DOCUMENTATION OF DESIGN DEFICIENCIES
SANTA CLARA RIVER LEVEE SYSTEM (SCR-1)

1. Project Description and Watershed Characteristics

The Santa Clara River Levee (SCR-1) system is located in the city of Oxnard, in Ventura County, California. It is approximately 4.72 miles long, extending along the southeast bank of the Santa Clara River from Highway 101, at its downstream terminus, to the community of Saticoy, at its upstream terminus (see Figure 1). SCR-1 was originally designed in 1958 by the U.S. Army Corps of Engineers (Corps) to control the Corps' predicted Standard Project Flood peak discharge of 225,000 cubic feet per second (cfs), a peak emanating from a partially regulated 1,600-square-mile Santa Clara River watershed. The height of SCR-1 varies from approximately 4 feet to 13 feet. The compacted fill embankment that forms SCR-1 has a top width of 18 feet. The levee embankment slopes are 2 horizontal to 1 vertical (2H:1V), on both the landward side and the riverward side. The riverward side of the embankment has a 1.5- to 2-foot-thick rock revetment, with a concrete facing at and near highway bridges. The rock revetment extends from the top of the embankment to varying depths. The lowest depth of the rock revetment is hereinafter referred to as the "toedown."

Construction of the SCR-1 project was completed in 1961. The levee was constructed adjacent to the active channel of the Santa Clara River. A review of historical aerial photography, dating as far back as 1927, indicates that before construction of the SCR-1, there were numerous locations along the project reach where the primary braid of the Santa Clara River impinged directly on the east and west banks of the river at rather abrupt flow angles. Aerial photographs of the SCR-1 project reach taken between 2002 and 2005 show no less than four separate locations along SCR-1 where the primary braid impinged directly on the east bank of the river at abrupt flow angles, resulting in lateral bank erosion (see Figure 2).

The Santa Clara River watershed includes several dams and large-scale urbanization. Major dams within the watershed, which regulate roughly 36 percent of the contributing watershed area include Bouquet (constructed in 1934), Santa Felicia (constructed in 1955), Pyramid (constructed in 1971), and Castaic (constructed in 1972) (Stillwater Sciences 2007).

1.1. Specific Features of Project Design

The reason for the varying depths of rock revetment along SCR-1 is documented in a Corps General Design Memorandum (GDM) (USACE 1958) that describes the differences between the project document plan and the recommended plan. The GDM indicates that, at the time of design, a board of consultants was convened to provide project design recommendations for the configuration of the rock revetment. According to the GDM, the board of consultants recommended, *that (a) instead of a levee with a deep toe-down (the toe-down would extend 12 feet below the streambed), where a 200-foot berm of undisturbed granular streambed material exists between the levee and the main-stream channel, the depth of the toedown to be extended only 5 feet below the top elevation of this undisturbed material or (b) in the absence of this undisturbed material and at locations subject to direct attack by streamflow, groins extending 150 feet into the stream and spaced 225 feet – with slight deflection in the downstream direction – be built.*

