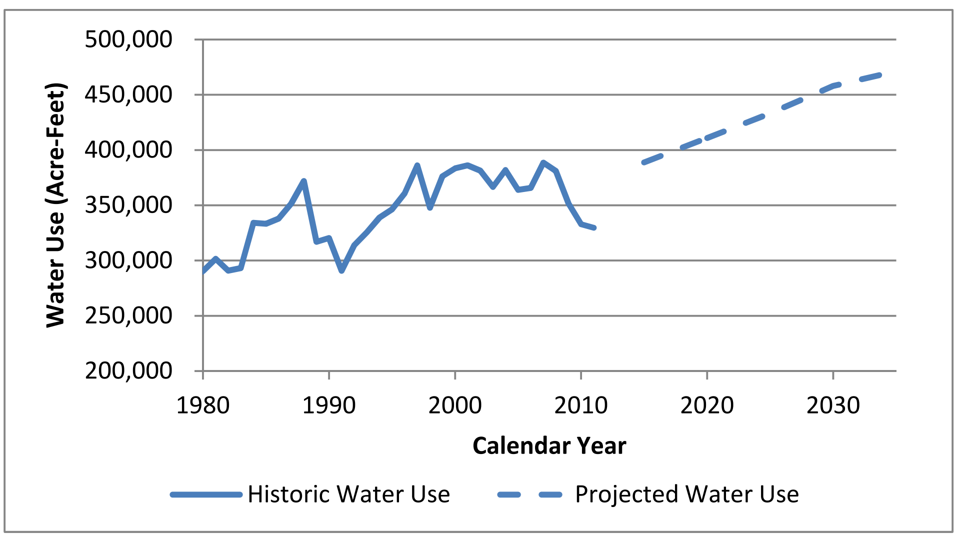
1 – A Reliable Water Supply is Important to the Community

Sustainable, high-quality water is essential for life, a healthy environment, and a prosperous economy. Water, more than any other resource, plays a significant and vital role in the everyday actions of any society. The development of public water systems is a primary requirement for an adequately functioning and sustainable society. A safe and reliable water supply extends beyond the significant social requirements of basic health and sanitation. This extension includes economic vitality, environmental needs, agricultural requirements, social benefit, cultural expectations and requirements, and quality of life enhancements. On behalf of the community, the Santa Clara Valley Water District (District) has made significant investments to develop water supplies and infrastructure to meet the county's water needs. The Water Supply and Infrastructure Master Plan (Water Master Plan) identifies the District strategy to continue investments to meet the county's future water supply needs through at least 2035.

Water Use is Increasing

As Santa Clara County's population has increased from about 1.3 million in 1980 to about 1.8 million in 2010, its water demand has grown. Water use increased from about 290,000 acre-feet (AF) in 1980 to about 329,000 acre-feet in 2010. The Association of Bay Area Governments[1] projects that the county's population will increase to about 2.4 million by 2035. This increase will equate to increase in water use to about 423,000 AF by 2035.[2] Figure 1 illustrates historic and projected water use in Santa Clara County.

Figure 1. Historic and Projected Water Use



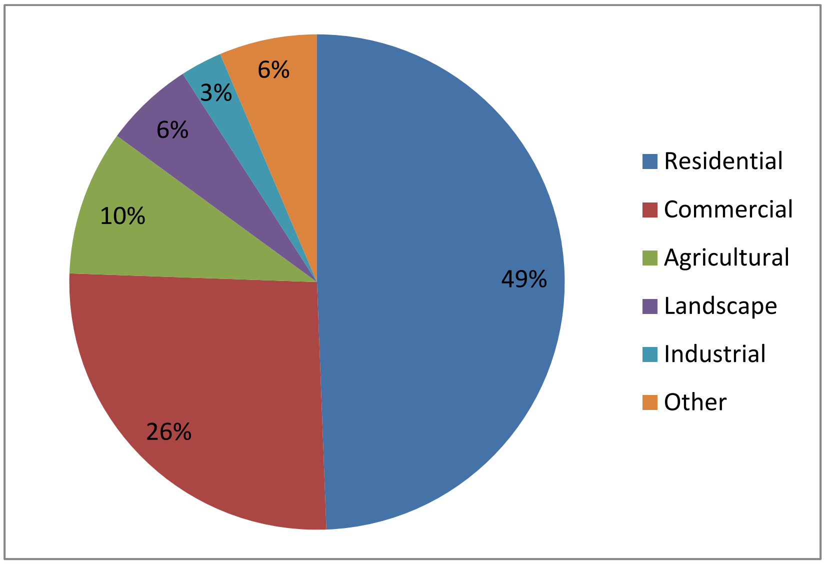
Water use would be higher, by about 51,000 AF in 2010 and 98,500 AF in 2030, if not for the community's efforts to conserve water. Water conservation reduces the need to make investments in new, more expensive capital facilities and is a critical element of meeting the community's future

[1] Association of Bay Area Governments Projections, 2009.
[2] Santa Clara Valley Water District 2010 Urban Water Management Plan. http://www.valleywater.org/services/uwmp2010.aspx

water needs. The community responds to droughts by further reducing water use. Figure 1 shows the dips in historic water use resulting from District calls for short-term water use reductions during the 1987 to 1992 drought and the drought that began in 2009.

The community uses water for a number of purposes, including residential, commercial, industrial, landscape irrigation, and agriculture. Figure 2 shows percentage of water use by these sectors. The community values a reliable supply of water for all these purposes. Residents need water for basic sanitation. Commerce and industry need water for product manufacturing and delivery. Farmers need water to grow crops. Water shortages would have severe economic consequences. Water reductions of 10 to 30 percent, if imposed on commerce or industry, could result in a decrease in the local economy's revenue of $900 million to more than $10 billion.[3] In addition, shortages can lead to groundwater overdraft and land subsidence, which can damage infrastructure and increase flooding risks.

Figure 2. 2010 Water Use by Sector



The District Makes Investments in Water Supply Reliability

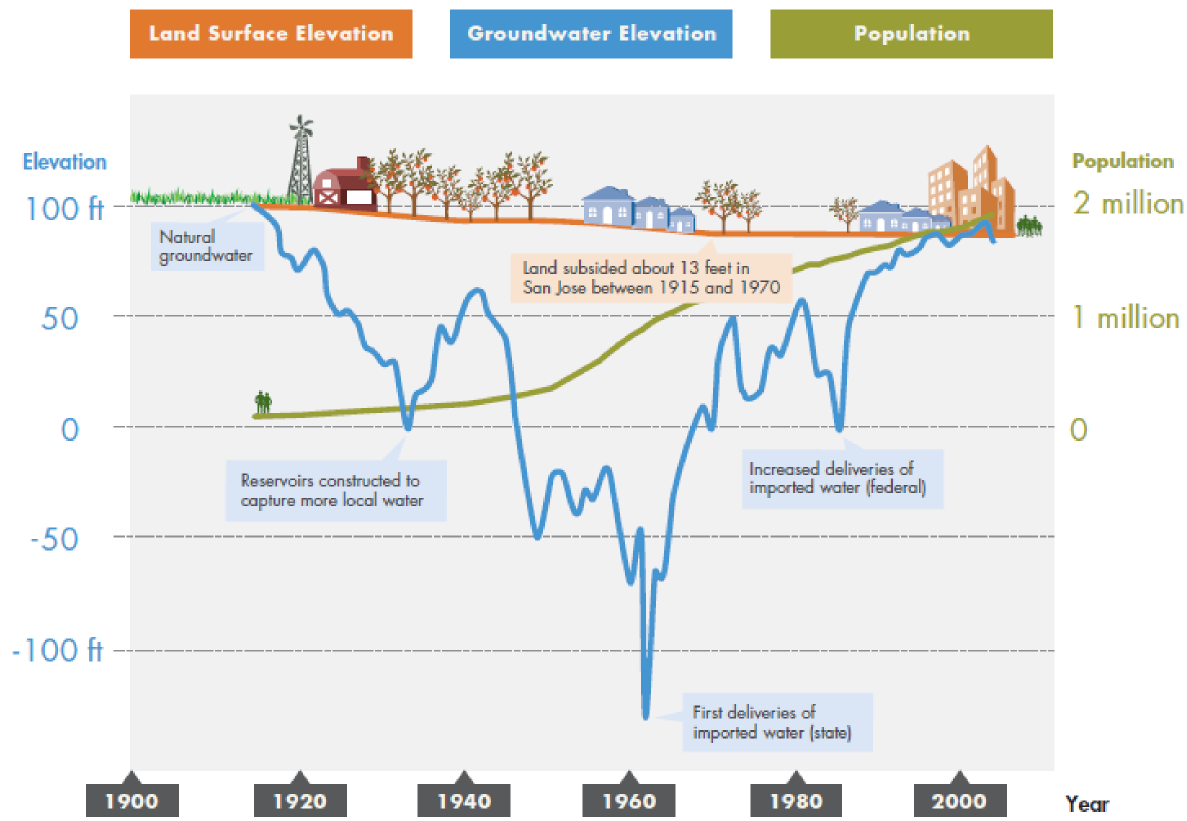
Voters approved the formation of the Santa Clara Valley Water Conservation District, a predecessor to today's water district, in 1929 to develop and manage water supplies to meet the county's needs. Northern Santa Clara County had experienced land subsidence from pumping more groundwater than could be replaced or replenished through rainfall. In response, the District constructed six reservoirs in the 1930s to store winter rains for groundwater recharge and summer irrigation use. Four additional reservoirs were constructed in the 1950s,[4] nearly tripling storage to about 169,000 AF. Still, local supplies were insufficient to meet the county's growing population and subsidence continued. In 1965, the District began importing water from the State Water Project for groundwater recharge and use at drinking water treatment plants. The District began receiving water from the Federal Central Valley project in 1987. By the end of the 20th century, groundwater levels recovered and land subsidence was

[3] Memorandum regarding Economic Analysis of Water Shortage in Santa Clara County from Dr. David Sunding, Berkeley Economic Consulting, to Joan Maher, Santa Clara Valley Water District. 2010.

[4] Two reservoirs were constructed by the Santa Clara Valley Water Conservation District and two reservoirs were constructed by the South Santa Clara Valley Water Conservation District which was annexed into the Santa Clara Valley Water District in 1987.

halted. The historic relationship between population growth, groundwater levels, subsidence, and water sources is illustrated in Figure 3.[5] As population and water use increases, the District will need to develop additional water supplies in order to meet the county's water needs and avoid land subsidence.

Figure 3. Relationship between Population Growth, Groundwater Levels, and Subsidence



The District operates an integrated water supply system to meet demands in Santa Clara County. Local surface water and water imported from the Sacramento-San Joaquin River Delta (Delta):

- replenish the local groundwater subbasins, which are pumped for use by individual well owners and retail water suppliers,
- supply the District's drinking water treatment plants for purification,
- are delivered directly to agricultural water users, and
- help meet environmental needs.

