Appendix H

Chapter 3 – Field Geomorphic Assessment
Chapter 4 – Hydrologic Modeling
Chapter 5 – Stability Assessment
Chapter 9 – Limitations

From SCVWD "Draft Hydromodification Report," June 2004

Prepared by
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Philip Williams & Associates
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APPENDIX H

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3 Field Geomorphic Assessment

3.1 Overview

A field geomorphic assessment was completed for the subwatersheds of Thompson, Ross and San Tomas Creeks as part of development of Hydromodification Management requirements. Conducting a geomorphic assessment is a critical step toward understanding the hydrologic and geomorphic processes that influence channel stability within an urbanizing watershed. The historic assessment and geomorphic field work conducted for this study provide the foundation for evaluating how past hydrology[1] has changed, how modified flow pathways have affected channel form and stability, and what this information means in terms of how the system might be managed to create an ultimately stable channel.

The geomorphic assessment complements and supplements information addressed by hydrologic models of storm runoff and stability assessment, and it helps in the interpretation of what the models mean in different stream systems.

This chapter describes:

- Previous work that guided the creation of a geomorphic assessment program
- The scales at which the geomorphic assessment was conducted (the identification of geomorphic reaches and hydrographic segments)
- Methods used to conduct the geomorphic assessment
- Results and discussion of the field surveys
- Subwatershed comparison

3.2 Previous Work

Several studies and reference items guided the geomorphic assessment and provided a strong framework for setting up and interpreting the results of the field survey:

- Santa Clara Valley Water District's Yellow Book[2]
- Information from the SCVWD maintenance crew on stream conditions, such as the location and extent of bank erosion
- Design drawings for Ross Creek channel modification from 1955 and 1957 generated by the Santa Clara County Flood Control and Water Conservation District
- Historical USGS topographic maps:
    a. San Jose quadrangle – 1899, 1943, 1953, 1961
    b. Mt. Hamilton quadrangle – 1897, 1943, 1947

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[1] In this usage, hydrology is taken to be the flow conditions affecting channel stability, with emphasis on the magnitude and duration of storm-flow events, but also including consideration of sediment and large-wood transport from upstream, channel-disturbing episodic events, and the droughts which may have affected riparian vegetation sufficiently to be geomorphically significant.

[2] The Santa Clara Valley Water District Maps of Flood Control Facilities and Limits of 1% Flooding (also known as the "Yellow Book") was prepared in June of 1993 by the Flood Control Planning Division and the Engineering Services Drafting Section. It contains maps of all of the creeks within the Santa Clara Valley Basin at a scale of 1"=1000'.

c. Palo Alto quadrangle – 1899, 1961

d. Los Gatos quadrangle – 1919, 1940

A consistent set of historical aerial photographs was sought, but not found, during this study.

3.3 Divisions Used in the Assessment

Creeks vary longitudinally—that is, from upstream to downstream, both with respect to channel bed and bank properties and with respect to the magnitude and duration of flows which act on them. Both the intrinsic properties of channel bed and banks plus the flows acting on them need to be considered when developing a method for predicting how future flows will affect the creek. Therefore, two different channel divisions were utilized for this study – geomorphic reaches and hydrographic segments, which explore the intrinsic properties of channel bed and banks and flows acting on them respectively.

3.3.1 Geomorphic Reaches

The project team distinguished subwatershed-specific *geomorphic reaches* that characterize each creek based on the longitudinal variation of channel bed and bank conditions. Within a given geomorphic reach, broadly-similar influences (whether vegetation, geology, topography, level of upstream development, etc. or some combination therein) affect channel form and processes in a similar manner. Sometimes, it is useful to recognize sub-reaches within a given reach.

The geomorphic reaches developed for the studied watersheds should not be interpreted as a regional classification system, but rather they were developed for description purposes aimed specifically for the development of the hydromodification management requirements. The identification of geomorphic reaches allows some generalization of channel characteristics and easier identification of patterns within specific sub-watersheds.

3.3.2 Hydrographic Segments

Hydrographic segments differ from geomorphic reaches in that they define a creek section based on significant flow additions, whether it is from tributaries, diversion structures, and/or stormwater outfalls, rather than physical characteristics of the channel. Cross-sections located within a common hydrographic segment are characterized as having similar discharges. The segmentation reflects important differences in channel-forming flows.

Hydrographic segments are more fully explored and utilized in Chapters 4 and 5.

3.4 Work Conducted

The geomorphic field work consisted of taking a set of qualitative and quantitative measurements at multiple cross-sections along Thompson, Ross, and San Tomas Creeks. Data collected at these cross-sections were primarily used as input parameters for the stability assessment calculations (discussed in Chapter 5), but were also used to interpret and evaluate feasibility of the results of the stability assessment and provide a field-based understanding of the studied subwatersheds.

Cross-sections were selected in each subwatershed to represent both typical "problem sites" and "stable" sections of creek that are not experiencing excessive and/or accelerated erosion. The selected problem sites typically reflected larger-scale erosion patterns versus site-specific erosion.

One of the goals of this study is to evaluate and test the HMP assessment method. Selecting cross-sections at sites that are currently eroding and stable allows us to test if the stability assessment model can differentiate between the two conditions.

3.4.1 Field reconnaissance

The project team conducted field reconnaissance surveys along the studied creeks during 2002 and 2003. The site visits consisted of walking most of the length of the creeks and noting problem areas, zones of deposition, sediment transportation and erosion, in-stream and bankside structures, and other qualitative observations on the geomorphic characteristics of the streams. Also as part of the field reconnaissance, the project team measured depth from "hanging" structures (such as pipes and outfalls) to the existing channel bed to obtain a rough estimate of how much incision has occurred at a specific site. The hanging structures were dated where possible to give a maximum period over which incision may have occurred.

3.4.2 Cross-sectional channel geometry

Channel geometry is used in the stability assessment model to calculate water depth, velocity and other hydraulic parameters. The project team measured channel geometry at each problem or non-problem ('stable') site by establishing a cross section that best represents the site. Each cross-section was monumented using a piece of rebar to allow future re-surveying and comparison.

The project team then measured the following:

- Cross-section distance (or 'station') across the channel (using a tape)
- Relative elevations of points along the cross-sections (measured using a automatic level and stadia rod) —see Figure T3-4
- All major breaks in slope, with particular focus on top of bank, toe of slope, edge of channel and in-channel bars

3.4.3 Longitudinal profile

A longitudinal survey of Ross Creek was performed by William Lettis & Associates, Inc.[3], on August 4, 5, 7; September 16, 17; and October 16 of 2003.

A TopCon digital laser theodolite total station was used to collect the Northing (N), Easting (E), and Elevation (Z) data for the longitudinal survey. The instrument was oriented to north before each survey using an azimuth estimated by Brunton compass. Survey data was first collected in an arbitrary Cartesian coordinate system, and later tied in to SCVWD benchmark coordinates.

Surveyed data were translated into State Plane coordinate system (Zone III, NAD 83). This was done by calculating the linear difference between the benchmark x, y, and z collected from our survey and the x, y, and z provided by the District. In a spreadsheet, the calculated x, y, and z difference (shift) was then applied to other points collected during the survey. Following this operation, a rotation was applied to the surveyed data to correct for small variations in the estimated north direction used to orient the Top Con instrument. The points were then imported into GIS for plotting on a geo-referenced ortho-photograph. The longitudinal profile was then computed and plotted in Excel. During the survey, we used the descriptor "GCS" to indicate portions of the Ross Creek channel that had a grade control structure installed. We did not note the specific design or estimate an age since installation. These points were included in the long profile calculation because they control the local bed elevation and slope, and were also added as an additional series on the long profile chart for illustrative purposes.

A longitudinal profile for San Tomas Creek was not conducted as part of the fieldwork for the HMP and a longitudinal profile for Thompson Creek was constructed using engineer surveys from 1968.