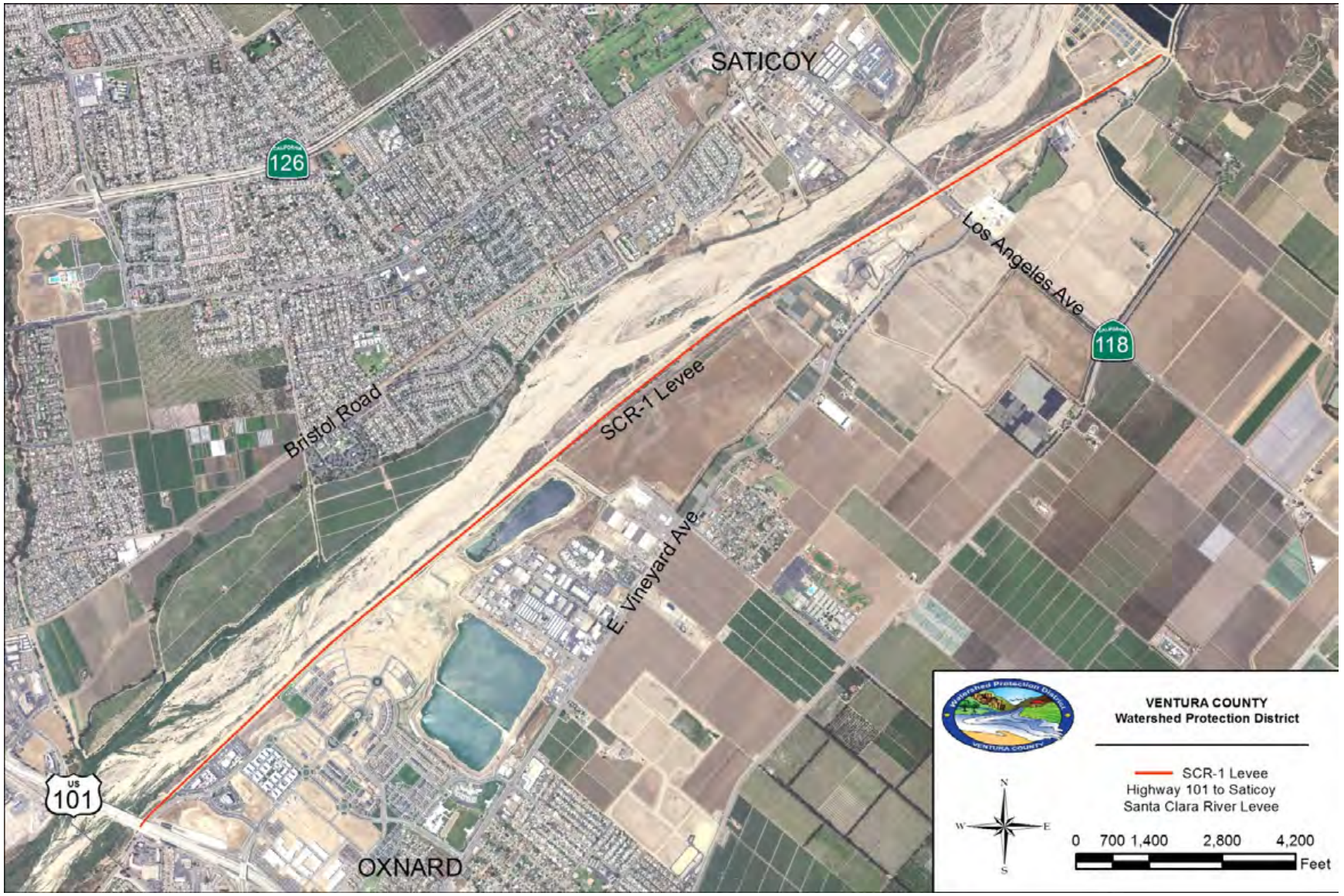
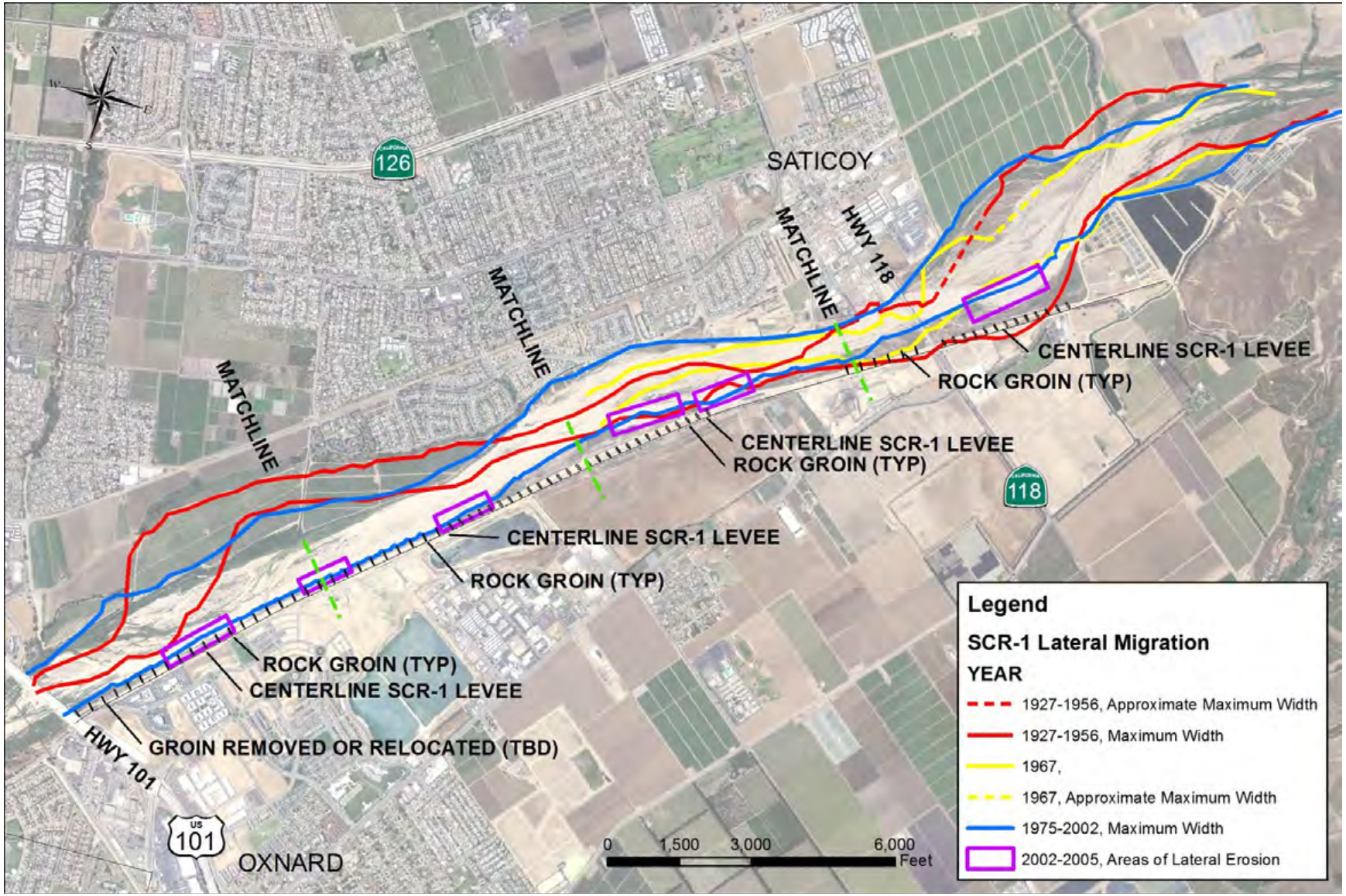


Figure 1: Location Map for Santa Clara River Levee System


SATICOY
126
MATCHLINE
MATCHLINE
MATCHLINE
HWY 118
118
CENTERLINE SCR-1 LEVEE
ROCK GROIN (TYP)
CENTERLINE SCR-1 LEVEE
ROCK GROIN (TYP)
CENTERLINE SCR-1 LEVEE
ROCK GROIN (TYP)
ROCK GROIN (TYP)
CENTERLINE SCR-1 LEVEE
GROIN REMOVED OR RELOCATED (TBD)
HWY 101
US 101
OXNARD
0 1,500 3,000 6,000
Feet
Legend
SCR-1 Lateral Migration
YEAR
1927-1956, Approximate Maximum Width
1927-1956, Maximum Width
1967,
1967, Approximate Maximum Width
1975-2002, Maximum Width
2002-2005, Areas of Lateral Erosion