The District manages groundwater supplies in conjunction with surface water supplies. In wet years, excess supplies are stored in the local groundwater basin or in a groundwater bank in Kern County for use in dry years. This helps the District manage the natural variations in rainfall and the associated variations in water supply availability.

[5] Elevations are feet above or below mean sea level.

Other agencies and organizations also contribute to water supply reliability in Santa Clara County. The San Francisco Public Utilities Commission delivers water to retailers in northern Santa Clara County. Stanford University and San Jose Water Company hold their own surface water rights. All four of the county's wastewater treatment plants produce recycled water for non-potable uses such as irrigation and cooling towers. The county's water supply, treatment, and distribution facilities are illustrated in Figure 4.

Background of the Water Supply and Infrastructure Master Plan

The District's mission is to provide for a healthy, safe, and enhanced quality of living in Santa Clara County through watershed stewardship and comprehensive management of water resources in a practical, cost-effective, and environmentally-sensitive manner for current and future generations.

The District Board of Directors adopted policies that provide direction to the CEO on achieving the District's mission. Board Policy E-2.1 states, "Current and future water supply for municipalities, industries, agriculture, and the environment is reliable." The District's strategy for achieving this goal is to develop water supplies designed to meet at least 100 percent of average annual water demand identified in the District's Urban Water Management Plan during non-drought years and at least 90 percent of average annual water demand in drought years. The policies and strategy recognize that a reliable water supply is vital to the social, economic, and environmental well-being of the county.

The analysis for the Water Master Plan found that the county's water supplies are insufficient to meet future water needs, especially during droughts. Shortages of up to 30 percent could occur toward the end of an extended drought like the one that occurred between 1987 and 1992. The District has to make investments to fill this need. The District also needs to continue to make investments to maintain, restore, and replace its existing assets, some of which were constructed 75 years ago. The Water Master Plan provides a strategy for investments in new water supply projects and programs that builds on the District's existing assets and avoids making investments that are unnecessary or premature.

Contents and Use of this Report

The Water Master Plan is organized as follows:

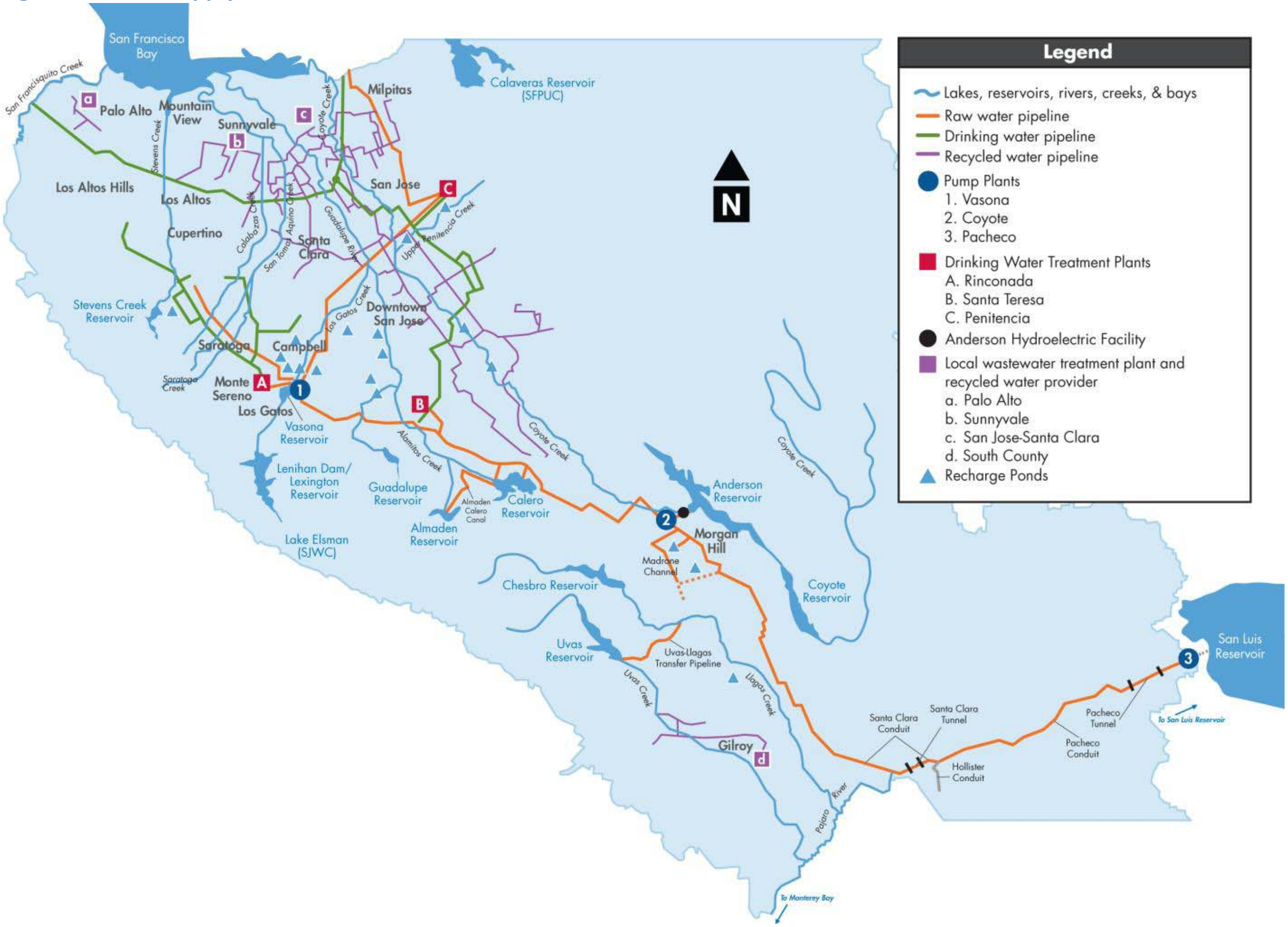
- Chapter 1 - The Importance of Water Supply Reliability, which discusses the community's water use and needs, the District's role in meeting those needs, and the background for the Water Master Plan.
- Chapter 2 - Challenges to Water Supply Reliability, which identifies the primary challenge of providing a reliable future water supply in Santa Clara County, and other risks to future water supply reliability.

- Chapter 3 – The Water Supply Strategy, which presents the District's strategy for meeting the county's future water supply needs.
- Chapter 4 – Next Steps, which describes how the water supply strategy will be implemented over time.

The Water Master Plan supports District Board of Directors decisions needed to ensure a reliable supply of safe, clean water for Santa Clara County. The water supply strategy provides a framework for investment decisions needed to secure existing water supplies and infrastructure and to meet future needs. The implementation schedule identifies the timing of key actions that are critical to the success of the strategy.

The Water Master Plan provides a strategy for investments in new water supply projects that builds on the District's existing assets and helps ensure timely, appropriate investment decisions.

Figure 4. Water Supply, Treatment, and Distribution Facilities



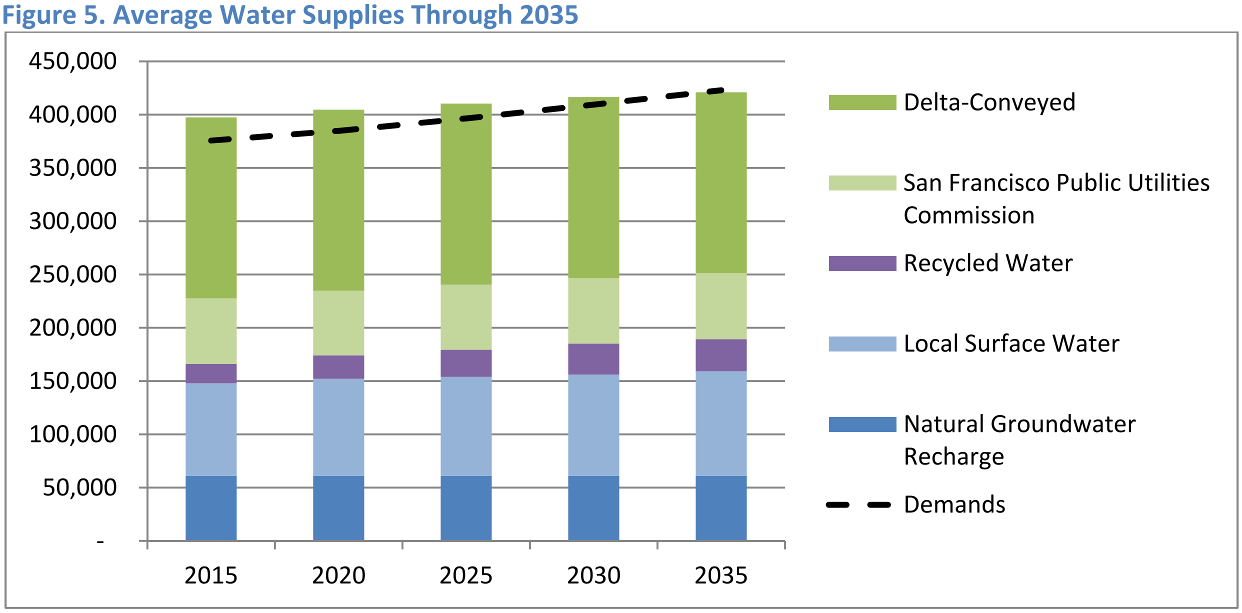
2 – The District Needs to Develop Supplies for Future Droughts

This chapter describes the water supply reliability outlook for Santa Clara County. The Water Master Plan evaluates the ability to meet projected water demands through Year 2035 with the current baseline water supply system. The evaluation shows existing supplies are sufficient to meet most future demands in normal years, but will not meet needs in future droughts. In addition, several risks could affect future water supply reliability. Risks such as climate change, changes to regulations, and new policies could affect local and imported supply availability. District strategy is to develop supplies that will meet future drought year needs and address multiple risks.

Existing Water Supplies are Sufficient to Meet Most Future Demands

Existing water supply sources and planned increases in recycled water use will be sufficient to meet most average demands through 2035. Figure 5 shows anticipated average water supplies from the baseline water supply system through year 2035. Until 2035, supplies exceed demands. In 2035, there is a shortfall of about 2,000 acre-feet per year (AFY) between supplies and demands.

Figure 5. Average Water Supplies Through 2035



Local Water Supply Sources

The groundwater subbasins are naturally recharged with rainfall, seepage from surrounding hills, seepage into and out of the groundwater subbasin, leakage from pipelines, and irrigation return flows. Natural groundwater recharge varies based on rainfall and groundwater levels. On average, natural groundwater recharge provides about 61,000 AFY of supply, which is far less than average groundwater pumping of about 148,000 AFY.