3.4.4 Local channel slopes

Channel slope for each cross-section was measured using an automatic level, stadia rod, and tape. The field crews measured an elevation upstream and downstream from the cross-section over a distance that varied depending on the homogeneity of the site, steepness of the slope, and visibility with the level. Field-measured channel slopes were then compared to regional slopes calculated from existing topographic maps and longitudinal profiles as a way to check the reasonableness of field results.

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[3] The longitudinal survey methods described in Section 3.4.3 for Ross Creek were written by William Lettis & Associates and inserted into this report.

3.4.5 Channel bank characterization

The stability of channel banks (the ability of channel banks to resist erosion) depends on several factors, including bank material composition and stratigraphy, bank angle, current and former bank vegetation, and subsurface conditions. These parameters were either directly or indirectly (through survey work) described at each cross-section.

At each cross-section, the project team characterized the channel banks by describing bank material; sketching bank stratigraphy; noting the type and density of bank vegetation (including root structure); and describing the types, frequency, and possible causes of bank failures observed at or near the surveyed cross-section.

3.4.6 Channel bed characterization

Channel bed material was characterized primarily to help evaluate channel bed and bank response during different flow events. Quantifying the size distribution of bed material allows the use of equations to calculate entrainment and bedload transport rates, and as a measure of grain roughness in the channel (Lane, 1948; Kondolf, 1997). Two methods were employed to characterize bed material at Thompson, Ross, and San Tomas Creeks—bed core samples and pebble counts. Both methods are quantitative methods used to characterize the distribution of particle sizes for analysis of sediment entrainment and transport.

Bed core samples were taken using a 6-inch (15-cm.) sediment canister (3-lb. coffee can) to collect the bed material sample at a representative location near the cross-section. The sample characterizes the distribution of sediment size in transport at high flows (those able to remove any armoring layer). Samples were analyzed at Cooper Testing Lab in Mountain View, California for particle size distribution (ASTM D-422, w/ #200 wash).

A pebble count, a random sampling of sediment particle-size on the river bed, was conducted at cross-sections that contained sediment too large to be sampled by the bed-core method. Grains were selected using the zig-zag method (modified from Bevenger and King, 1995), measured (along the intermediate axis), and tallied. These data were then used to develop a particle-size distribution. Results are summarized by a calculated median value, which is the size, in millimeters, for which 50 percent of the sample is finer (D-50).

It is important to note that there is a substantial difference in the way that sample statistics are calculated from the two different sampling methods. Bed-core calculations are based on weight, whereas pebble count calculations are based on the proportion of the bed area occupied. Additionally, the bed-core method integrates the sediment stored beneath the bed (also known as 'bed material' or 'bulk bed material'), whereas pebble counts sample only the material at the surface (formally known as 'bed-surface material'), which may be the result of formation of a surface layer or 'armor'. A substantial body of emerging research suggests that the bed-surface population may be different from that just below the surface. Median size descriptors for the two populations (sampled as described above) are used in a number of analytical methods or sediment-transport formulae. While we recognize that these differences exist, we do not quantitatively analyze differences between the surface and subsurface bed material in the particle-size results; this may not be necessary for the purposes of evaluating overall channel stability.

3.4.7 Erosion rankings

Erosion rankings of 'high', 'medium', or 'low' were assigned to each of the cross-sections along Thompson, Ross and San Tomas Creeks by Balance geomorphologists. These rankings were qualitative in nature, which means that no absolute numerical standard was applied. Instead, all factors affecting channel bank and bed stability (channel slope, undercut banks, bank slope, type and density of bank vegetation, in-channel obstructions, knickpoints, etc.) were combined with the observed extent, estimated age, and magnitude of existing erosion to designate an appropriate erosion ranking.

Channel cross sections that received "high-erosion" rankings typically showed signs of active reach-wide undercutting, bank retreat, and/or incision. "Low-erosion" rankings were assigned if the amount of channel erosion (bed and bank) noted at the cross-section was minimal and deemed typical of a natural setting. Therefore, we did not classify all erosion as "medium" or "high," but instead recognized that erosion is a natural process in stream systems. Our goal was to distinguish severe erosion that had occurred at an accelerated rate over an entire reach or sub-reach that would indicate a systematic channel response to a watershed disturbance. Balance field staff also did not select or classify cross-sections manifesting site-specific problems, such as erosion that occurred around an individual stormwater outfall, sackcrete bank protection, or grade control structure.

3.4.8 Photographic record

A set of photographs was taken at each cross-section from at least three different vantage points; across the cross-section, upstream from the cross-section, and downstream from the cross-section. Additional photographs recorded features of interest, such as unique or diagnostic bank stratigraphy, failing grade control structures, and areas where depths of incision from bridge abutments or pipes were measured. This photographic record illustrates problems sites and can also serve as a frame of reference for evaluating the creeks in the future.

3.5 Results

This section describes key results of the geomorphic field work along Thompson, Ross and San Tomas Creeks. The creeks are presented in a consistent format for ease of comparison.[4] The Thompson Creek measurements were completed in early 2003 to aid in the development of the stability assessment model. The Ross Creek and San Tomas Creek work was completed in the late-summer of 2003 to test the model results in different hydrogeomorphic regions of the Basin. For this reason, the Thompson Creek work is the most comprehensive, and work in the Ross and San Tomas subwatersheds was simplified to incorporate a wider geographic range of test cross-sections.

3.5.1 Thompson Creek

3.5.1.1 Geomorphic reaches

The project team distinguished ten *geomorphic reaches* based on the longitudinal variation of channel bed and bank conditions along Thompson Creek. The reaches are shown on Figure T3-1 and include seven along the main stem of Thompson Creek and three that describe the major tributaries of Thompson Creek. Within a given reach, broadly-similar influences (whether vegetation, geology, topography, level of upstream development, etc. or some combination therein) affect channel form and processes.

The primary geomorphic features of the seven reaches along the main stem of Thompson Creek are as follows:

- Geomorphic Reach A: Exposed claypan (and/or hardpan) with localized patches of deposition
- Geomorphic Reach B: Incised, with severe bank erosion
- Geomorphic Reach C: Incised, with a sinuous planform, and bank erosion at bends
- Geomorphic Reach D: Channel form presently controlled by dense vine vegetation
- Geomorphic Reach E: Actively incising with bank erosion
- Geomorphic Reach F: Upper end of urbanization, less disturbed with minimal bank erosion
- Geomorphic Reach G: Canyon-like channel with landslides

The three reaches along the tributaries of Thompson Creek are distinguished as follows:

- Geomorphic Reach H: Actively incising with bank erosion and large knickpoints
- Geomorphic Reach I: Stable rock- or clay-cut tributary channels
- Geomorphic Reach J: Engineered channels or storm drains

Table T3-1 summarizes the geomorphic reaches along Thompson Creek, the key characteristics defining each, and how the reaches overlap with the hydrographic segments discussed below.

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[4] Because of differences in the work scope tailored for each creek, not all information is available for all reaches of all creeks.

3.5.1.2 Hydrographic segments

The project team identified six hydrographic segments based on significant flow increases in the downstream direction due to confluences with major tributaries (Figure T3-2). Each hydrographic segment is assumed to have similar stream discharges.

The six hydrographic segments are as follows (listed from downstream to upstream):

- Segment TC1: Thompson Creek between Norwood Creek and Quimby Creek
- Segment TC2: Thompson Creek between Quimby Creek and Fowler Creek
- Segment TC3: Thompson Creek between Fowler Creek and Evergreen Creek
- Segment TC4: Thompson Creek between Evergreen Creek and the confluence of Yerba Buena Creek
- Segment TC5: Thompson Creek upstream of Yerba Buena Creek
- Segment YB1: Yerba Buena Creek

The results of the geomorphic fieldwork are presented by segment. As previously noted, Table T3-1 shows how the geomorphic reaches overlap with the hydrographic segments.