On the basis of the board of consultants recommendations for the design of SCR-1, it appears that the board relied on a "200-foot berm of undisturbed granular streambed material between the levee and the main-stream channel" to justify reducing the depth of the toedown protection from 12 feet below the streambed to 5 feet below the top elevation of the undisturbed material. This indicates that the board of consultants either overlooked or was unaware of the erosive potential of flow impingement on the levee due to strong braided flow conditions and a wide stream such as the Santa Clara River when it recommended reducing the depth of the toe protection.

The revetment toedown for SCR-1 varies from 5 feet to 10 feet below the river streambed between Highway 101 and a point approximately 8,500 linear feet upstream, beyond which the depth of the toedown changes significantly, from approximately 5 feet below the streambed to approximately 10 feet above the streambed. Still farther upstream, at Highway 118, the toedown depth changes to approximately 5 feet above the streambed. Beyond Highway 118, the toedown depth changes from approximately 5 feet above the streambed to approximately 18 feet above the streambed at the upstream end of the levee. In the upstream reaches, the bottom of the levee toe, as well as the existing rock groins, are located above the streambed elevations of the Santa Clara River. If during a flood the existing rock groins should fail to restrain the flow within the main channel, the levee would potentially be undercut.

The existing rock groins were recommended in the Corps' 1958 GDM. They were subsequently constructed in order to divert low to moderate flows away from the rock revetment along the levee. In addition, a weighted stone toe section was designed and constructed along the levee toedown. This weighted stone toe section was constructed with the intent that it would launch into the river during flood flow in order to prevent the rock revetment from being undermined.

1.2. The "As-Constructed" Project

The original construction, completed in 1961, included 40 rock groins. After extensive damage occurred along SCR-1 during floods in January and February 1969, the Corps repaired 7 of the original 40 rock groins (located between Station 330+00 and Station 344+50), restored 2,100 linear feet of levee embankment and provided deeper rock revetment (between Station 311+00 and Station 332+00), and added 35 additional rock groins (between Station 246+00 and Station 330+00 and between Station 421+80 and Station 436+80). These repairs and enhancements were completed in 1971. A total of 75 rock groins are now in place along the SCR-1 project reach, extending from Station 246+00 to Station 470+00. In December 1985, Ventura County restored five rock groins near a location of a 1969 levee failure (i.e., between as-built Station 316+45 and Station 356+45). The damages that occurred may have been caused by a 1983 flood, which had an estimated peak discharge of 100,000 cfs. The damage to the rock groins was likely due to the low-flow channel encroaching and washing out the top portion of the groin tips. After the 1983 flood, the riverward tips of five rock groins, as well as a portion extending between 40 and 100 feet along the groins, were damaged. Ventura County repaired these five rock groins, which included one of the original 1961 rock groins and four of the rock groins added by the Corps in 1971 (from Station 321+00 to Station 333+07). The Ventura County repairs included the removal of approximately 2 feet of existing rock and the placement of 2-ton rock riprap back to the original design dimensions, followed by backfilling with uncompacted fill. This is the only known location along SCR-1 where non-Corps stone revetment was added to the system.