Local reservoirs and streams capture rainfall and run-off. This water is used for recharge, irrigation, or drinking water treatment. On average, the District's local surface water supplies will provide about 87,000 AFY.[6] On average, San Jose Water Company and Stanford University local surface water supplies provide additional supplies of about 11,000 AFY.

Baseline Water Supply System

- Groundwater basin
- Existing water supplies, including imported and local surface water supplies and recycled water
- Existing conservation savings
- Existing infrastructure with planned improvements and maintenance for dam, pump stations, treatment plants, and pipelines
- Planned increases in water conservation savings and non-potable recycled water use

Recycled water is a local source that is not dependent on rainfall. Recycled water is produced by the county's four publicly-owned wastewater treatment plants. It is municipal wastewater that has been treated to levels that make it appropriate for various non-drinking water (non-potable) purposes. Non-potable recycled water use is projected to increase from about 15,000 AF in 2010 to 29,000 AF in 2035.

Imported Water Supply Sources

Imported supplies are used to meet a large percentage of county water needs–about 55 percent on average. Imported water conveyed though the Delta via the State Water Project (SWP) and Central Valley Project (CVP) is used to supply District drinking water treatment plants, groundwater recharge facilities, and irrigators. In addition, when available, the District stores excess Delta-conveyed supplies in the Semitropic Groundwater Bank and San Luis Reservoir in the Central Valley, and locally in Anderson and Calero Reservoirs. The District has a contract for 100,000 AFY of SWP water and 152,500 AFY of CVP water. However, the actual amount of water allocated under these contracts each year is typically less than these contractual amounts and depends on hydrology and regulatory restrictions. The average allocation of Delta-conveyed water is about 170,000 AFY.

Santa Clara County began using San Francisco Public Utilities Commission (SFPUC) Hetch-Hetchy system water to supplement local supplies in 1952. This water is provided to north county cities with access to Hetch-Hetchy pipelines. On average, the SFPUC delivers about 61,000 AFY to Santa Clara County.

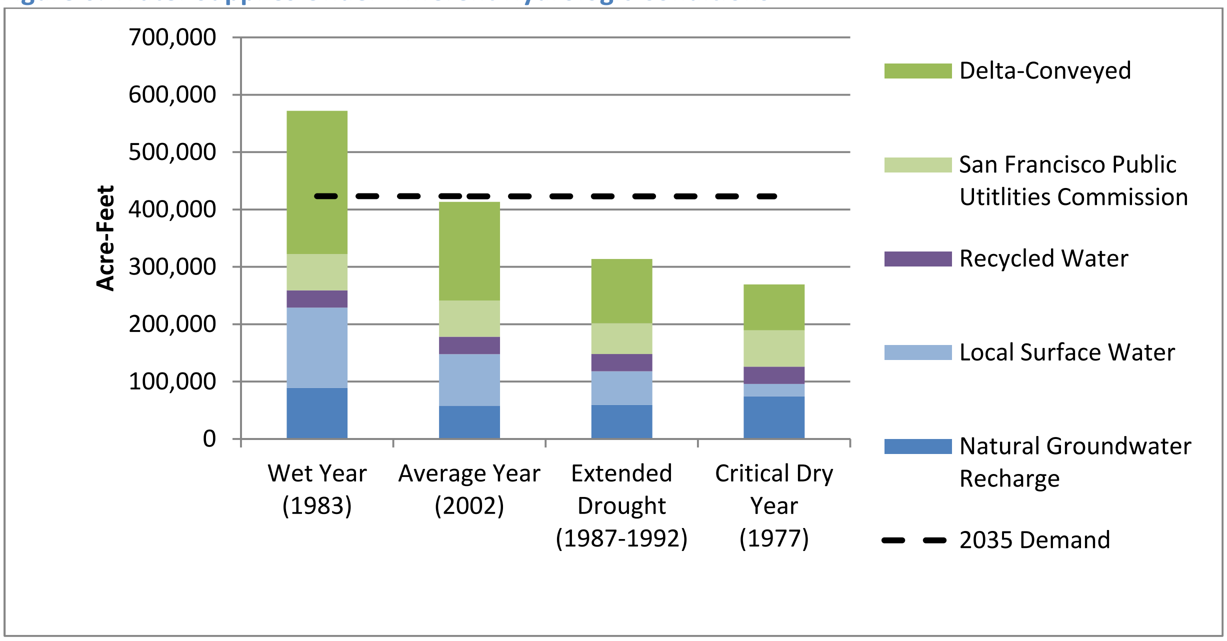
Supply Variability and Hydrology

Santa Clara County, like the rest of California, experiences drastic changes in year-to-year annual precipitation. The variation in precipitation, both locally and in the Sierra Nevada Mountains, results in fluctuations in the amount of water supply available from year to year. In many years, annual supplies exceed demands, while in some years demands can greatly exceed supplies. The District's basic water

[6] Currently, District surface water supplies are constrained to an average of about 76,000 AFY by operating restrictions on local reservoirs for seismic safety. These supplies will be restored by 2020.

supply strategy to compensate for this supply variability is to store excess wet year supplies in the groundwater basin, local reservoirs, San Luis Reservoir, or Semitropic Groundwater Bank. The District draws on these reserve supplies during dry years to help meet demands. The reserves are normally sufficient to meet demands during a critical dry year and the first several years of an extended drought. Figure 6 illustrates county water supplies under different hydrologic conditions compared to projected water demands in 2035.[7]

Figure 6. Water Supplies Under Different Hydrologic Conditions

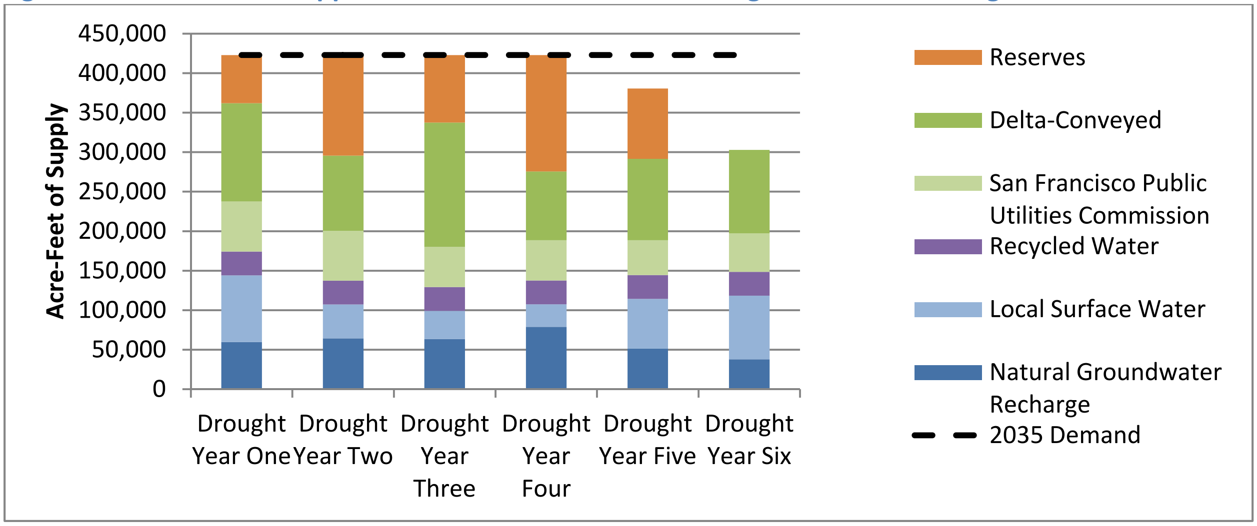


Future Droughts are the Primary Water Supply Challenge

Water supply reserves are insufficient to meet needs during an extended drought. Due to growing demand, water supply shortages during droughts begin to appear in 2015 and increase in magnitude and frequency over time. By 2035, without new supplies or conservation savings, shortages could occur in about 11 percent of years, and supplies would only be able to meet about 70 percent of average demand during these years. Short-term water use reductions of up to 30 percent would be needed to avoid shortages and minimize the risk of land subsidence. Figure 7 shows the supplies and groundwater reserves that would be available in 2035 during a six-year drought like the one that occurred between 1987 and 1992.

[7] The extended drought supplies are the average over a six-year drought period. Some years are less dry than others, so the average is higher than in a single critical dry year. Also, natural groundwater recharge is higher than average in a critical dry year due to increased seepage into the groundwater subbasins as groundwater levels decline.

Figure 7. 2035 Baseline Supplies and Reserves Available during an Extended Drought

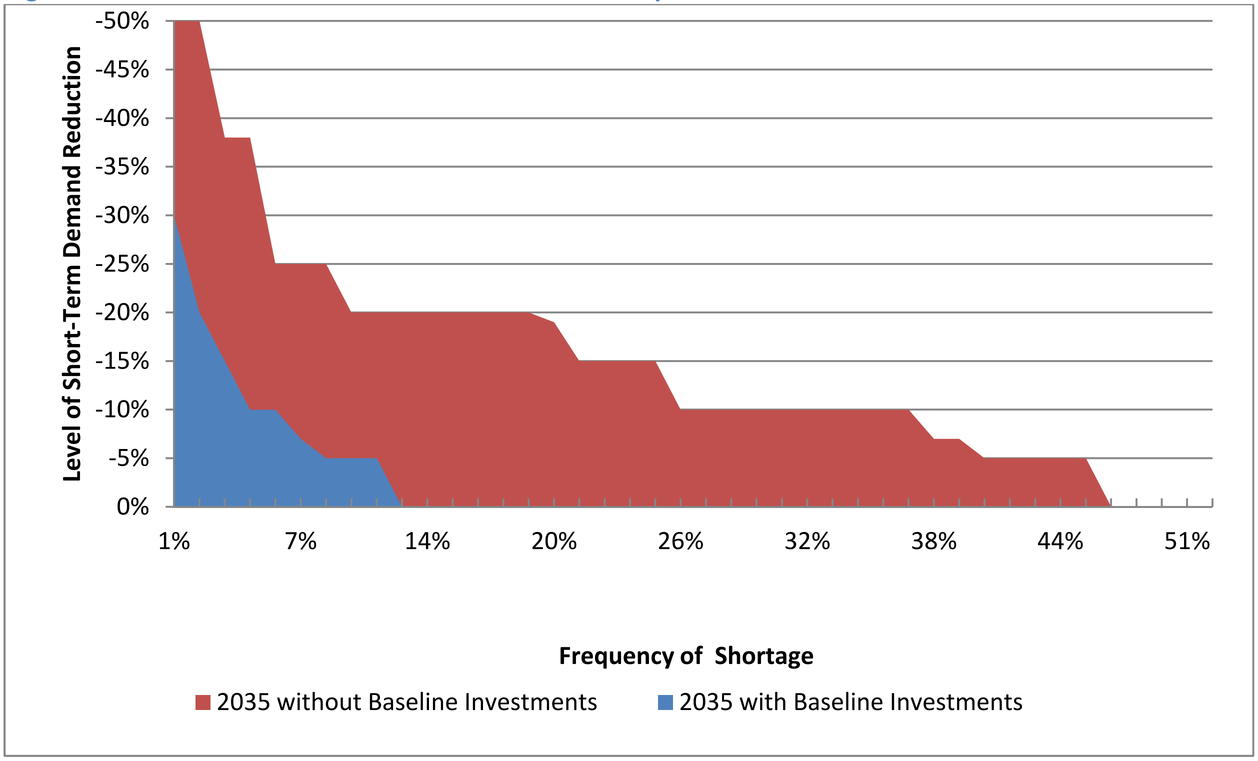


A Secure Baseline and New Dry Year Supplies Are Needed to Meet Future Water Needs

First and foremost, the District will continue to rely upon its baseline water supply system to support future needs. The water supply outlook assumes the District will secure existing local and imported water supplies, make investments consistent with its Five-Year Capital Improvement program and Five-Year Water Utility Operations Plan, work with other agencies to expand non-potable water recycling, and support increased water conservation savings. Without the baseline investments, the water supply outlook would be worse. Shortages would occur sooner, more frequently, and would be more severe.