3.5.1.3 Field reconnaissance

The following observations are among those made during the reconnaissance visits:

- Upper Thompson Creek near the headwaters has very erodible banks, a canyon-like form, and is prone to landslides. The channel banks there are composed primarily of shaley material.
- During the November 20, 2002 site visit, most of Thompson Creek was dry. However, portions of the creek were wetted due to urban runoff, particularly near subdivisions upstream from the Yerba Buena confluence. The entire creek showed signs of having sustained flow during the November 8th storm, even though most of it was dry twelve days later; this illustrates the intermittent nature of the stream.
- Dense blackberry vines cover the banks and overhang into the channel of Thompson Creek near the Yerba Buena confluence. This appears to have a significant effect on channel stability, as well as on flow.
- Several old grade control structures, outfall structures, and bank protection projects were observed along the length of Thompson Creek. Many of these structures have failed, and “hanging” structures were deemed a useful tool to measure approximate depths of incision.

3.5.1.4 Channel geometry and channel slope

Channel geometry and slope measurements are summarized in Table T3-2 and described here by segment and cross-section in the upgradient direction. The Yerba Buena Creek tributary is described last. The channel geometry of TC1 is generally variable due to continued changes induced by the historical and current channel modifications (described in 3.6.1). Moving upgradient from TC1-1 to TC1-5, channel width increases from 16.8 ft to 25.8 ft and depth increases from 4.3 ft to 9.5 ft. Cross-section TC1-6 widens to 52.0 ft with a depth of 11.5 ft and drastically narrows to 11.1 ft and only 3.4 ft deep at TC1-7. Local channel slopes range over an order of magnitude (0.002 to 0.017 ft/ft), varying throughout the reach.

Segment TC2 through TC3 is extremely variable in width and depth. The channel attains its greatest width and depth of 59.4 ft and 13.2 ft, respectively, at TC2-10. In contrast, at TC3-7, the width and depth are 13.6 ft and 3.6 ft, respectively. Channel slope is generally steep, averaging 0.010 ft/ft through Segment TC2, decreasing to an average slope of 0.007 ft/ft through Segment TC3.

Segment TC5 shows a rapid transition in channel geometry, because the upgradient extent of incision is located within this segment. TC5-1 is characterized with a channel width of 46.1 ft and a depth of 11.9 ft. Further upgradient the channel width decreases to less than 20 ft, whereas the channel depth ranges between 1.8 and 7.3 ft. TC5 is located in the uppermost reach of the Thompson Creek watershed and averages a slope of 0.012 ft/ft.

The Yerba Buena Creek tributary increases in width from 4.4 ft, at the upper most cross-section, YB1-0, to 27.2 ft at its confluence with Thompson Creek. Channel depth varies along this reach, but ranges from 0.9 ft to 9.4 ft. The slope of the Yerba Buena tributary is generally steeper than the main stem of Thompson Creek, averaging 0.019 ft/ft.

3.5.1.5 Bank material

Channel banks along Thompson and Yerba Buena Creeks are not homogenous; instead, they consist of multiple layers with different sedimentological characteristics that vary longitudinally through the subwatershed.

In general, the project team identified four distinct types of bank material in the Thompson Creek subwatershed:

- Well-consolidated (or cohesive) laterally-continuous stiff clay/silty clay
- Moderately soft silty/sandy loam
- Colluvium (silty loam, not stiff or dense, and often of limited continuity)
- Alluvial deposits (mixed sands, gravels, some silt and clay)

A stiff clay or silty clay layer was generally found in the lower portion of the bank, extending upward from one to six feet. The same type of bank material was found exposed on the channel bed in Segments TC1 and TC3. This material varies in color from dark brown to brownish-orange (near TC5-2) and reflects that there are at least two units with similar sedimentological composition and erosive resistance, likely deposited at different times historically. The cohesive silty clay/stiff clay layer is very resistant to erosion.

The silty/sandy loam material was found in many cross-sections of the Thompson Creek subwatershed, and varied both in compactness and dominance of silt versus sand. In some cross sections of Segment TC1 the material observed as silty/sandy loam might be artificial fill. Throughout the subwatershed, this layer was usually observed in the upper portions of the banks, where it often holds vertical or near vertical angles.

Colluvial deposits, composed of non-compacted loam, were generally very erodible. This unit is the least continuous of the identified units, as it is found only locally where the creek has cut into slope wash deposited at the base of the stream banks.

Alluvium, former channel bed and bar material, was often observed in the channel banks. These layers, composed of moderately to well-sorted sands and gravels with some silt and clay, often represented the weakest portion of the bank. Widespread undercutting often occurred at the contact between these weaker alluvial deposits and more resistant silty clay or dense sandy loam layer.

3.5.1.6 Bed material

Table T3-3 summarizes the results of the Thompson Creek bed characterization study. D-50, the sediment size that 50% of a sample is finer than, ranged from 3.2 to 10.2 millimeters, with the smallest value from the upper portion of Segment TC2 and the largest value from upper Yerba Buena Creek.

D-50 values are quite varied in the upper portion of Segment TC5 (samples from cross-sections TC5-5 through TC5-7), reflecting the diverse characteristics of this section of TC5. The low D-50 value at cross-section TC5-7 is possibly influenced by debris flow material from the upper subwatershed.

The D-50 value at cross-section YB1-7 is finer than that at YB1-1. However, the bedload sample collected near YB1-7 during the December 14, 2002 storm (YBSF)[5] is more similar to the bed material at YB1-1. This may be due to recent deposition of sand at the lower cross-section since the December 2002 storms, or an historic shift in the material being deposited at the cross-section.

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[5] See methods section for discussion of bedload sampling.

The small (micrometer) D-50 numbers in Table T3-3 reflect the high clay and silt content of the cohesive bed material that was sampled at select cross-sections in Segment TC1, TC3, and Yerba Buena. At these cross-sections, the claypan was exposed and a grab sample was collected for hydrometer analysis. Our intention was to evaluate whether the cohesive bed material exposed in Segment TC1 was similar to TC3, and how both of these compared to the cohesive bed material found along Yerba Buena Creek. Results indicate that the cohesive bed material collected at TC1-3 and TC3-6 are very similar in clay, silt, and sand content, both being primarily composed of silt (approximately 45 percent) with a significant clay component (greater than 30 percent). The Yerba Buena sample (taken at YB1-6) contains more sand and less clay than the samples from Segments TC1 and TC3, resulting in a slightly higher D-50.

3.5.1.7 Vegetation

The vegetation within the Thompson Creek subwatershed consists mainly of grasses, trees (most frequently bays, oaks, and some eucalyptus and maples), blackberries, and poison oak. Some sections of the creek also have a thin layer of moss that is partially stabilizing bank slopes.

Trees and blackberries probably play the most important role in slope stabilization. In Segment TC4 and the lowest portion of Segment TC5 the blackberry vines are so thick that the plants—not the actual banks—define the channel dimensions. In the upper portion of Segment TC1 and throughout Segment TC2, severe bank erosion often stops where there are large trees with a deep root structure that stabilizes the banks. In general, vegetation density below the top of the banks decreases downstream. The lower portion of Segment TC5 and the upper portion of Segment TC4 have the densest vegetation, with some portions having in-channel vegetation. The lower portion of Segment TC1 has very little vegetation, with only grasses and small trees on the top of the banks.

Riparian corridor width also decreases downstream. This affects stream bank stability, because one row of trees provides less stability than a gallery or a more developed riparian corridor. The vegetated banktop riparian corridor width is narrowest in Segment TC2, where roads, fences, and parking lots are present at the top of the stream banks.