2. Past Performance History

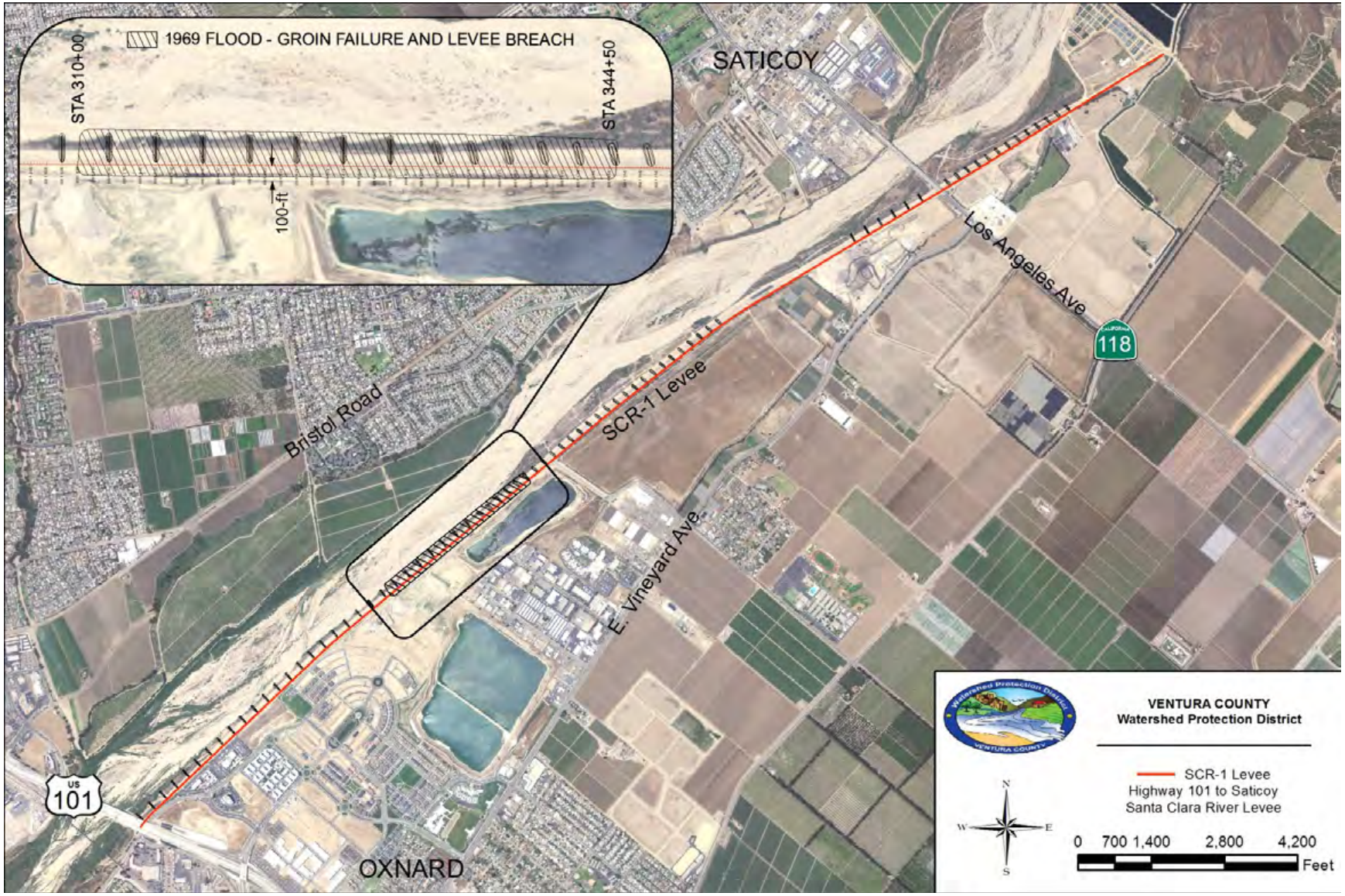
Before the completion of the as-constructed SCR-1, the occurrence of several severe storms had been documented by the Corps (USACE 1968), including the February/March 1938 flood, which damaged the Highway 118 bridge (Los Angeles Avenue) and the January 1943 flood, which caused severe damage to adjacent agricultural land, crops, and bridges. The January 1952 flood was severe enough to cause flood and erosion damage to properties adjacent to the river. The 1968 documentation included no specific details of the type and extent of flood damages resulting from these floods. The estimated peak discharges for the 1938, 1943, and 1952 floods were 95,000 cfs, 72,000 cfs, and 45,000 cfs, respectively (VCWPD 2006).

The floods that occurred in Ventura County in January and February of 1969 were the most damaging floods of record along the Santa Clara River. The estimated peak discharge during the 1969 floods was 165,000 cfs, based on a stream measurement made around the time of the peak.

The following text, which is an excerpt from a 1969 Corps report (USACE 1969), pertains specifically to the reach of the Santa Clara River located between Highway 118 and Highway 101.

The only significant damage that occurred in this reach during the January flood was damage to the revetment of an existing levee constructed by the Corps of Engineers. February floodflows washed out about 500 feet of State Route 118 bridge, damaged agricultural property and utilities, and severely damaged flood-control improvements constructed by the Corps of Engineers. …The flood eroded the south bank near the existing Corps levee, damaging some groins; then deflected, ricocheted from the State Route 118 bridge, and returned to the south bank – where the floodflows cut in close to the Corps levee, bounced off to the north bank, and carved a long arch. The floodflows then deflected to the south bank where they undercut the toe protection on the Corps levee, causing the failure of about 2,000 feet of levee and eroding the ground behind the levee for a distance of about 100 feet.

The location of the 1969 levee failure is shown on Figure 3. From 2002 through 2005, SCR-1 continued to experience episodes of streambank erosion/lateral migration that threatened the integrity of the levee system.


1969 FLOOD - GROIN FAILURE AND LEVEE BREACH
STA 310+00
STA 344+50
100-ft
SATICOY
Los Angeles Ave
118
Bristol Road
SCR-1 Levee
E. Vineyard Ave
US 101
OXNARD
VENTURA COUNTY
Watershed Protection District
SCR-1 Levee
Highway 101 to Saticoy
Santa Clara River Levee
N
W
E
S
0 700 1,400 2,800 4,200
Feet

3. Potential Future Performance

Currently, potential future performance of SCR-1 will be adversely affected if the following deficiencies are not addressed in a timely manner:

- Existing rock revetment
- Rock groins
- Mitigation of lateral channel migration

3.1 Existing Rock Revetment

The existing rock revetment is composed of several types of rock (e.g., sandstone, igneous, and conglomerate), much of which is desiccated and broken down into smaller pieces along the entire length of the levee. For much of the levee, the existing rock revetment was not design deep enough to prevent undermining of the levee by the river. Accordingly, the ability of the existing rock revetment to provide an appropriate level of protection during future floods is questionable.

3.2 Rock Groins

The condition of the rock groins is similar to that of the rock revetment. In addition, rock groins along a 2,000 foot levee reach completely failed during the February 1969 flood event. Currently erosion has come within 200 feet of the levee embankment. Some of the river erosion has a 20- to 25-foot-deep cut, which is trending toward the levee embankment.

3.3 Mitigation of Lateral Channel Migration

Lateral migration of the river channel could undermine the existing rock revetment and rock groins along the Santa Clara River. A deeper toedown of scour and erosion protection would be required to prevent the levee from being undermined.