Figure 8 illustrates the importance of baseline investments in water supply reliability. The figure presents water supply shortages, represented by level of demand reductions during droughts, under two scenarios. The first scenario (shown in blue) reflects the assumption that existing and planned supplies (the baseline system) will be in place in 2035. The second scenario (shown in red) shows shortages that would occur if local reservoir operating capacity is not restored, recycled water use is not expanded, and conservation does not increase as planned. This second “no action” scenario does not take into account likely additional imported water reductions that would occur if investments are not made in restoring the Delta ecosystem and reliable Delta conveyance, in which case there is a risk that greater shortages could occur.

Figure 8. Level of Short-Term Demand Reductions Required with 2035 Demands



Risks Threaten Water Supply Reliability

The water supply outlook assumes existing water supplies are available in the future. However, there are risks that threaten the reliability of the existing water supplies. The water supply strategy needs to address the need for drought year supplies and perform well under multiple risks. The risks are summarized below.

Climate Change

Potential effects of climate change on imported water supply availability have been incorporated into the water supply projections in this report.[8] However, potential climate change effects on local precipitation are not included in the water supply projects, because specific predictions for this area are not possible at this time. Predictions for the Southwestern US and California generally indicate that reduced quantity of surface water from local runoff is likely. Climate models suggest a drying tendency and a decline in the frequency of precipitation events, but not a clear-cut change in the intensity of precipitation events. Precipitation patterns and intensity in the local watersheds have more impact on reservoir inflows than do the frequency of precipitation or overall season averages. For instance, back-to-back to storms of high intensity will result in more runoff due to saturated ground conditions than

[8] Imported water allocations are derived from the California Department of Water Resources' State Water Project Water Delivery Reliability Report 2009 and associated modeling results.

runoff from storms that are more spread out and intermittent. Therefore, while the overall precipitation trend may be diminished, intense storms in the small watersheds of Santa Clara County may still provide adequate runoff to fill local reservoirs. Anticipating quantitative climate change effects on local surface water capture is not possible at this time given the uncertainty in future changes in precipitation.

Temperature projections for the Bay Area show a shift in the timing of spring and summer heat extremes,[9] as well as an increase in the frequency and intensity of heat waves.[10] These temperature changes could result in changes in water demands.

The District needs to be proactive in compiling and analyzing data that could provide insights into potential local changes in runoff and demands.

Reductions in Imported Water Supplies

In the last 15 years, major changes have been made to state and federal water project operations as a result of regulations to protect Delta water quality and help recovery of endangered and threatened fish species. These regulations reduce Delta exports at certain times of the year and there is the possibility of more stringent requirements in the future. To address this risk, the District is participating in development of the Bay Delta Conservation Plan to achieve co-equal goals of water supply reliability and ecosystem restoration for the Delta.

The California Aqueduct delivers Delta-conveyed supplies to customers municipal, industrial, and agricultural customers

The District's CVP Municipal and Industrial (M&I) water supplies are provided pursuant to an interim administrative policy that gives priority to CVP M&I water service over CVP agricultural water service. The United States Bureau of Reclamation (Reclamation) is in the process of finalizing this policy. To mitigate the impacts and provide support for the policy, the District entered into a supplemental agreement with

[9] Ekstrom, Julia A., and Susanne C. Moser. 2012. *Climate Change Impacts, Vulnerabilities, and Adaptation in the San Francisco Bay Area: A Synthesis of PIER Program Reports and Other Relevant Research.* California Energy Commission. Publication number: CEC-500-2012-071.

[10] Cayan, Dan, Mary Tyree, and Sam Iacobellis (Scripps Institution of Oceanography, University of California, San Diego) 2012. *Climate Change Scenarios for the San Francisco Region.* California Energy Commission. Publication number: CEC-500-2012-042.

agricultural districts in the San Luis and Delta-Mendota Water Authority and Reclamation. If Reclamation's final M&I policy substantially changes or the supplemental agreement is not maintained, there is a risk that the District's CVP supplies could be reduced in the future.

The quantity of SFPUC supplies used in the county could be reduced in the future. This could result from retailers' shift of their use as SFPUC supplies become more expensive than District groundwater, or from an SFPUC supply interruption to the cities of San Jose and Santa Clara, which have temporary and interruptible contracts with SFPUC. SFPUC will supply a combined annual average of 9 MGD to the cities of San José and Santa Clara through 2018, subject to interruption or reduction. By December 31, 2018, SFPUC will make further decisions regarding long-term water supplies through 2030. The District will support local water retailer efforts to secure long-term water supplies.

Provided the baseline system remains intact, existing water supply sources are sufficient to meet the county's water future supply needs in normal years and a single dry year.

Additional water supplies are needed to meet demands during extended droughts. Drought year shortfalls could occur as early as 2015 and will become severe by 2035. An extended drought in 2035 could result in shortages up to about 64,000 AFY.

Reduced Revenue

For the decades ahead, the highest priority work of the District's Water Utility Enterprise is to implement a program of activities to ensure that water supplies are diversified and reliable to meet current and future demands and that treated water quality standards are met. This program of operations, maintenance, and capital improvement activities that support that support direct and in-lieu groundwater recharge will require increased funding from groundwater production charges and other sources of revenue. If revenue from the groundwater production charges is reduced or eliminated, several programs or facilities would also need to be reduced or eliminated, and water supply reliability would be at great risk.

The District continues to monitor risks that can change the water supply outlook and works to influence key external decisions that have the potential to impact water supply reliability. The Water Master Plan will be reviewed annually and updated at least every five year. This planning cycle allows risks to be evaluated on an ongoing basis, so that the water supply strategy can be updated as better information becomes available.

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3 – The Water Supply Strategy Ensures Sustainability

To provide a reliable supply of water to meet needs through 2035 the water supply strategy relies on the following three elements:

- secure baseline supplies and infrastructure,
- optimize the use of existing supplies and infrastructure, and
- increase recycling and water conservation to meet future increases in demands.

> ***"Water is one of the Region's most precious resources, serving a multitude of needs… Sustainability in the long run requires that households, workplaces, and agricultural operations efficiently use and reuse water."***
>
> ***– Silicon Valley Index 2012***

This strategy ensures sustainability because it meets future increases in demands with conservation and recycling, builds on the existing baseline system, and manages risks to water supply reliability from climate changes and reduced imported water supplies. The strategy is also consistent with District policies and stakeholder interests.

The Elements of the Water Supply Strategy Work Together

The three elements of the water supply strategy work together. The baseline water supply system will continue to support most of future water needs. Optimizing the use of existing supplies and infrastructure leverages the investments the District has already made in water supply reliability and increases the system's flexibility. Additional recycling and conservation will bridge the gap between existing system capability and future demands, as well as manage risks from climate change and imported water reductions. Each of the water supply strategy elements is discussed below.

Secure Baseline Water Supplies and Infrastructure

The baseline water supply system is the most critical element of the water supply strategy, because it will provide the most water supplies and is the foundation of future water supply investments. The baseline water supply system is comprised of the existing and previously planned water supplies and infrastructure. The Water Master Plan is built on the assumption that baseline system will be available through the planning horizon of 2035. Baseline water supplies are expected to increase from the current average of about 398,000 AFY to an average of 421,000 AFY in 2035. The increase in baseline supplies is due to removal of operating restrictions on existing reservoirs and increased non-potable water recycling. Baseline conservation savings are projected to increase from about 53,000 acre-feet (AF) in 2011 to 98,500 acre-feet per year (AFY) by 2030. These savings reduce demands on the water

2035 Baseline Water Supply System

- Increase water conservation savings by about 46,000 AFY
- Increase recycled water use by about 14,000 AFY
- Average local supplies of about 160,000 AFY
- Average imported water deliveries of about 232,000 AFY
- Anderson, Calero, Almaden, and Guadalupe Reservoirs operating at full capacity
- Rinconada Water Treatment Plant capacity of 100 MGD
- Madrone Pipeline capacity of at least 20 cfs
- Existing assets managed to maintain their level of service

supply system and the need for more capital-intensive improvements. Ensuring adequate investment in the existing system is critical to reliability, because without the baseline system future water supply shortages could be severe.

Optimize the use of Existing Supplies and Infrastructure

Groundwater Recharge

To fully utilize additional supplies that could be developed under this strategy, new groundwater recharge ponds will increase the District's groundwater recharge capacity. The yield from the new ponds is about 3,300 AFY on average. The recharge ponds will likely be located on the west side of the valley, along Saratoga Creek near Highway 85. Additional groundwater recharge ponds provide additional capacity to process wet-weather flows and help maintain groundwater levels, both of which help manage risks due to climate change and supply interruptions.

Reservoir Pipeline

A connection between Lexington Reservoir and the raw water system will provide greater flexibility is using existing local water supplies. Use of recycled water for recharge, as described below under Indirect Potable Reuse, will allow surface water from Lexington Reservoir to be put to beneficial use elsewhere in the county. In addition, the pipeline will enable the District to capture some wet-weather flows that would otherwise flow to the Bay. The pipeline is expected to provide an average annual yield of 1,500 acre-feet.

Imported Water Reoperations

The District would reoperate the Semitropic Groundwater Bank when it is nearly full and the District water supply needs are otherwise met to sell or exchange up to 50,000 AFY of stored water. This would create additional space in the Semitropic Groundwater Bank for carryover of supplies during wetter years, maximize the value of the District's existing assets (imported water contracts and investment in the Semitropic Groundwater Bank), and potentially help fund investments in infrastructure and additional local supplies.