3.5.1.8 Erosion Rankings

Erosion rankings of high, medium, or low were assigned to each of the cross-sections along Thompson Creek. A rank of “stable” was assigned to two upper sections on Thompson Creek and one on Yerba Buena Creek.

Cross-sections that received an erosion ranking of “high”’ were typically severely incised or actively incising with actively eroding banks, either through processes of undercutting, shearing and/or slumping. Channel banks were generally vertical and bare, with vegetation stabilizing only the very tops of the banks. A few cross-sections designated as “high” did not display tall, vertical banks (such as TC5-5) and with brief visual inspection appear in relatively good condition; however, recently exposed roots on the channel bed and banks indicate that incision is just starting to occur in these cross-sections on a reach wide scale. Without change in the existing magnitude and frequencies of flow, it is likely that these creek sections will experience further incision and bank erosion comparable to cross-sections located in older incised portions of the creek that also received “high” designations.

In total, nine of the thirty-seven cross-sections were assigned a ”high” erosion ranking, with two additional cross-sections bordering between “medium” and “high.” Cross-sections with “high” erosion rankings are located throughout the Thompson Creek subwatershed, but particularly concentrated in the lower portion of Segment TC5, just downstream from some of the most recently-constructed housing.

Cross-sections were the erosion ranking was designated “low” typically exhibited banks that were either not eroded or eroded but now in a stable configuration. Also, ‘low’ cross-sections generally had gentler slopes and denser vegetation, and sometimes were located behind grade control structures where the bed had aggraded. Cross-sections ranked as “medium” had characteristics in between those described for “high” and ‘“low.” Thirteen out of thirty-seven cross-sections were designated as “medium” and thirteen designated as either “low” or “low” to “medium.”

The two uppermost cross sections on Thompson Creek (TC5-6 and TC5-7) were assigned a “stable” condition as well as YB-0 on Yerba Buena Creek. Stable conditions are defined in Chapter 5.

3.5.1.9 Segment characteristics

3.1.1.1 Segment TC1 - Thompson Creek between Norwood Creek and Quimby Creek

Segment TC1 of Thompson Creek (between Quimby and Norwood Creeks) is the most downstream segment of Thompson Creek included in the field survey. This segment has engineered flood control levees on both sides of the channel, with significant bank and instream structures. Based on aerial photographs, it appears that the lower portion of Segment TC1, below cross-section S1-6, was straightened sometime prior to 1968. The bed in Segment TC1 has incised in the past, leaving raw, vertical banks in many places. The amount of incision in this segment is *at least* three feet, based on measurements of a former subsurface pipe that is now exposed in the bank; it is unknown when major incision began. The incision has been effectively halted by a claypan layer that now forms the channel bed in many portions of the segment. The clay layer resists erosion; it appears to incise slowly by the process of shear and abrasion rather than by knickpoint propagation, as is seen in Yerba Buena Creek and the upper reaches of Thompson Creek.

Currently, grade control structures are modifying the pattern of bed erosion and deposition in Segment TCI, as follows:

- A weir installed at the Quimby Road crossing has generated localized aggradation that extends about 150 feet upstream behind the weir.
- Upstream from the Quimby Road weir, a large sackrete grade control structure has been installed in the channel (see Figure T3-5).
- A series of four boulder cross-vane grade control structures were recently installed in the middle of Segment TC1 as part of a channel stabilization/restoration project. Sediment has already started to accumulate behind these structures.
- In the middle to upper portion of the segment, an old partially destroyed weir is still acting as a small grade control structure and creating a zone of localized aggradation.

Although Segment TC1 has localized zones of aggradation, much of the segment is still experiencing erosion. Most of the active erosion is targeted at the banks, with undercut and slumped banks common features throughout the reach.

Gravel deposits or hard clays make up the bed material throughout Segment TC1. The gravel often appears as a thin veneer in the lower to mid portions of the segment, where the ‘claypan’ is either directly exposed or is covered with only three to four inches of gravel. The depth of mobile material in this segment rarely exceeds 12 inches, and when it does, it is usually behind grade control structures such as the Quimby Road weir. Most of the gravel is fairly transient, moving downstream with each significant flow event. Little to no pool-riffle morphology is found, although the bed is slightly more complex at the upper end of the segment.

The banks are composed primarily of hard clay near the channel bed and a thick silty loam layer (possibly artificial fill) extending to the top of bank. At some sites, sand and silty gravel deposits are interspersed between the hard clay and fill material. The weakest layers are these alluvial deposits composed of sand and gravel. Undercutting occurs at the interfaces between the weak sandy gravel and the more resistant clay and fill layers (see Figure T3-6).

Grasses and small woody vegetation make up most of the bank vegetation along the lower portion of Segment TC1 near Quimby Road. Larger trees become more common near the confluence with Quimby Creek. The deep roots of these larger trees aid in stabilizing some of the eroded banks in the upstream portions of Segment TC1.

3.1.1.2 Segment TC2 - Thompson Creek between Quimby Creek and Fowler Creek

Segment TC2 (just upstream of segment TC1, between Quimby and Fowler Creeks) can be divided into two sub-segments based on geomorphic characteristics, with the break at the Aborn Road crossing. The lower portion of TC2 is very similar to the upper portion of TC1 (above TC1-5), with steep banks about ten feet high and many areas with vertical, actively eroding faces. Undercutting and slumping of banks is common in this sub-segment; mature trees are growing below the top of the banks, partially stabilizing the banks in some areas.

The portion of Segment TC2 above Aborn Road has a slightly higher sinuosity than that downstream. In general, vegetation is denser than in the lower portion of Segment TC2 and, partially because of that, the channel banks are more stable (see Figure T3-7). Several areas with severely eroding banks are present within this section of Segment TC2, mostly at outside bends in the creek, though they are not as extensive or as common as those downstream. Development (roads, parking lots, fences) in this area is often very close to the top of the stream bank, which makes bank stability of particular concern.

Throughout Segment TC2, the lower portion of the channel banks are typically composed of clayey sand and gravel to moderately well-sorted sand and gravel. Above this is a layer of dense, poorly sorted material about five feet thick, probably fill material underlying the surrounding developed areas. Because the fill has been compacted, it is slightly more resistant to erosion than the lower layers; as a result, there is undercutting (up to a foot) below the fill layer.

The bed in the upper portion of Segment TC2 is more complex than segment TC1 and has distinct pools (deeper areas) and bar forms, likely due to its meandering planform. Depth of mobile sediment is generally greater than one foot, but is highly variable because of the more complex bed morphology.

A grade control structure is present at the downstream end of the Aborn Road crossing; the structure arrested any downcutting that may have been occurring and probably caused local aggradation upstream from the structure. There is also a concrete slab (probably an old bridge crossing) upstream from cross-section TC2-6 that provides a grade control for the upper portion of this segment.

3.1.1.3 Segment TC3 - Thompson Creek between Fowler Creek and Evergreen Creek

Segment TC3 is very similar morphologically to the upper portion of Segment TC2 and as a segment is fairly homogenous in terms of bed and bank characteristics, as well as channel geometry. Like the upper portion of Segment TC2, the channel planform is quite sinuous, exhibiting in places very tight meander bends (see Figure T3-8). Severe erosion is occurring at the outside of meander bends where the creek is close to the road, including in some sections where the creek is constrained by a retaining wall.

The bed consists of a mixture of sand, gravel, and some cobbles. The median grain size is mostly fine gravel. The bank material throughout the segment consists of a silty pebbly loam or silty clay loam with some embedded gravels.

Segment TC3 is characterized by very dense vegetation, with more shrubs and vines than trees. There is a significant amount of debris in the channel, resulting in shifts in flow path direction, scour holes, and bank erosion. The types of debris found in the channel include telephone poles, riprap, old bridge structures, remnants of previous retaining walls, and trees.