4. Conditions Warranting Recommendation for Corrective Action

As stated in Engineer Regulation (ER) 1165-2-119, it is a general policy of the Chief of Engineers, that completed Corps projects be observed and monitored by the Corps to ascertain whether they continue to function in a satisfactory manner and whether there is potential for better serving the public interest (USACE 1982). Although significant modifications to existing projects require authorization by the U.S. Congress, occasionally a project may warrant modification because its original development was inherently deficient. Under certain conditions and qualifications, measures to correct such deficiencies may be undertaken. Construction to correct a design deficiency may be recommended for accomplishment under existing project authority without further congressional authorization if the proposed corrective action meets all the following conditions (USACE 1982):

1. It is required to make the project function as initially intended by the designer in a safe, viable and reliable manner, e.g., pass the original design flow without failure. This does not mean the project must meet present-day design standards. However, if current engineering analysis or actual physical distress indicates the project will fail, corrections may be considered a design or construction deficiency if the other criteria are met.
2. It is not required because of changed conditions.

3. It is generally limited to the existing project features. Remedial measures that require land acquisitions or new project features must not change the scope or function of the authorized project.
4. It is justified by safety or economic considerations.
5. It is not required because of inadequate local maintenance.

All of the preceding conditions are applicable to SCR-1, for the reasons articulated in Sections 4.1 through 4.5.

4.1. Condition 1

4.1.1 General Design and Construction Deficiencies

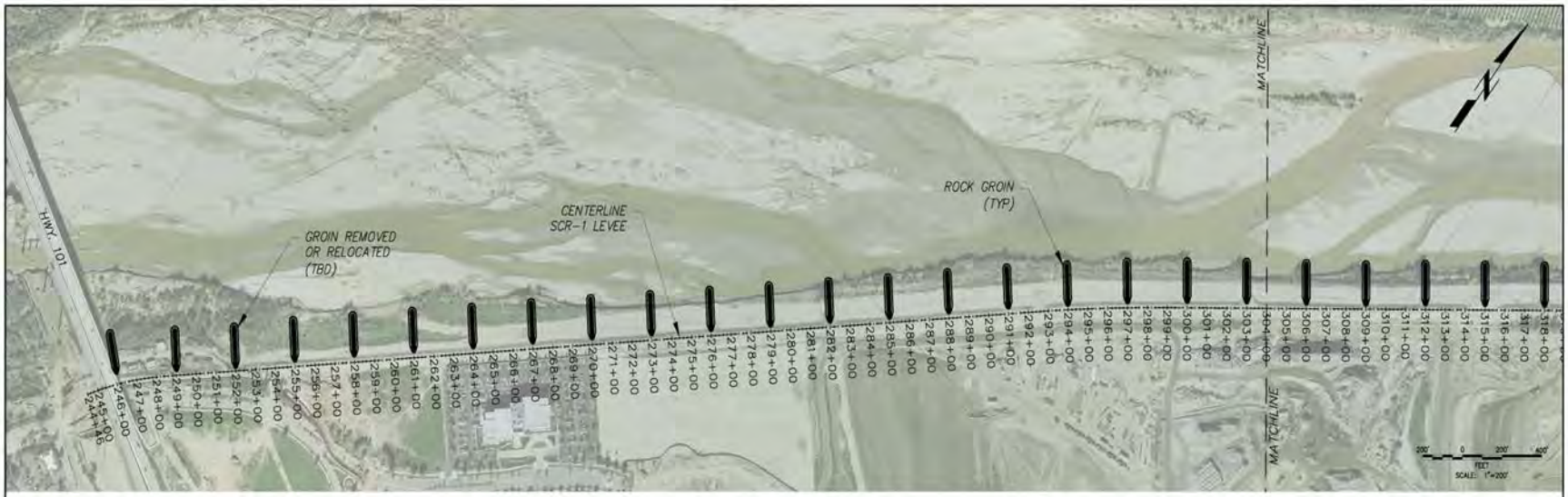
During ordinary and extraordinary flow events, a wandering low-flow channel will create a highly non-uniform flow distribution along SCR-1, which in turn will increase the potential for the initiation of high-angle flow impingements on the levee in various locations along the levee system. Consequently, over the past 50 years these altered flow conditions have led to channel migration toward SCR-1 that was greater than that anticipated at the time of design (see Figures 4A, 4B, 4C, and 4D).

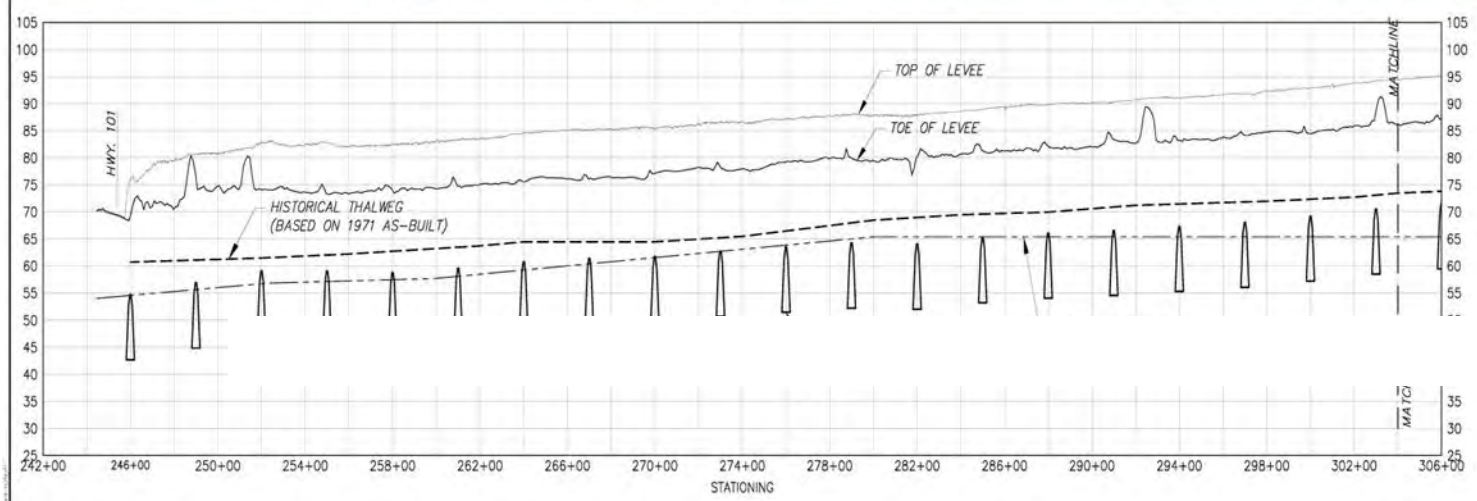
Mitigating ongoing migration problems along SCR-1 would require predicting, with reasonable certainty, site-specific locations where the braiding and high-angle impingements will adversely affect the levee system. However, the locations of potential future problems cannot be predicted with a high degree of accuracy. Such problems could occur anywhere along SCR-1.