Dry Year Options

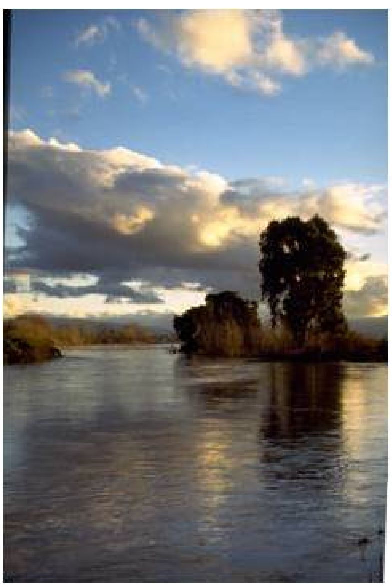
Dry-year option agreements will continue to provide supplemental supplies, on an as-needed basis, until the Water Master Plan is fully implemented and during extreme drought conditions. The Water Master

Plan assumes these will be long-term imported water dry-year option transfer agreements with flexibility to modify the options amounts as District needs and conditions change over time. Other dry-year options could include participating in a future Los Vaqueros Reservoir expansion, agreements to exchange wet year water for a lesser amount of dry year water, and agreements with regional partners on projects like regional desalination.

Increase Recycling and Conservation

Indirect Potable Reuse

Indirect potable reuse is a high-quality, local drought-proof supply that is resistant to climate change impacts and most other risks identified in Chapter 2. It will provide a new local supply for recharge, which will help maintain reservoir supplies that are used to meet flow and temperature requirements for fish in local creeks. Indirect potable reuse would also reduce discharges to South San Francisco Bay from the wastewater treatment plants. Using advanced treated recycled water for recharge also provides groundwater quality benefits, in that advanced treatment removes nearly all the salts from the water that is used for recharge, resulting in high quality water being recharged into the groundwater basin.



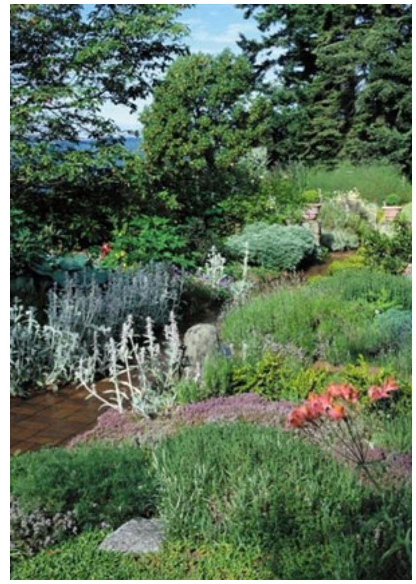
Indirect potable reuse includes delivering advance treated recycled water to groundwater recharge ponds

The strategy relies upon development of indirect potable reuse to provide most of the new water supply to meet future water needs. The Water Master Plan assumes that at least 20,000 AFY of advanced treated recycled water will be available for groundwater recharge by 2030. A number of potential projects are being identified, and future development will be influenced by strategic planning currently underway in partnership with South Bay Water Recycling and others. For purpose of this Water Master Plan, a project was assumed to use water treated at the existing San Jose/Santa Clara Water Pollution Control Plant and pumped to existing recharge ponds in the Los Gatos Recharge System.

One challenge to indirect potable reuse project will be overcoming some people's concerns about the quality of advanced treated recycled water. New regulations could also affect the benefits of indirect potable reuse. When State regulations move toward permitting direct potable reuse (putting advanced treated recycled water directly into pipelines that supply drinking water treatment plants), the District may want to consider that option as it adds flexibility, reduces costs, and potentially reduces energy use. The water supply strategy is to support indirect potable reuse by 1) conducting technical studies, 2) increasing public awareness, 3) monitoring regulatory development, and 4) participating in and conducting regional recycled water master planning.

Gray Water Reuse Rebate Program

The gray water reuse rebate program will provide financial incentives to customers who install reuse systems. This would result in about 300 AFY in water savings, at a relatively low cost. The program could be expanded to increase water savings, depending upon resolution of public agency concerns about water quality and public health issues.

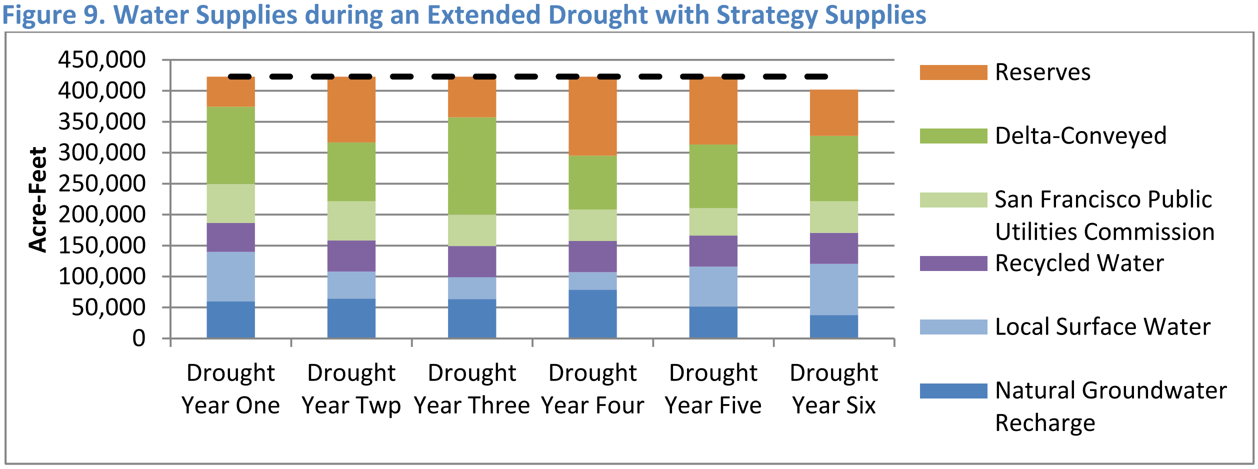


Gray water reuse provides a sustainable supply of water for irrigation

Water Supply Reliability Improvements Meet Level of Service Goals

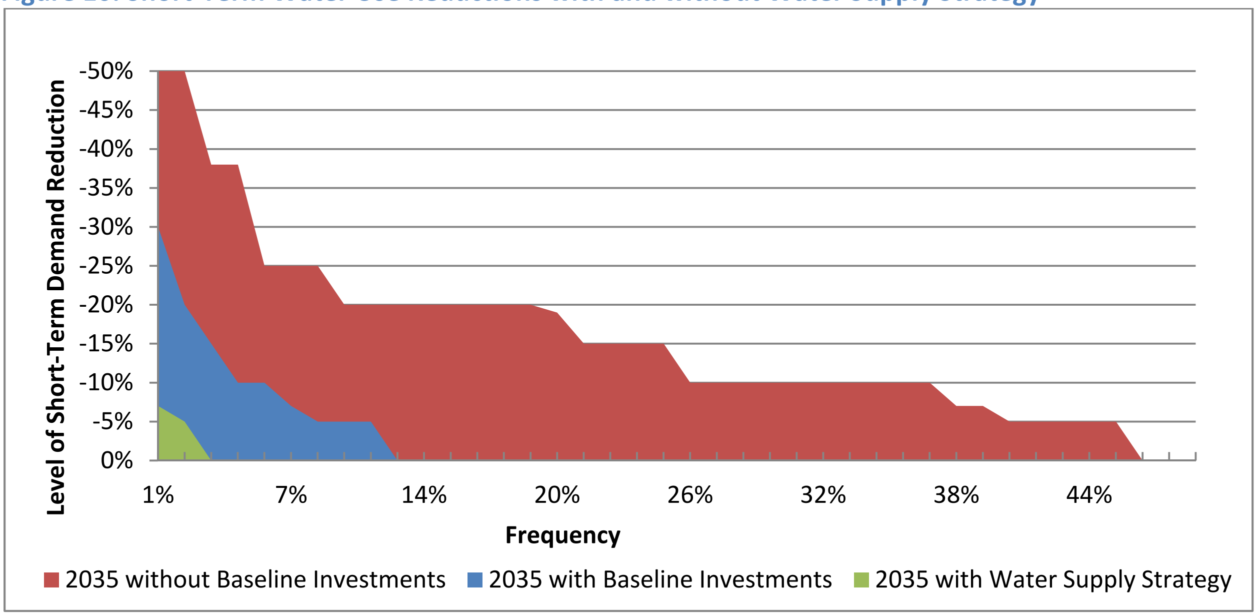
The District Board approved a long-term water supply reliability level of service goal on June 12, 2012. The goal is to develop supplies to meet at least 100 percent of average annual water demand identified in the District's Urban Water Management Plan during non-drought years and at least 90 percent of average annual water demand in drought years. Figure 9 shows water supply availability during an extended drought like the one that occurred from 1987 to 1992 with the water supply strategy supplies in place. Supplies are sufficient to meet 100 percent of demand during the first five years of drought and 90 percent of demands during the sixth year of an extended drought. This is an improvement over the baseline projection in Chapter 2, Figure 7, where existing supplies could only meet about 70 percent of demands during the sixth year of extended drought.

Figure 9. Water Supplies during an Extended Drought with Strategy Supplies



Implementation of the water supply strategy would reduce the frequency and magnitude of short-term water use reductions under 2035 demands. Figure 10 shows shortages with different investment strategies. The small green area in Figure 10 shows that, will full implementation of the water supply strategy, short-term water use reduction would occur only two percent of the time and the level of short-term water use reductions would be less than 10 percent. This level of service is consistent with recommendations from the Stakeholder Review Committee. If only baseline investments are made, which is illustrated by the blue area in Figure 10, the model predicts that water use reductions would occur more often and the level of short-term water reduction could be as high as 30 percent. Water use reductions this high would necessitate water use restrictions and impact the local economy. Finally, the red area in Figure 10 shows short-term water use reductions if investments in the baseline system are not made. Water use reductions would be needed almost half the time and in some years water supply would only be available to meet health and safety needs. This scenario does not take into account likely additional imported water reductions that would occur if investments are not made in restoring the Delta ecosystem and reliable Delta conveyance, in which case there is a risk that greater water use reductions would be needed.

Figure 10. Short-Term Water Use Reductions with and without Water Supply Strategy



The Water Supply Strategy Supports Other Important Public Benefits

In addition to ensuring water supply reliability, the planning process relied on the stakeholders to evaluate a full range of water supply strategies to assess the extent to which various options could support Board policy and planning objectives. The planning objectives listed in Table 1 are derived from Board policies, and reflect specific goals to be considered in optimizing integrated water resources management responsibilities.