3.1.1.4 Segment TC4 - Thompson Creek between Evergreen Creek and Yerba Buena Creek

Segment TC4 was not included in the field survey because no problem sites identified by SCVWD were located there and dense vegetation made access to the segment very difficult. However, based on the project team’s familiarity with the upstream and downstream segments, and some observations during early reconnaissance walks, it appears that Segment TC4 shares similar qualities with Segment TC3, at least in the lower portion. Near the Yerba Buena confluence, the banks are covered with blackberry vines, as occurs in the downstream-most sections of Segment TC5.

3.1.1.5 Segment TC5 - Thompson Creek upstream of Yerba Buena Creek

Segment TC5 (located upstream of the Yerba Buena Creek confluence) includes the headwaters of Thompson Creek, however the most upstream cross-section surveyed was located at Early Morning Drive (TC5-7), a little over two miles upstream of the confluence with Yerba Buena Creek. Upstream from this cross-section the watershed remains relatively undeveloped, with only scattered homes and roads.

From cross-section TC5-7 to at least cross-section TC5-6 the creek has been relatively unaffected by development except where it is crossed by roads. The banks are well vegetated (mainly with grasses and trees), there has been little or no incision, and the banks are stable throughout most of the section. Some slumping of the banks has occurred, primarily where the creek is confined against the valley wall by San Felipe Road.

The portion of Segment TC5 just upstream of the bridge crossing near The Villages Parkway subdivision, at cross-section TC5-5, is characterized by thick vegetation, and a straight channel with a relatively steep local slope. Bed degradation is beginning at this cross-section, as there are many exposed roots and root mats at the base of the channel banks and on the stream bed (see Figure T3-9).

Downstream of cross-section TC5-5 the stream generally shows an increase in incision and bank degradation. Between cross-sections TC5-2 and 5-3 is an old bridge crossing dated 1947. The creek has down-cut about 3.2 feet below what looks to be the original base of the abutment (see Table T3-4).

Several portions of lower Segment TC5 are now underlain by a tan, compact clayey silt, similar to that seen in Segments TC1 and TC2. This has certainly slowed incision, and provides some stability for the lower portions of the banks (see Figure T3-10).

The section of creek just upstream of Yerba Buena is characterized by dense vegetation, mostly blackberries, poison oak, and shrubby trees. In one section, the blackberries were so dense that they seemed to be the primary feature channeling high flows, rather than the banks. Because of this dense vegetation, no cross-sections were surveyed in this portion of the segment.

3.1.1.6 Segment YB1 - Yerba Buena Creek

Segment YB1 is Yerba Buena Creek, a tributary to Thompson Creek. The two streams join at the upper end of Segment TC4. Yerba Buena Creek is actively incising throughout most of its length, except for the uppermost sections of the creek, above the golf course and the upstream-most urban-area outfalls, and possibly near the confluence with Thompson Creek where it is locally aggrading.

Segment YB1 is one of the most complex and diverse segments in the Thompson Creek subwatershed. This segment has several large knickpoints that divide it into several sub-segments with different geomorphic characteristics, especially with respect to channel geometry. The characteristics of this segment are described from upstream to downstream.

The portion of Yerba Buena Creek upstream of Villa Vista Road is in a fairly stable configuration, with only minor bank erosion evident at localized sites. This section of Yerba Buena Creek is comparable to the upper portions of Thompson Creek, described for Segment TC5. The bed consists of angular to subangular coarse material (mainly coarse gravel with some cobbles), and these materials seem to be readily entrainable during high flows. The upper portion of Yerba Buena Creek is not as sinuous as the downstream section. Most of the banks are composed of the pebbly silty loam complex, with the exception of one location where fine-grained sedimentary rock is exposed. The bed slope is gentle and the banks appear stable, although the bed is incising progressively downstream from the first outfall.

The first large knickpoint (with an approximate drop of seven feet) in a series of knickpoints along Yerba Buena Creek occurs just downstream from this upper section, approximately 50 feet downstream from the new SCVWD sediment sampling and gage site near the upstream end of Villa Vista Road (YBVV). This knickpoint has temporarily stopped migrating upstream due to a sackrete sill built across the channel at the location of an outfall structure. The knickpoint may be associated with additional stormwater runoff from this outfall structure, which is located just at the head of the knickpoint.[6]

Downstream of Villa Vista Road, another outfall structure with sackrete is being threatened by significant incision. Downstream from this incision, the channel recovers back to the shape similar to the more stable upstream reach, although wider. At some locations, it is also deeper. In general, the banks average two to three feet.

Continuing downstream, the channel becomes tightly confined, with deep, vertical banks. There are two knickpoints in the section between Silver Estates Road and Creek Estates Road. The first knickpoint is located between the two

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[6] During each of the significant rainfall events during water years 2003 and 2004, we repeatedly found discharges of more than three cubic feet per second (cfs) emanating from this outfall during rainfall events, while the channel upstream remained dry. Even when it was not raining up to 0.25 cfs of was flowing from the outfall structure.

roads. It has a drop of approximately five to six feet. Upstream from this knickpoint, the channel is about six feet deep and six feet wide. Downstream from the knickpoint, the channel is approximately 12 to 15 feet deep. Further downstream, immediately after the pedestrian bridge west of Creek Estates Road, there is another knickpoint with a drop of approximately eight feet. At this portion of Yerba Buena Creek, near cross-section YB1-5, the channel is deeply incised (approximately 20 to 25 feet) and very narrow (see Figure T3-11), and hard clays are exposed on the channel bed. This narrow and deep section is relatively short (about 700 feet) and ends downstream of Sunny Creek Road.

Downstream from Sunny Creek Road, the channel reverts to a geometry with five to six feet of depth and approximately eight feet of width, and meanders tightly. Further downstream and immediately upstream of the confluence, the channel is wider and the banks are shallower.

The bed material varies between fine gravel and coarse gravel depending on the sand and cobble content. There is significant local supply throughout the segment, with active transport of sediment from the upper watershed to downstream portions of the creek.

The large knickpoints in Yerba Buena Creek will likely continue to propagate upstream and therefore Yerba Buena Creek will continue to supply high amounts of sediment to Thompson Creek.

3.1.1.7 5.5.1.10 Discussion

This section of the report discusses what the field observations may mean, primarily with respect to:

- Speculating on how these findings might be extenable to other subbasins in the Thompson Creek catchment and other watersheds in the Santa Clara Basin.
- Developing useful local criteria for managing hydromodification
- Working toward design criteria for evaluating likely future channel configurations

3.1.1.8 Range of values

The project team compared the values of the data collected for Thompson Creek to data recorded from other streams. Some parameters, such as slope and width-to-depth ratio, appear broadly typical of other stream systems in the region that are affected by hydromodification.

Width-to-depth ratios recorded in Thompson Creek are typically in the range of three to five, compared to ratios of four to six reported for channels throughout clayey soils in southern Contra Costa and central Alameda Counties. The difference is not large and may be due to recent incision along Thompson Creek and the fact that the banks there have not yet retreated to a semi-stable position. The field measurements and reconnaissance indicate that most channel banks in the Thompson Creek subwatershed can hold steep, nearly vertical angles. This is especially true in Yerba Buena Creek. It is possible that some sections of the creek may not retreat into a semi-stable position in the near future and will instead preferentially incise instead of widen (such as the canyon-like banks of Yerba Buena Creek where the banks are over 20 feet deep – see Figure T3-11). This is most likely to occur where the banks are composed of very cohesive clay and silt material.

Data may not be directly applicable to streams with non-cohesive banks, where width-to-depth ratios of 8 to 20 are more typical. Coyote Creek and reaches of Uvas and Llagas Creeks are examples of such the latter type of channel.