4.1.2 Specific Deficiencies

4.1.2.1 Inadequate Toedown

- Historical aerial photographs and an evaluation of lateral migration along SCR-1 indicate that the Santa Clara River has the potential to erode the riverbank and expose the rock revetment and groins during a single large flood event.
- At the time of the design, the elevation of the river streambed was below the elevation of the rock revetment along the levee where it extends from location of the 1969 levee failure (near as-built Station 330+00) to the upstream end of the levee system (at Station 490+90).
- At the time of the design, the elevation of the river streambed was lower than the elevations of the rock-groin toedown that extends from Station 360+00 to Station 392+00.
- Analysis indicates that from as-built Station 335+50 to Station 391+75, the volume of the as-built weighted stone toe is insufficient, by a factor of 3.0, to protect against the currently predicted scour depth, particularly if the channel thalweg were to migrate toward the levee (Tetra Tech 2009).





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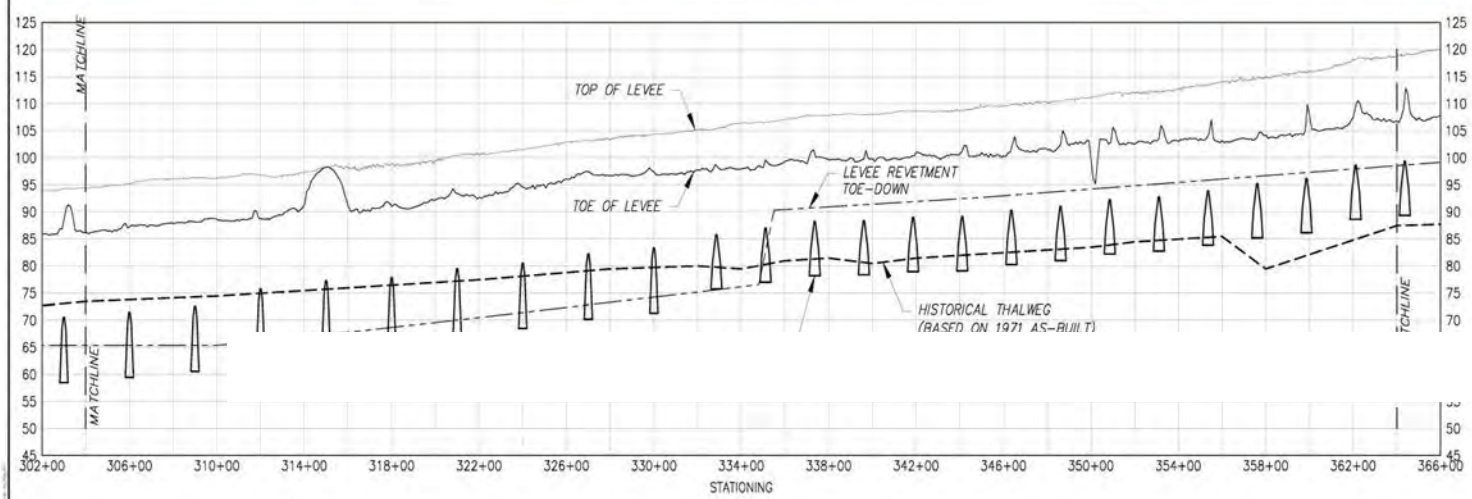

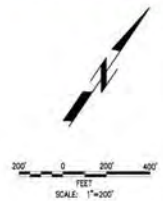

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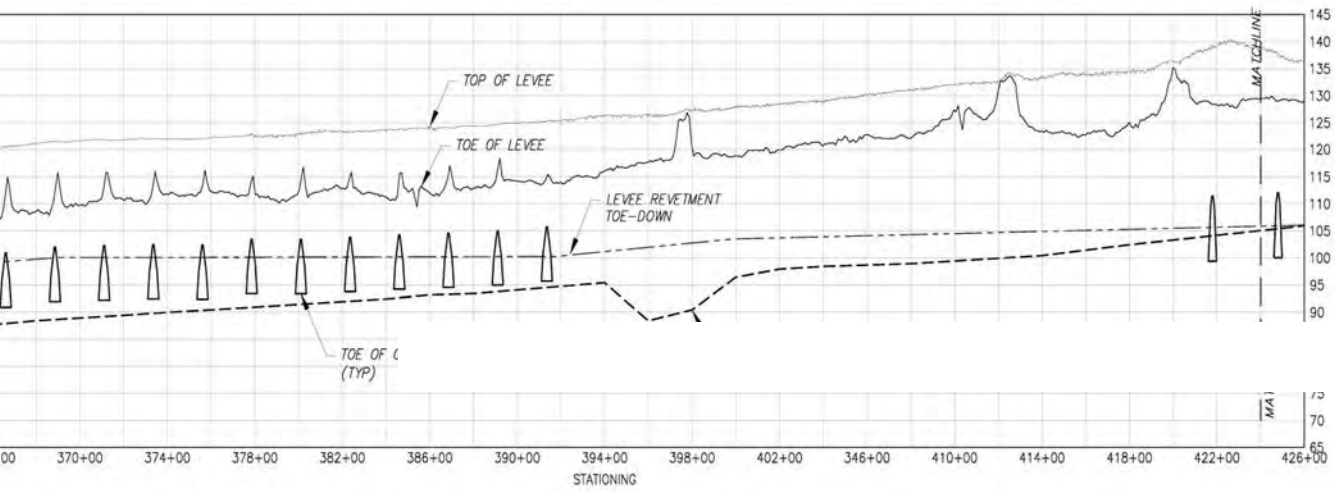