Table 1. Planning Objectives

Planning Objective	Sub-Objectives
Ensure Water Supply Reliability	• Meet Service Area Demands • Develop Local Supplies • Maximize Flexibility to Respond to Change
Ensure Drinking Water Quality	• Protect Groundwater Quality • Meet Drinking Water Quality Regulations • Maximize Treatability
Minimize Cost Impacts	• Minimize Lifecycle Costs
Maximize Implementation Potential	• Maximize District Influence over Supplies and Operations • Minimize Implementation Complexities and Barriers
Maximize Water Conservation	• Maximize Water Conservation
Protect the Natural Environment	• Provide Benefits to Watersheds, Creeks, and Natural Resources • Reduce Greenhouse Gas Emissions
Ensure Community Benefits	• Ensure Equitable Distribution of Benefits • Provide Flood Protection and Recreation Benefits

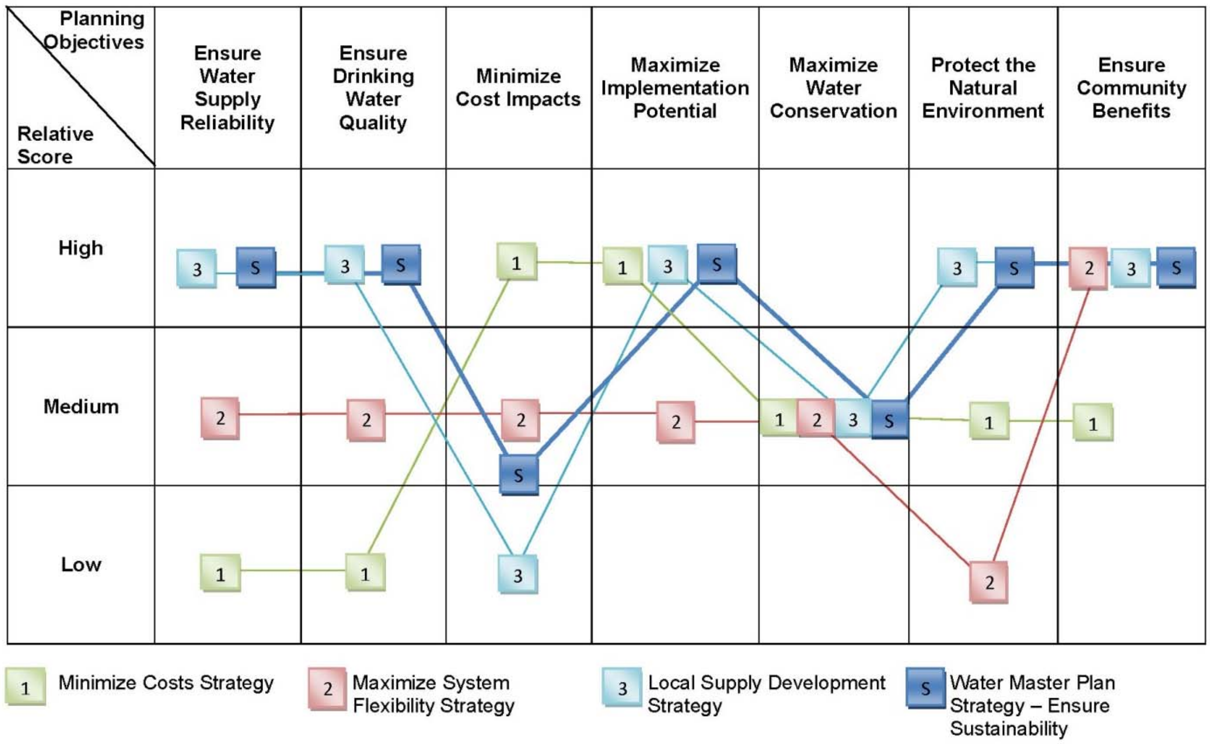
Table 2 summarizes the water supply strategies considered during the planning process. All the strategies included baseline system investments, including expanded non-potable water recycling and increased conservation.

Table 2. Water Supply Strategies That Were Considered for the Water Master Plan

Strategy	Description	Present Value Cost
Minimize Costs	This option relies primarily on imported water supplies to meet future needs.	$75 million
Maximize System Flexibility	This option focuses on infrastructure improvements that would optimize existing water supplies.	$250 million
Local Supply Development	This option relies upon the development indirect potable reuse as a local water supply to meet future needs, along with some infrastructure improvements.	$375 million
Water Master Plan Strategy – Ensure Sustainability	This option includes a mix of local supply development, infrastructure improvements, and imported water reoperations.	$300 million

Figure 11 shows how the Stakeholder Review Committee rated the different strategies in Table 2 against the planning objectives in Table 1. The Water Master Plan strategy was rated as high or higher than other water supply options in all areas except costs.

Figure 11. Relative Scoring of Water Supply Options



The rationale for the ratings for each planning objective is summarized below.

- **Ensure Water Supply Reliability**: The Water Master Plan strategy meets service area demands by providing a high level of reliability. It also develops local supplies that are independent of rainfall, which is consistent with State policy to reduce reliance on the Delta for meeting future needs.[11] Lastly, the strategy includes infrastructure improvements to improve system flexibility.

- **Ensure Drinking Water Quality:** The Water Master Plan strategy improves groundwater quality by using advanced treated water for groundwater recharge. Also, connecting Lexington Reservoir to the raw water system maximizes drinking water treatability by providing another source of water for blending at drinking water treatment plants to manage water quality issues such as high algae episodes at San Luis Reservoir.

- **Minimize Cost Impacts:** The Water Master Plan strategy is more expensive than other strategies. However, an economic analysis found that the benefits exceed the costs.[12]

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[11] California Water Code, Division 35, Chapter 2, Section 85021.

[12] Santa Clara Valley Water District. Water Supply and infrastructure Master Plan Final Technical Report. 2012.

- **Maximize Implementation Potential:** Non-potable recycled water, water conservation, and indirect potable reuse are the cornerstones of the water supply strategy. They are local, drought-resistant supplies that will be available to meet future water needs in the county. A proven track record exists of working together with local partners to implement non-potable recycled water and conservation programs. The strategy to further expand recycled water will be phased to address implementation risks.

- **Maximize Water Conservation:** All strategies included the same water conservation elements that would nearly double annual water conservation savings from current levels by 2030.

- **Protect the Natural Environment:** The Water Master Plan strategy reduces discharges to southern San Francisco Bay and improves the availability of local surface water for environmental uses in creeks. Construction projects in the water supply strategy would primarily be within the urbanized area of the county. The water supply strategy will result in increased greenhouse gas emissions due to the energy intensity of the treatment processes. Future improvements in treatment process efficiency may help mitigate greenhouse gas emissions or the District may be able to offset the emissions through improvements at other facilities or development of additional solar energy facilities.

- **Ensure Community Benefits:** The Water Master Plan strategy does not have disproportionate impacts between zones and it has the potential for providing water recreation benefits near new groundwater recharge facilities.

Strategy is Consistent with Stakeholder Input

The water supply strategy incorporates stakeholder input. The Stakeholder Review Committee (SRC) provided input and feedback on key Water Master Plan decisions and approaches throughout the planning process and concurred with the strategy. District Board Advisory Committees had opportunities to provide input during the Water Master Plan process. Staff also made presentations to the Water Retailers Committee, Water Retailer Subcommittees, and other agencies and organizations. Stakeholders provided the following input on the Water Master Plan strategy and other water supply options:

- Maintain water supply reliability,
- Plan for population increases and climate change,
- Continue an aggressive level of water conservation programs,
- Evaluate regional recycled water projects,
- Consider indirect potable reuse projects and pursue direct potable reuse,
- Be aware of concerns about local reservoir expansion,

- Investigate regional projects such as the Regional Desalination Project or Los Vaqueros Reservoir Expansion that may provide dry-year options, and
- Address concerns about the reliability of imported supplies conveyed through the Delta.

Some Water Supply Options May Become Feasible in the Future

The District considered a variety of water supply options for the Water Master Plan. Some of the water supply options are not feasible at this time, some did not meet the primary need for drought year supplies, and some did not manage risks well. Other water supply options that were considered for the Water Master Plan are discussed below.

Local Reservoir Expansion

Expanding Anderson Reservoir was one of the options considered for the Water Master Plan

A number of stakeholders expressed concerns about local reservoir expansion, while a number of stakeholders saw value in the increased storage provided by reservoir expansion. Staff analysis indicated that even a large expansion project would not significantly improve the ability to provide water through an entire drought, which is the primary challenge the Water Master Plan addresses. Storage would be depleted by about the fourth year of drought. Consequently, the water supply strategy does not include reservoir expansion, though it may be reevaluated in the future as understanding of local climate change impacts improves, or in considering broader operational and water management needs such as emergency storage.

Direct Potable Reuse

Several stakeholders expressed an interest in the District implementing a direct potable reuse project, in which advanced treated water is added to the District raw water system and can be sent directly to drinking water treatment plants. At this time, California does not allow direct potable reuse. The California Department of Public Health (DPH) is required by law to determine the feasibility of developing regulations for direct potable reuse by December 2016. The District will re-evaluate the feasibility of direct potable reuse after the DPH analysis is complete.

Regional Supply Options

The District has been participating in the Bay Area Regional Desalination Project feasibility study since 2003. The project is currently completing technical studies that will help inform decisions regarding whether to proceed with participation in project design and construction. Options for delivering water to Santa Clara County include exchanges with San Francisco Public Utilities Commission or exchanges of imported water delivered through the Delta.

One stakeholder also expressed an interest in the District participating in an expansion of Los Vaqueros Reservoir, which is owned and operated by Contra Costa Water District (CCWD). CCWD recently expanded its Los Vaqueros Reservoir from 100,000 acre-feet to 160,000 acre-feet, and is continuing to explore further expansion. CCWD has characterized the 160,000 acre-foot expansion as having emergency and dry-year storage opportunities for local Bay Area agencies, but these opportunities have not yet been defined. Similar to local reservoir expansion, the usefulness of participation in Los Vaqueros in meeting multi-year drought water needs would be limited.

The District will further consider these regional projects as dry-year options if there is a mechanism for receiving the water in dry years that is independent of the conveyance through the Delta.

Rainwater Harvesting and Other On-Site Stormwater Reuse Projects

Although there is some community interest in rainwater harvesting, at this point, analyses show relatively high cost and low benefit. For example, rainwater cannot be easily saved at residences for later summer use when it is needed. The District will continue to monitor these types of activities as potential future opportunities. The District will also continue to support low impact development policies that reduce water demands, protect water quality, and improve groundwater recharge.

4 - Implementation Will Be Phased In over Time

Implementation of the water supply strategy would occur over the 2035 planning horizon. Planned investments in water conservation, water recycling, and the existing water supply system will provide for most of the increased water supply needed to meet future demands. This gives the District time to conduct the necessary work to support the most costly project in the water supply strategy: indirect potable reuse. Necessary work includes building the foundation of public support, researching advancements in treatment effectiveness and efficiency, and monitoring regulatory developments.

This chapter contains detailed information on what activities can be undertaken to implement the recommended strategy. The chapter is divided into the program areas of water conservation, recycled water, imported water, other water supply programs, and treated water, though there is some overlap between these categories. For each category, this chapter presents a summary of the implementation plan, risks associated with implementation, and projects and programs that need to be monitored into the future. The chapter concludes with information regarding monitoring and future updates to the Water Master Plan.