3.1.1.9 Stable versus unstable cross-sections

The Thompson Creek subwatershed is fairly diverse in terms of channel form, geology, hydrology, vegetation, and the classes of erosion problems manifested, which is reflected in the classification of ten distinct geomorphic reaches along Thompson Creek and its major tributaries. Even with such complexity, much of Thompson Creek (except the upper portions of Thompson and Yerba Buena Creeks) is considered unstable or excessively eroding, where the hydrology has changed and the existing channel form is no longer stable.

The terms “stable” and “unstable” are often used as a shorthand when conducting geomorphic assessments, with stable indicating that all forces (erosive and resisting) are in balance, or equilibrium. Generally, the designation of a cross-section, site, reach or watershed as stable or unstable is qualitative and based on visual inspection (see Chapter 5 for a discussion of stability).[7]

The field crew identified three stable cross-sections during the field campaign: YB1-0, TC5-6 and TC5-7. These cross-sections can be cautiously extended to state that Geomorphic Reaches F, G and I are 'stable' reaches. Geomorphic Reaches F and G are located above most existing development (Figure 3-1). Downstream changes in channel form as a result of hydromodification have not yet influenced these upstream reaches. Geomorphic Reach I is stable because the channel bed in this reach is cut into bedrock or hard, dense clay. It is also possible that Reach D is stable due to the dense vegetation cover that is protecting the channels banks throughout the reach. However, no cross-sections are located in this reach and visual inspections of channel bed stability were not conducted.

The remaining thirty-four cross-sections, including all cross-sections in Segments TC1, TC2 and TC3 were identified as unstable. The lower portions of Thompson Creek have experienced incision of *at least* three feet and as a result channel banks are steep, bare, and failing in many places. Although some individual cross-sections appear in a relatively stable configuration, there is high potential for instability to develop. Active incision is still occurring along the lower to mid portion of Segment TC5 and in Yerba Buena Creek, causing the cross-sections located in these reaches to be defined as 'unstable.'

3.1.1.10 Role of vegetation

Vegetation appears to be a significant stabilizing element for many of the channel banks along Thompson and Yerba Buena Creeks. In the Thompson Creek subwatershed, the principal means by which vegetation stabilizes the channels appears to be:

- Banktop vegetation. Such vegetation holds the looser soils in place, and the roots strengthen the banks or (when exposed to high flows) reduce the velocities impinging on the bank. The banktop vegetation often includes large coast live oaks or bays, but sometimes includes deciduous trees or brush.
- Roots as grade control. Root systems or major roots of larger trees frequently serve to inhibit incision, even sometimes serving as a local base level. With a very few exceptions, roots inhibit incision only in channels up to a certain size. Stabilizing roots are found on upper Thompson Creek beginning perhaps one mile upstream of the Yerba Buena confluence, and also on Yerba Buena Creek as far downstream as the lower end of Evergreen College.
- Smaller woody vegetation. Vines and brush are the predominant stability-lending element in some of the channels, at least up to certain thresholds. Thompson Creek upstream of the mouth of Yerba Buena Creek provides a good example of stabilizing brush covering the banks.
- Small woody debris jams. While small woody debris jams temporarily stabilize the channel, their effects are considered transient and are not as long-lasting as those imparted by large-conifer logjams.

The role of vegetation in stabilizing the banks and bed is considered in the stability assessment through the selection of the hydraulic roughness coefficient. Higher values of roughness slow velocity and reduce shear stress on the boundary.

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[7] References throughout this report to sites or reaches as 'stable' or 'unstable' are solely for the fluvial geomorphic planning-level analysis underlying this report. They are expressly not intended to substitute for the detailed site geotechnical or slope-geomorphic investigations required prior to site evaluation or design of facilities and structures.

3.5.2 Ross Creek

3.5.2.1 Geomorphic reaches

The project team distinguished six *geomorphic reaches* based on the longitudinal variation of bed and bank conditions along Ross Creek; five along the main stem of Ross Creek, with the tributary of East Ross Creek identified as a distinct reach. The reaches are shown on Figure R3-1 and further described in Table R3-1.

The primary geomorphic features of the six reaches along Ross Creek are as follows:

Geomorphic Reach A:	Earthen trapezoid channel with meandering low flow channel and in-channel "bench"
Geomorphic Reach B:	Earthen trapezoid channel with steep channel banks and severe bank erosion (widening)
Geomorphic Reach C:	Earthen trapezoid channel punctuated with grade control structures
Geomorphic Reach D:	Non-engineered, 'natural' channel with numerous bank protection projects, low erosion
Geomorphic Reach E:	Non-engineered, 'natural' channel with active bank widening
Geomorphic Reach F:	East Ross Creek; a headwaters tributary

3.5.2.2 Hydrographic segments

Hydrographic segments were not defined for Ross Creek due to the high number of stormwater outfalls that discharge to the channel over small intervals of channel length. Clear increments in flow volume were not as distinguishable in the channel profile as with Thompson Creek, which had several tributaries and large outfalls that marked clear transitions between different hydrographic segments.

3.5.2.3 Field Reconnaissance

The following observations are among those made during reconnaissance visits to Ross Creek in July 2003:

- Approximately two feet of consistent incision is observable in the lower, channelized[8] reaches of Ross Creek. This incision occurred sometime after channelization during the mid- to late-1950's and has in many instances been halted due to local grade control or, where active erosion is minimal, the establishment of a new quasi-equilibrium form.
- The former channel bed of the engineered channel is now a distinct linear "bench" along much of the channelized portion of Ross Creek.
- The lower, engineered reaches of Ross Creek do not support a riparian corridor, as the channel is often confined between two gravel maintenance roads at the top of the banks. Some vegetation, mostly grasses, forbs and some shrubs, cover the channel banks, but trees are rare. All bank vegetation along the lower extent of the main stem of Ross Creek (where maintenance roads exist) is regularly mowed to maintain flood capacity.
- At the time of our reconnaissance in July 2003, Ross Creek was flowing throughout much of its length. The stream was dry below Cherry Avenue, but flowing throughout the upper reaches. East Ross Creek was dry in

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[8] The terms 'channelized' and 'channelization' are used in this report to mean 'engineered' (see discussion in Knighton, 1998). In the specific case of Ross Creek, the 'channelized' reaches are those that were altered in the late 1950's for flood control purposes. The 'channelized' portion of Ross Creek extends from the confluence with the Guadalupe River upstream to Camino Del Cerro. Similarly, 'unchannelized' is used to describe the unmodified, 'natural' reaches of creek upstream from Camino Del Cerro and including most of East Ross Creek.

the upper portion of its watershed (at ERC-3), but flowing through much of the lower portion of the watershed (at and below ERC-2).

3.5.2.4 Channel geometry and channel slope

Several channel geometry parameters were calculated from the cross-section survey data for Ross Creek, including top-of-bank (TOB) widths, average depths from TOB, width-to-depth ratios, and in relevant cross-sections, widths and depths of natural or artificial in-channel "benches." Top-of-bank was used as a reference for width and depth measurements because bankfull dimensions, which are geomorphically more meaningful in self-formed alluvial channels than TOB dimensions, were not relevant in the highly modified Ross Creek system. The top of bank for each cross-section was identified in the field where possible, and interpreted from plotted cross-sections when field data did not explicitly designate a TOB. The top of bank can roughly be defined as the first significant break in slope the field crew encountered when conducting the cross-section surveys. In the lower reaches, this generally corresponded to the edge of the gravel maintenance roads. Channel geometry and local channel slope measurements are summarized in Table R3-2.

Top-of-bank widths at cross-sections along the main stem of Ross Creek range from approximately 24 to 41 feet. The channelized cross-sections have the widest channels from TOB, averaging around 38 feet. This reflects the engineered channel form that was initially constructed in the mid- to late-1950's and perhaps subsequent channel maintenance and modifications[9]. East Ross Creek has smaller TOB widths than the main stem of Ross Creek, with the upstream-most cross-section, ERC-3, having a TOB width of 4.3 feet.