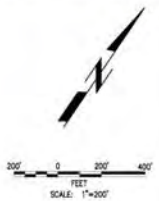

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COUNTY OF VENTURA – PUBLIC WORKS AGENCY
VENTURA COUNTY WATERSHED PROTECTION DISTRICT

EXHIBIT 1
SANTA CLARA RIVER LEVEE (SCR-1)
PLAN AND PROFILE – STA. 364+00 TO STA. 424+00

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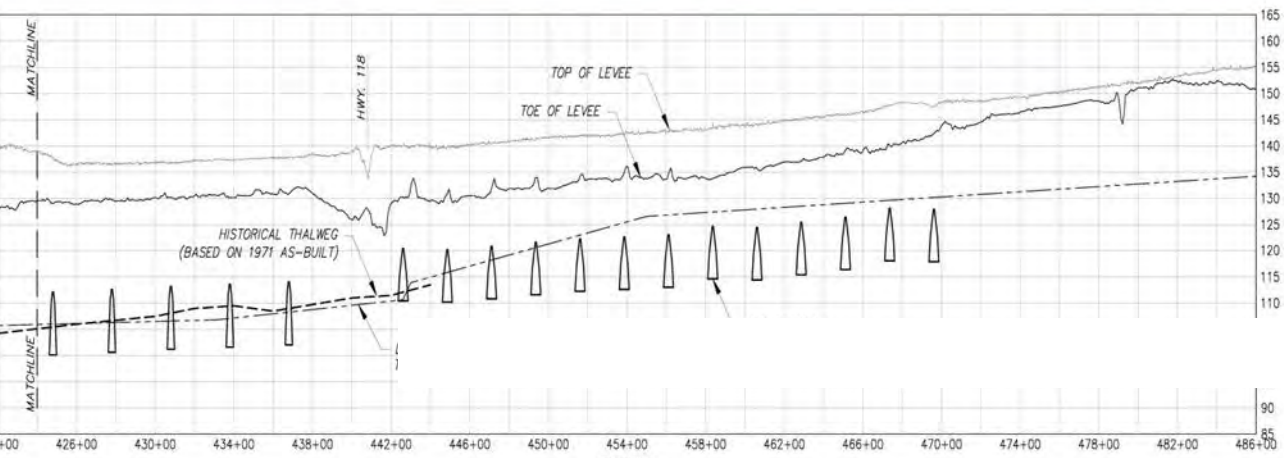

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4.1.2.2 Inadequate Rock Size

- A comparison of computed groin rock size versus as-built groin rock size indicates that the as-built groin rock is undersized to withstand the predicted hydraulic forces during the design flood event. The results of this evaluation are consistent with the observed damage to the groins that resulted from the flood events in 1969 and the early 1980s, where river flows came into direct contact with the rock groins and caused portions of the groins to fail.
- Recent test results indicate that, at one location, the lower portion of the rock gradation (i.e., D_{40} and finer) is smaller than the lower bound of the required rock size. A visual assessment indicated the extent of the levee that would have rock revetment similar to the undersized rock found at the referenced test location is approximately 9,000 linear feet, extending from as-built Station 262+00 to Station 350+00 (located near the Central Avenue Drain) and approximately 7,000 linear feet, extending from Station 420+00 to Station 490+90 (i.e., the upstream terminus).
- The visual assessment indicated that the remainder of the levee would have rock revetment similar to that at two test locations, which both exhibit poorly distributed gradations. Additionally, poor gradation distribution of field-observed rocks from all of the test locations may result in an inability of the rock to interlock properly.

4.1.2.3 Inadequate Rock Quality

The revetment consists of several types of rock (e.g., sandstone, igneous, and conglomerate), much of which is desiccated and broken down into smaller pieces. In some reaches of the SCR-1 system, the Conejo Creek Quarry revetment stone began to deteriorate due to exposure before the original construction was completed.

4.1.2.4 Inadequate Rock Groins

The rock groins were placed along SCR-1 to prevent the river from migrating against the levee side slopes. Because of the rock groin placement, the toedown for the levee slope protection was not designed for impingement of the channel thalweg on the levee toe. However, the rock groins are inadequate to prevent the migration of the channel for two reasons:

- They are undersized and cannot withstand the hydraulic forces of the design flood event.
- For much of their length, they are not buried deep enough to prevent their failure due to undermining from lateral migration and scour.

Because the rock groins are insufficient to prevent lateral migration of the river thalweg against the levee side slope, the levee, in order to remain stable, must resist the hydraulic forces and the attendant scour that would occur with the thalweg located against the toe of the levee. However, the current levee protection is inadequate to resist the resulting forces and scour for several reasons:

- The estimated maximum potential total scour depth of 13.1 feet below the existing river thalweg during the design flood would undercut the entire rock-revetment toedown along the levee.