Phased Implementation Will Help Ensure Efficient and Effective Investments

The implementation plan consists of four phases over the next 20 years. An overview of the plan is shown on the following page in Table 3. A summary of the implementation plan for new projects and programs is below.

- **Phase 1: 2012 – 2016:** Further studies and planning for projects and programs, as well as public education, outreach, and engagement
- **Phase 2: 2017 – 2021:** Project level planning for a new recharge pond and the IPR project, as well as beginning imported water reoperations and the gray water rebate program. Begin design for IPR and groundwater recharge ponds.
- **Phase 3: 2022 – 2026:** Complete design and begin construction of IPR; complete design and construction of groundwater recharge ponds.
- **Phase 4: 2027 – 2031:** Complete construction of IPR and begin operations.
- **Phase 5: After 2031:** Operations of all new projects and programs

The District will monitor water supply conditions, update assumptions, and periodically validate this implementation plan. The Water Master Plan does not commit the District to a particular course of action. To capture changing conditions such as changes in supply and demand projections, climate, regulations, and baseline systems, the District will conduct a master plan update every five years and will adjust the strategy and implementation plan accordingly.

Table 3. Implementation Approach

Strategic Elements	Phase 1: 2012 – 2016	Phase 2: 2017 – 2021	Phase 3: 2022 – 2026	Phase 4: 2027 – 2031	Phase 5: After 2031
Secure & Monitor Baseline Supplies and Demands ***No Increase – Maintain existing and planned supplies***	• RWMP Updates • BDCP Completion • Secure SFPUC supplies • FAHCE Settlement Completion • Evaluate Climate Change Impacts • 2015 UWMP update • WSIMP Update	• Secure CVP M&I Allocation Agreement beyond 2022 • Dam Seismic Retrofits Construction • Main and Madrone Pipelines Rehabilitation • Secure Llagas basin drought supplies • 2020 UWMP update • WSIMP Update	• 2025 UWMP update • WSIMP Update	• Conservation program savings of 98,500 AFY • Renew CVP Water Supply Contract • 2030 UWMP update • WSIMP Update	• Recycled water use of approximately 30,000 AFY • 2035 UWMP update • WSIMP Update
Develop Indirect Potable Reuse ***At least 20,000 AFY***	• Continue stakeholder engagement • Monitor advanced recycled water treatment effectiveness • Monitor regulations and policies	Project-level planning for IPR facilities and Lexington Pipeline; begin design	Complete design and begin construction	Complete construction and begin operations	Operations
Additional Groundwater Recharge Ponds ***3,000 AFY***		Project-level planning; begin design	Complete design and construction	Operations	Operations
Imported Water Reoperations ***No increase***	Obtain necessary approvals	Revised operations	Revised operations	Revised operations	Revised operations
Gray Water Reuse Rebate Program ***300 AFY***	Develop groundwater protection guidelines	Operations	Operations	Operations	To Be Determined
Dry Year Option Agreements ***Up to 23,000 AFY***	Up to 8,000 AFY in droughts	Up to 6,000 AFY in droughts	Up to 15,000 AFY in droughts	Up to 23,000 AFY in droughts	Up to 12,000 AFY in droughts

BDCP = Bay Delta Conservation Plan; FAHCE = Fisheries and Aquatic Habitat Collaborative Effort; SFPUC = San Francisco Public Utilities Commission; RWMP = Recycled Water Master Plan; UWMP = Urban Water Management Plan; WSIMP = Water Supply and Infrastructure Master Plan; AFY = Acre-Feet per Year

Water Conservation Reduces Demands for Water

Most of the water conservation program in the next 25 years is related to continuing current and planned programs to reach the goal of 98,500 acre-feet of water conserved per year by 2030. The master plan strategy adds one new water use efficiency program: gray water rebates. As shown in Table 3, in the first phase of implementation, the District will develop groundwater protection guidelines and program details. Groundwater protection guidelines will address concerns with the quality of the gray water potentially being returned to the aquifer. This rebate program will begin in about 2017.

It will be challenging to meet the current 2030 target for water conservation, as the District has already implemented many basic conservation programs including programs to reduce residential, commercial and industrial, and landscape water use. However, conservation is dynamic with new technologies being developed, new implementation methods being tested, and associated costs declining. It is a field the District will continue to monitor to ensure it is cost-effectively meeting its short-term and long-term water supply reliability goals. Other specific areas that the District will continue to monitor include:

- **Technology and Policy:** New technologies, cheaper technologies, new local or state programs, and new policies may create new opportunities or requirements for increased conservation.

- **Local Land-use Policy Changes:** Land use policies supporting low water use development typically require multiple agencies to implement, and, therefore, are more difficult to rely upon for achieving water conservation objectives. However, the District will continue to encourage land use agency efforts to implement low-impact development, and monitor opportunities to increase conservation through land use policy.

Developments in either of these areas may result in new conservation activities becoming feasible for future Water Master Plan updates.

Recycled Water is a Local, All-Weather Supply

Non-Potable Recycled Water Use

Non-potable recycled water use is projected to expand from about 15,000 AFY to 29,000 AFY by 2035. Currently, the recycled water producers and retailers in northern Santa Clara County are updating their recycled water master plans. Over the next five years, the District will focus on participating in these master planning efforts, and postpone any further capital investments until master plans are completed. Specific tasks related to recycled water master planning include:

This pipeline in Gilroy provides recycled water to a local farmer

- Partner in the development of a Recycled Water Master Plan for the South Bay Water Recycling (SBWR) system.
- Postpone investment in the Regional Recycled Water Connector project until the SBWR Recycled Water Master Plan is completed.
- Monitor and participate in Recycled Water Master Plans for the Palo Alto and Sunnyvale systems.
- Evaluate the need for a regional master plan after the SBWR, Palo Alto, and Sunnyvale master planning efforts are complete.
- Align District recycled water program goals with SBWR, Palo Alto, Sunnyvale, and South County Recycled Water Master Plans, or with a regional master plan.

Expanding non-potable systems is not without risks. A primary concern is that expansion of non-potable use could have negative impacts on groundwater quality. Continuing technical studies on the effects of irrigation with recycled water, and completing the Salt and Nutrient Management Plans for north and south county groundwater subbasins will help address this risk. Blending advanced treated recycled water also helps address this risk, and will become increasingly important as non-potable use is expanded. Another risk of expanding non-potable use is that assets may become stranded. As locations of recycled water use change, pipes to those areas may become obsolete. Recycled water master planning will help mitigate this risk.

Two programs related to recycled water have been identified for continued monitoring and possible future development.

- **Storm Water Reuse:** Storm water reuse, in this context, refers to larger scale projects than those designed for on-site reuse such as rainwater harvesting. Though not defined at this time, the District will continue to look for opportunities for additional storm water reuse recharge projects as part of developing groundwater recharge capacity and planning flood protection projects. These types of projects could help optimize local supplies.

- **South County Expansion Projects:** The 2004 South County Recycled Water Master Plan recommended three phases of capital improvements – Immediate, Short-Term, and Long-Term. The Immediate phase, which was completed in 2006, expanded recycled water production capacity and added distribution pipeline to increase recycled water distribution capacity by about 800 AFY. The Short-Term phase, which is in progress, will add distribution pipelines and increase capacity by about 1,000 AFY. The Water Master Plan found that the Long-Term capital improvement phase, which included additional pipelines and storage, is not cost-effective at this time. However, the District will re-visit the feasibility of the projects as compared to other water supply options in future master plan updates.

Indirect Potable Reuse

The first phase of implementation for indirect potable reuse consists of continued stakeholder engagement, further study and testing of advanced treated water quality, monitoring state regulations regarding indirect and direct potable reuse, and confirming maximum brine and minimum fresh water flows that are necessary to support a healthy Bay ecosystem. The District will soon complete construction of the Silicon Valley Advanced Water Purification Center, an advanced water treatment facility that will produce up to 8 million gallons per day of highly purified recycled water. The District will use this facility to monitor and test treatment effectiveness for the proposed indirect potable reuse system. The Center will also serve as a center-piece to gain public support for use of advanced treated water in the water supply system.

Reverse osmosis treatment is one step in the purification process that makes recycled water suitable for potable purposes

The next master plan update (2016) will validate the project before making any large capital investment. The second through fifth phases of implementation for the indirect potable reuse project include project level planning, design, construction and operations, respectively.

One of the major risks associated with investing in indirect potable reuse is public perception. Overcoming negative messages and fostering public acceptance is critical to the success of the indirect potable reuse project. Another risk is the potential for stranded assets. As purification technologies improve and more testing is completed, regulations may change to allow for direct potable reuse. If this occurs, pipelines from wastewater treatment plants to the ponds could become stranded assets. The extended implementation period helps to address these risks.

Imported Water Continues to Be an Important Water Supply

Almost 40 percent of the District's current water supply is conveyed through the Delta

Maintaining the availability and reliability of the county's imported supplies is a critical element of the water supply strategy. The District's state and federal imported water supplies, water banking in the Central Valley, and water transfer agreements all rely on conveyance of water through the Delta. The District is well aware of risks associated with Delta water including potential catastrophic levee failures and more stringent endangered species regulations. Other imported water risks include an interruption of SFPUC supplies to the cities of San Jose and Santa Clara, and loss of reliability in the District's CVP M&I water supplies.

Recommended actions to address these risks and secure baseline imported water supplies include participation developing the Bay Delta Conservation Plan (BDCP), securing SFPUC supplies to the county, and supporting an acceptable CVP M&I water reliability policy. District participation in the BDCP is expected to continue through the first phase of Water Master Plan implementation, depending on the outcome of permitting decisions that will be made in summer 2013. Securing SFPUC supplies to the county will also occur in the first phase of implementation, as SFPUC decisions about its contract with the cities of Santa Clara and San Jose are scheduled to be made by 2018. The District will work with water retailers to supply guarantees from SFPUC. The Bureau of Reclamation is expected to complete environmental documentation and finalize its CVP M&I water shortage policy in the first phase of implementation, and the District will continue to implement its supporting supplemental agreement with CVP agricultural districts. This agreement is valid through 2022, and any needed work to extend it does not need to occur until the second phase of implementation.

The water supply strategy includes imported water reoperations to sell or exchange up to 50,000 AFY of imported water when Semitropic Groundwater Bank storage levels are nearly full and District water supply needs are otherwise met. In the first phase of implementation, the District will identify potential water transfer and exchange partners, and develop necessary agreements and approvals.

The District currently uses various imported water options to supplement supplies during water shortages. The Water Master Plan includes securing such dry-year supplies, though dry-year option agreements. The amount of water secured in the option agreements increases from 6,000 acre-feet per year (AFY) in phase two, to 15,000 AFY in phase three, to 23,000 AFY in the beginning of phase four.