Channel depths from TOB range from 6.0 to 10.4 feet in the main stem of Ross Creek, and from 0.7 to 6.5 feet in East Ross Creek. The channelized reaches of Ross Creek are the deepest, with depths of around nine feet. Width-to-depth ratio (top-of-bank width divided by mean depth) is a channel geometry parameter that can be used to compare different reaches within the same stream system to evaluate incision and widening. Typically, a high width-to-depth ratio represents a wide and shallow channel and a low width-to-depth ratio represents a narrow and deep channel. What constitutes a "high" value compared to a "low" value is dependent on the characteristics of the watershed and will vary by soil type and region. Width-to-depth ratios for the channelized cross-sections in Ross Creek all calculate to about 4.0, which is not surprising due to the relative uniformity of engineered, trapezoidal channels. Width-to-depth ratios for the unchannelized cross-sections RC-7 and RC-8 are 4.3 and 3.8 respectively and width-to-depth ratios for lower East Ross Creek are 3.0 for cross-section ERC-1 and 4.1 for ERC-2. Only cross-section ERC-3 has a width-to-depth ratio that deviates from 4.0 by more than 1.0, at 6.4. Width-to-depth ratios are fairly uniform for most of Ross Creek, especially when compared to the range of width-to-depth ratios for nearby watersheds, such as Thompson and San Tomas Creeks.

A prominent, linear "bench" was noted at several cross-sections in the channelized reaches of Ross Creek, specifically at cross-sections RC-1, RC-2, RC-4, RC-5, and RC-6. The "bench" is nearly unbroken and appears to be a remnant of the original engineered channel. The depth from the top of the "bench" to the channel bed ranges from approximately 2 to 3 feet in cross-sections RC-1, RC-2, RC-4, and RC-6. This corresponds to the amount of incision Balance staff measured at various culverts and outfall structures located in these reaches suggesting that the

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[9] Although available, engineering drawings from the 1950's showing the original designs planned for the channelized portions of Ross Creek offer minimal assistance for evaluating channel change over time. It appears that the design drawings either substantially differed from what was actually constructed or that subsequent large-scale maintenance and/or repair activities altered the channel from the original design so that comparisons to current conditions are not relevant. For instance, the design drawings suggest that TOB widths were to range from 18 to 22 feet, which is over ten feet less than what exists today. No field observations made by Balance staff suggest that channel banks have retreated over ten feet to their current position. Also, current channel depths from TOB are up to two feet shallower than what is shown in the design drawings, yet we found evidence of channel bed incision (not aggradation) over much of the channelized length of Ross Creek.

observed "bench" is actually the former channel bed of the original engineered channel. At the one cross-section, RC-5, where the depth from the "bench" to the channel bed exceeds 4 feet, design drawings from the 1950's show a mid-bank bench incorporated into the design.

Local channel slopes range from 0.0039 to 0.0067 (ft/ft) in the channelized reaches of Ross Creek. Slopes in the unchannelized reaches of Ross Creek are 0.0145 and 0.0078 for cross-sections RC-7 and RC-8 respectively. Cross-sections in the East Ross Creek tributary have local channel slopes that increase upgradient from 0.0098 to 0.0191. Since all of Ross Creek was flowing during our surveys, water surface elevations were used to measure local slope unlike Thompson Creek where all local slopes were calculated from bed topography. Chapter 5 describes how these local slopes were applied in the stability assessment model.

3.5.2.5 Bank material

Channel banks along Ross Creek vary longitudinally through the subwatershed, but the types of bank material present in Ross and East Ross Creeks can be generalized into several types:

- Silty sand and gravel with some cobbles (alluvial deposits)
- Poorly consolidated fine sand, silt, and clay (overbank deposits)
- Poorly sorted silt, sand, clay, and gravel (construction fill)
- Poorly sorted clay, silt, sand, and gravel (debris flow deposits)

Throughout the engineered section of Ross Creek, the upper portion of the banks is predominately composed of engineering fill material. This fill typically overlies layers of alluvial deposits, with varying amounts of gravel and cobbles. The non-engineered portions of Ross Creek have banks composed of similar alluvial deposits, without the overlying layer of fill material.

The bank material in the upper portion of East Ross Creek is almost exclusively old debris flow deposits, often a matrix-supported mixture of clay, sand, silt, and gravel, with some angular cobbles. At ERC-1, however, there are several feet of engineering fill material on top of debris flow/alluvial deposits.

3.5.2.6 Bed material

Table R3-3 summarizes the results of the Ross Creek bed characterization study. D-50 values, the sediment diameter, in millimeters, for which 50 percent of the sample is finer, ranged from 1.7 to 23 millimeters. The lowest value was from a sample taken at ERC-3, the cross-section highest up in the watershed, and consisted predominately of sand. The other four samples had median (D-50) sizes similar to one another (between 15 and 20 millimeters), and were composed mainly of gravel-sized particles. Differences in these values may in part be due to differences in sampling methods.

Depth of mobile bed material in Ross and East Ross Creeks (where measurable) was generally less than two feet, ranging from six to eighteen inches. In the lower reaches, mobile material was underlain by moderately well-consolidated fine sand and silt. In the upper reaches the underlying material was a cohesive mixture of clay, sand, and silt.

3.1.1.11 3.5.2.7 Vegetation

The vegetation within the Ross Creek subwatershed is sparse in the lower reaches of the main stem of Ross Creek from the confluence with the Guadalupe River upstream to Camino Del Cerro. These channel reaches have been modified and constructed into a trapezoidal shape. Gravel maintenance roads border both sides of the channel on top of the channel bank. Bank vegetation is maintained through mowing and trimming activities on a regular basis in these lower reaches of Ross Creek. Little to no woody vegetation is present, with grasses and some shrubs most prevalent. Vegetation has become established on in-channel benches and/or bars where erosion is minimal.

A riparian corridor is first evident at the transition from earthen trapezoid channel to the "natural" channel upstream from Camino Del Cerro. Bank vegetation density and riparian corridor width generally increase in the upstream direction toward the headwaters and where residential development decreases in density.

3.1.1.12 3.5.2.8 Erosion rankings

In total, 6 of the 11 cross-sections were assigned a ”medium” or ”high” erosion ranking, with one additional cross-section bordering between “medium” and “high.” Cross-sections with “medium” or “high” erosion rankings are located throughout the Ross Creek watershed, but are especially clustered in Geomorphic Reaches B and C, where the earthen trapezoid channel is eroding and has yet to reach a quasi-equilibrium state as observed in Geomorphic Reach A.

Cross-sections where the erosion ranking was designated “low” typically had banks that were either not eroded or eroded but now in a stable configuration. Two out of 11 cross-sections were designated as “low to medium” erosion and two designated as “low” erosion. The two cross-sections classified as “low to medium” erosion are RC-1 and RC-2, which are the downstream-most cross-sections evaluated. The bed at these cross-sections, and all of Geomorphic Reach A, has experienced incision since channelization in the late 1950’s, but now seems to be in or approaching a quasi-equilibrium state. A low flow meandering channel has developed within the channel and bars have formed that support vegetation in the summer. Active incision is not apparent and bank erosion, although still occurring, is not of the magnitude observed upstream.

Only cross-section ER-1 was deemed “stable” in the Ross Creek subwatershed. Stable conditions are defined in Chapter 5.

3.1.1.13 3.5.2.9 Geomorphic reach characteristics

Geomorphic Reach A

Geomorphic Reach A extends from the confluence of Ross Creek with the Guadalupe River to Meridian Avenue and is characterized as having an earthen, trapezoid channel with a meandering low-flow channel located within the engineered channel. The channel in Geomorphic Reach A was constructed into its current engineered form in the late-1950s prior to large-scale urbanization of the watershed. The current channel path does not follow the historical, ‘natural’[10] path of the channel.