- The additional volume of material that was placed as the weighted stone toe is insufficient to launch and protect the levee toedown against the currently calculated scour depth.
- Based on data from test pits, the rock revetment on the levee side slope is suspect, particularly in terms of its size at some locations and the quality of its gradation at others.

4.1.2.5 Observed System Failure

The inadequacy of the current configuration of the SCR-1 levee protection system has been demonstrated by past failures. For example, the levee failed in the 1969 floods, with the occurrence of a peak discharge of 165,000 cfs, which is 73 percent of the Corps standard project flood discharge of 225,000 cfs—the level of flood protection for which the levee was originally designed (USACE 1969).

4.2. Condition 2

The corrective action is not needed due to changed conditions. The conditions requiring correction existed and were operating in the Santa Clara River when the original project was constructed. This is documented by the damage to the levee in 1969, just 8 years after the initial construction was finished.

4.3. Condition 3

The action required to correct the project deficiency is strictly limited to providing only the flood protection the original design was authorized to provide. It would not involve work outside of the existing project features and it would not change the scope or function of the authorized project.

4.4. Condition 4

In its current condition, the existing SCR-1 levee system has a reasonable failure potential due to undermining of its toedown during major flood events. Failure of the levee would result in countless millions of dollars of urban infrastructure, commercial, and residential property losses, not to mention the potential for significant loss of life—particularly if a portion of the levee were to collapse suddenly during the night. ER 1165-2-119 stipulates that when a construction project is required to correct a design deficiency, that project can be justified by either safety or economics. Economically speaking, the impact of a levee breach on properties, businesses, and infrastructure would be great; however, life safety is the more compelling justification for making upgrades and improvements to SCR-1.

Accordingly, there is very strong safety and economic justification for implementation of the corrective measures along SCR-1 to reduce the flood risk in the project reach.

4.5. Condition 5

The local sponsor, Ventura County Watershed Protection District, has diligently patrolled the levee during flood flows and has provided timely and aggressive flood fighting when necessary. The levee system has been well maintained by the local sponsor.

5. Supporting Documentation

The Corps 1958 GDM for SCR-1 states that the initial design was to place a deep toedown, which would extend 12 feet below the streambed (USACE 1958). Such a suggested toedown depth indicates that this was the practice at the time (i.e., circa 1958). It was not until a board of consultants was later assembled to provide recommendations that the "as-constructed" design was developed (i.e., whereby the levee erosion-protection toedown and rock-groin scour protection was constructed above the streambed). Although it apparently was the practice at the time for the Corps to use boards of consultants, it is unclear whether there were any other projects during the same time period that were designed and constructed in a manner similar to what was recommended by the board of consultants for SCR-1.

In a recently prepared periodic inspection report (USACE 2011), the first sentence of Section 4.4.1 (Degradation and Deterioration of Revetment and Groin Stone) reads, "In some reaches of the Santa Clara River 1 Levee System, the Conejo Creek Quarry revetment stone began to deteriorate from exposure before the original construction was completed."

In a report of inspection prepared by the Corps (USACE 1977), the conclusion reads, "Due to failure of a large quantity of stone placed during the initial construction and the restoration projects it is suspected that the structures in part may not have adequate facing stone protection to satisfy the minimum size requirements established by EM 1110-2-1601."

In two condition survey reports (USACE 1981, 1987), the conclusion is that the stone facing does not appear to comply with the design gradation requirements by being undersized at virtually all locations along the levee. Specifically "this small size of the stone, in both the overlays and the original stone facing, may be the result of placement during construction and the disintegration process of the rock used."

The preceding statements indicate that the gradation of the stone used in the revetment has been an issue since construction.

The deficiency of SCR-1 in terms of the level of protection for which it was designed has been demonstrated by past failures of the system. The levee failed in the 1969 floods, when the peak discharge was estimated to be 165,000 cfs—a peak that is only 73 percent of the Corps 1958 standard project flood peak discharge of 225,000 cfs, the level of flood protection for which the levee was originally designed.

6. Summary

A river with a large width-to-depth ratio, such as the Santa Clara River, historically exhibits robust braided flow conditions. In this type of fluvial system along a levee system such as SCR-1, it is impossible to accurately predict the future location of high-angle flow impingements. In this regard, at the time of the design and construction of SCR-1, four critical elements were overlooked by the designers, even after convening a board of consultants that subsequently recommended replacement of a deep toedown and/or rock groins. The four critical elements are (1) adequacy of the toedown, (2) adequacy of rock size, (3) adequacy of rock quality, and (4) adequacy of rock groins. The inadequacies that resulted from the failure to account for these four critical elements during the initial design and construction has rendered SCR-1, as originally constructed and subsequently rehabilitated, susceptible to failure during floods due to ongoing lateral migration. The scour caused by the impinging flow from a wandering low-flow thalweg has the potential to lead to subsequent undermining of the levee toedown and rock groins. As a

result, these underlying deficiencies have had an adverse effect on the performance of SCR-1 over the long term, as observed since its initial construction in 1961 to the present. Furthermore, these four deficient elements suggest that without proper rehabilitation of SCR-1 a sudden future collapse or breach of the levee is likely to result from undermining of the levee due to a significant amount of lateral migration, with accompanying scour. Failure of the levee would result in countless millions of dollars of urban infrastructure and commercial/residential property losses, not to mention the potential for significant loss of life—particularly if a portion of the levee were to collapse suddenly during the night.

While SCR-1 has performed for over 50-years, it has had a major failure and this performance period should not detract from the initial design and construction deficiencies.

7. References

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