Once indirect potable reuse supplies are available in phase four, the option agreement amount decreases 12,000 AFY.

Other Water Supply Projects and Programs Support Water Supply Reliability

Conservation, recycled water, and imported water are all part of the District's water supply system. This section focuses on the remainder of the District's water supply system, including the groundwater basin, local surface storage, recharge ponds, and the raw water distribution system.

The five year Capital Improvement Program (CIP) includes several projects that maintain or upgrade existing water supply facilities. The Water Master Plan validated the need for three of these capital projects: Main and Madrone Pipelines Restoration, Dam Seismic Upgrades, and Vasona Pump Station Upgrades.

- **Main and Madrone Pipeline Restoration:** The pipelines are currently not being used to their design capacity but are needed for future supply reliability in the Llagas groundwater subbasin. The water supply outlook assumes these two pipelines will be restored to full capacity. Without the pipelines restored, projected future shortfalls would be more severe. Restoration of the Madrone pipeline is more urgent, as it is not meeting current service requirements. The restoration of the Main and Madrone pipelines will be completed by the end of phase two.

Pipelines and other infrastructure need periodic rehabilitation and replacement

- **Dam Seismic Upgrades:** The water supply outlook also assumes the District's reservoirs will be restored to full capacity. The District needs to maintain all its local storage capacity. The District will continue to make seismic improvements to its dams including Anderson, Calero, Guadalupe, and Almaden. Dam seismic upgrades will not be completed until the end of phase two, as some dams are still being studied to determine if retrofits are needed, and seismic retrofits take many years to complete.

- **Vasona Pump Station Upgrades:** Replacement of the Vasona pumps has been delayed in order to validate the appropriate sizing. This capacity analysis has been completed. The analysis found that the pumps are adequate for typical operations, and upsizing the pumps will add operational flexibility. The District needs to further analyze life cycle costs and benefits associated with upsizing the pumps in a business case before starting work on the project. The Vasona Pump Station Upgrades will be implemented in phase one, as the pumps are in poor condition and in need of replacement.

The water supply strategy adds new infrastructure to the water supply system. The Lexington Pipeline will be constructed concurrently with the IPR facilities. The pipeline will allow continued utilization of existing local water rights once the indirect potable reuse project is in place. The strategy also includes construction of new recharge ponds near Saratoga Creek. Project-level planning and design for the pond will begin in phase 2, and construction will occur in phase 3.

In addition to capital projects, the water supply strategy identifies several programs needed to secure baseline water supplies for the future. These are listed below.

- **Fisheries and Aquatic Habitat Collaborative Effort (FAHCE) Implementation:** Since 1996, the District has been working to address a legal challenge to its water rights in the Stevens Creek, Guadalupe River and Coyote Creek watersheds. Before the challenge can be resolved, the District must prepare a Habitat Conservation Plan (HCP) covering all three watersheds to provide incidental take coverage for all the activities included in the draft settlement agreement. When implemented, and the necessary environmental reviews conducted, the plan will improve local fisheries and serve as the basis for dismissal of the water rights challenge. The District will continue work to ensure the FAHCE settlement agreement is implemented, thereby providing assurances that its water rights are protected from future challenges. The District expects to begin implementation of the FAHCE settlement agreement in the next five years.

- **Secure Drought Supplies to Llagas Subbasin:** The District's treated water contracts have provisions for the availability of water if there is a water shortage due to drought or other uncontrollable reason. In case of shortages, the District must first reduce deliveries for groundwater recharge, secondly reduce deliveries of agricultural water, and finally, reduce treated water deliveries. Since South County does not receive treated water, its supplies could be greatly impacted by a county-wide water shortage. Consequently, the District will work with its retail water agencies and stakeholders in north and south county to clarify expected operations under shortage conditions. The District intends to provide a minimum delivery of about 5,000 AFY to the Llagas Subbasin in a drought. Securing drought year supplies to Llagas subbasin is scheduled for phase two, in line with restoration of the Main and Madrone pipelines.

- **Study Climate Change Impacts on Local Supplies:** The Water Master Plan analyzed climate change to the extent possible, but has insufficient data for forecasting effects on local water supplies. In order to better analyze climate change impacts in future Water Master Plan updates, the District will gather additional data and perform additional analyses. Climate change studies will be completed in phase one so that climate change data is available for analysis in the next Water Master Plan update.

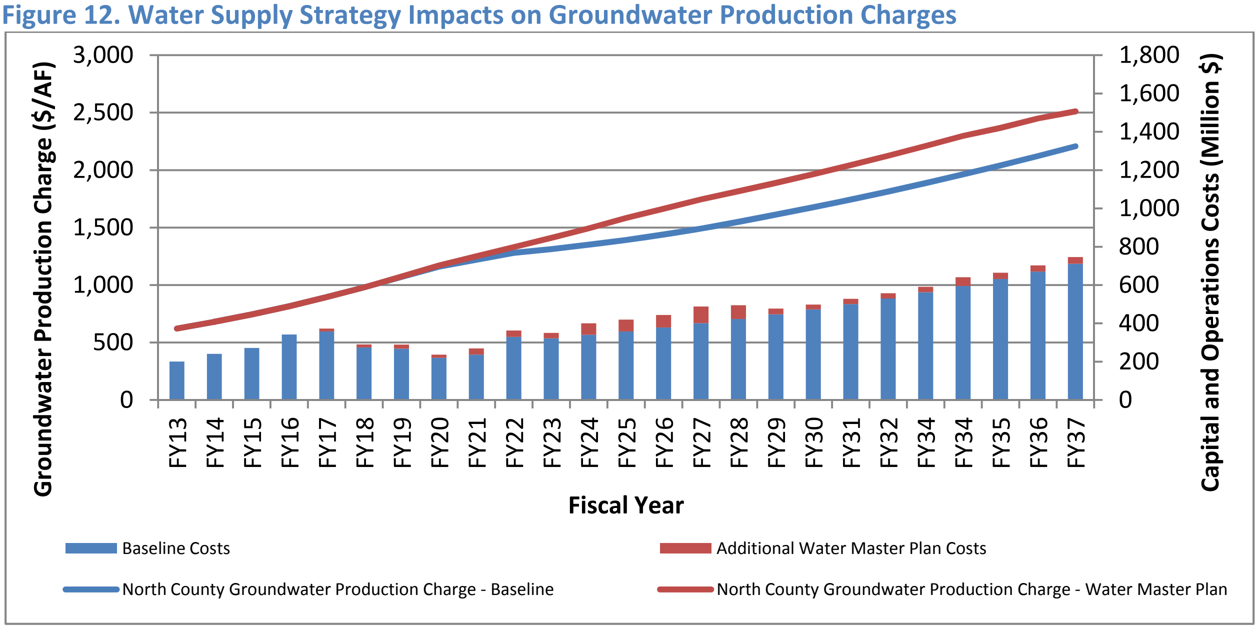
Aside from general risks of construction or project delays, the recommended projects and programs discussed in this section have relatively low implementation risk. Also, during Water Master Plan analyses, no additional programs or projects were identified for further monitoring.

Water Supply Costs Will Also Be Phased

Stakeholders value water supply reliability and most are willing to pay for it. The Stakeholder Review Committee was almost unanimous in their support of the water supply strategy, even though it costs much more than other water supply options. The economic analysis found that the benefits of the water supply strategy are more than double the costs. The present value cost of the water supply strategy, excluding securing the baseline system, is about $440 million. This does not include a potential present value benefit of about $70 million from imported water reoperations. The estimated impacts on groundwater production charges in Zone W-2 in northern Santa Clara County range from no incremental change up to a peak of about $335/AF in 2034. By that time, the groundwater production charge for the baseline system is projected to be about $1,960/AF, based on the District's current understanding of the future investments that are necessary to maintain the baseline water supply system. The recommended strategy, as laid out in this plan, will have minimal effects on groundwater production charges in Zone W-5 in southern Santa Clara County. Figure 12 shows the anticipated impacts of the water supply strategy on groundwater production charges in Zone W-2 (North County).

> *"I would rather answer calls about water rate increases than have to tell someone I can't deliver water to them." – Stakeholder Review Committee Member*

Figure 12. Water Supply Strategy Impacts on Groundwater Production Charges



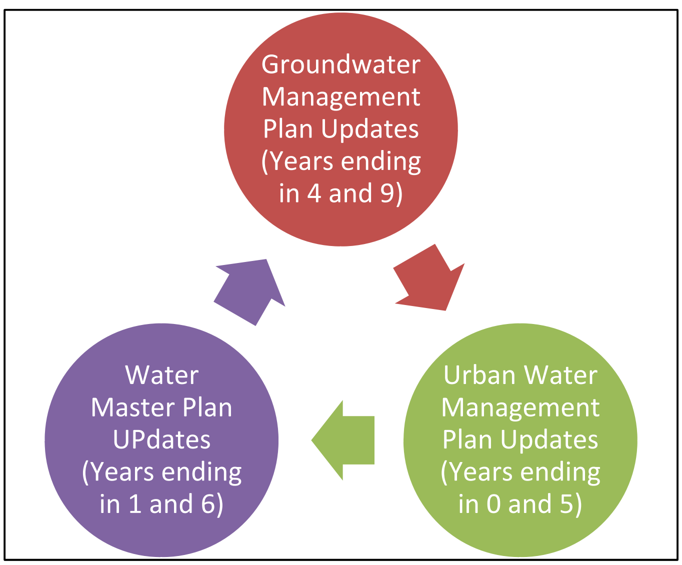
The District may be able to reduce costs for the water supply strategy if the following opportunities become available in the future:

- Direct potable reuse is permitted and accepted by the community and regulatory agencies;
- Advanced treatment technologies become less expensive, more efficient, or both; and
- Partners are willing to enter into imported water exchange agreements.

The Water Master Plan Will Be Monitored and Updated

The Water Master Plan recognizes that baseline supplies and infrastructure are subject to change. Therefore, the long-term strategy will be updated every five years following preparation of the Urban Water Management Plan to capture updated supply and demand projections, as well as changes in groundwater basin management objectives. This water management planning cycle is illustrated in Figure 13. The implementation plan will be reviewed annually over the next five years to ensure that the recommendations are still valid, and to ensure that all Water Master Plan projects and programs are budgeted, planned, and completed at the appropriate times. The District will report on progress annually, and will measure success using performance measures and milestones.

Figure 13. Water Resources Planning Cycle



The Water Master Plan recognizes that completion of baseline projects and programs such as the BDCP and FAHCE implementation, and many other circumstances such as water reuse regulations, can significantly affect the Water Master Plan strategy. Additionally, new issues will likely arise over the planning horizon. The plan will be updated every five years to address any changed and new circumstances. Periodic plan updates will allow the District to address any new or changed circumstances and to adjust its water supply strategy to fit the needs of the county in the future.