Geomorphic features observed in the reach include pools and riffles that occur at fairly regular intervals. This reach is considered meta-stable (at or approaching a quasi-equilibrium form), with recent bed incision and bank widening evident, but not currently active on a reach-wide scale. It is likely that the 1.5 to 2.0 feet of incision observed throughout the reach occurred as a response to a) channelization in the late 1950’s and/or b) the urbanization of the watershed soon thereafter. A mid-bank linear bench is found in Geomorphic Reach A at a relatively consistent height above the existing channel bed (Figure R3-2). This linear bench is likely the former channel bed at the time of initial channelization. Subsequent incision lowered the bed approximately 2 feet below the linear bench, which is also consistent with measurements of “hanging” structures found within the reach.

As with most of the channelized reaches of Ross Creek, gravel maintenance roads border both sides of Geomorphic Reach A and vegetation is sparse and mainly limited to grasses and other non-woody vegetation.

Bank material in Geomorphic Reach A consists of a bottom layer of sandy silt with some gravels and a top layer of fill material. The bottom layer varies in thickness throughout the reach, and in some instances has distinct bedding, suggestive of a former stream channel bed. The engineered fill layer is composed of loose silt and gravels and is prone to gullying. Median size (D-50) of bed material in Geomorphic Reach A is approximately 15 mm.

Geomorphic Reach B

Upstream from Meridian Avenue to Camden Road is defined as Geomorphic Reach B. Several large stormwater outfalls enter the channel in this reach, which is characterized by actively eroding channel banks (Figure R3-3). Like Geomorphic Reach A, this reach has an earthen, trapezoid channel constructed in the mid- to late-1950’s.

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[10] Although we use the term ‘natural’ when referring to Ross Creek prior to channelization, the channel at that time (1950’s) had already been modified in sections, especially near bridges and due to some farming practices. Therefore, we do not mean to indicate that Ross Creek was completely undisturbed at that time, rather it still retained a meandering planform and had not yet been engineered at a reach-wide scale.

However, unlike Geomorphic Reach A, the engineered channel occasionally follows the former 'natural' channel path (Santa Clara County Flood Control District, 1955). Where the former channel intersects the engineered channel is often an area of instability.

The active channel bed in Geomorphic Reach B is considerably wider than the other channelized reaches along Ross Creek. And the prominent "bench" observed in Geomorphic Reaches A and C is almost completely absent.

Bank stratigraphy consists of a lower layer of sandy silt that is relatively more resistant to erosion than the upper layers. A middle layer, approximately 2 to 3 feet thick, is composed of alluvial material that is mostly sands and gravels. This middle layer is often observed where the former 'natural' channel bed intersects the engineered channel and is the weakest layer, being the most susceptible to erosive flows. The upper-most layer is engineered fill typical of the channelized reaches. The mechanics of bank erosion in Geomorphic Reach B consists of active shearing and undercutting of the middle alluvial layer and resultant slumping of the upper fill layer.

Channel bank vegetation is sparse and regularly maintained by mowing and trimming throughout the reach. Gravel maintenance roads border both sides of the channel. Median size (D-50) of bed material in Geomorphic Reach B is approximately 15 mm.

Geomorphic Reach C

Geomorphic Reach C is located between Camden Road and Camino del Cerro, and is also an earthen, trapezoid channel constructed in the late 1950's. In this reach, the engineered channel intersects the former 'natural' channel at several locations because the engineered channel was constructed in straight segments roughly centered on the meandering 'natural' channel path (Santa Clara County Flood Control and Water Conservation District, 1957).

Geomorphic Reach C is characterized by several grade control structures that have experienced failure (Figure R3-4). Reach-wide bank widening is prevalent although less severe than the bank erosion observed in Geomorphic Reach B. Approximately 1.5 to 2.0 feet of recent or historical incision is noted, but the incision does not appear active and is controlled by the grade control structures.

The linear mid-bank "bench" present in Geomorphic Reach A is again found in Geomorphic Reach C. Bank material and stratigraphy vary throughout the reach based on whether the area surveyed intersects the former channel, was constructed through the floodplain of the former channel, etc. Regardless of the bottom-most layers, the top bank layer is consistently fill material as with the other channelized reaches. Median size (D-50) of bed material in Geomorphic Reach C is approximately 20 mm, slightly larger than the downstream reaches of Ross Creek. Channel banks have minimal grassy vegetation and provide little in the way of bank stabilization.

Geomorphic Reach D

Geomorphic Reach D is a relatively small reach extending upstream from Camino del Cerro to upstream of Linda Court. Camino del Cerro marks the transition from an earthen, trapezoid channel to a less modified channel form. The channel in Geomorphic Reach D is confined between residential neighborhoods on both sides, however, still has a narrow riparian corridor with several woody species. The amount of erosion is low in this reach, with some areas experiencing minor undercutting stabilized by large trees (Figure R3-5). Several sections of the reach are hardened by sackcrete structures and a large grade control structure is located at the downstream end of the reach.

Bed material is large throughout the reach, with a median grain size (D-50) of approximately 30 mm, measured using the conventional pebble-count technique (see Section 3.4.6).

Geomorphic Reach E

Upstream from Linda Court and downstream from the confluence with Ross Creek is Geomorphic Reach E. This channel reach has banks that are actively being eroded and are widening, leaving small roots exposed along the banks (Figure R3-6). Bed material in Geomorphic Reach E is smaller than that measured downstream, with a median grain size (D-50) of approximately 14 mm.

Geomorphic Reach F

Geomorphic Reach F is East Ross Creek, one of the major tributaries to Ross Creek. East Ross Creek joins Ross Creek upstream from Blossom Hill Road, and is underground for a portion of its length near the confluence. East

Ross Creek has been modified for flood control purposes in the downstream-most sections (cross-section ER-1). However, the upstream, headwater portions of East Ross Creek remain in an unmodified form (Figure R3-7). The cross sections located on East Ross Creek progress from "high" erosion to "low" erosion in the upstream direction.

3.1.1.14 3.5.2.10 Discussion

3.1.1.15 Range of values

The project team compared the values of the data collected for Ross Creek to data recorded from other streams, including Thompson and San Tomas Creeks. Some parameters, such as slope and width-to-depth ratio, appear broadly typical of other stream systems in the region that are affected by hydromodification.

Width-to-depth ratios recorded in Ross Creek are typically in the range of three to four, compared to ratios of two to five reported for Thompson Creek and two to ten for San Tomas Creek. The range of width-to-depth ratio values is quite narrow for Ross Creek, with a standard deviation of only 0.40 for the mean value of 3.9, when excluding ER-3. This is due to the highly modified nature of most of Ross Creek.

Channelization and channel maintenance activities

The activity of constructing channels into a straightened planform with trapezoidal channel geometry affects the stability of these channels. Much of Ross Creek was initially channelized in the late-1950s for flood control purposes. One of the reasons Ross Creek was chosen as a test watershed was to test the HMP assessment method in these highly modified channels. Discussed below are some of the more pertinent ideas regarding channelization and Ross Creek that lend a framework for our results.

- Typical geomorphic responses associated with channelization, especially where channel straightening has occurred, are changes in channel morphology via re-meandering processes, incision, downstream aggradation, and bank failure. It is therefore extremely difficult to discern a specific cause of incision and general channel instability in the lower reaches of Ross Creek, rather it is likely a combination of factors that include major channel modification in the 1950s and increasing urbanization and runoff in the watershed since channelization.
- Distinct zones of channel bank instability occur along Ross Creek at intersections with the former 'natural' channel. One potential effect of straightening a meandering channel is creating a zone of weakness where the new channel intersects the former channel. The project team observed several of these channel intersections in the field in reaches that were experiencing large-scale bank failure.
- Channelization indirectly affects channel bank stability in similar ways as urbanization by the removal of bank and bank-top vegetation. This is compounded at Ross Creek by the construction of maintenance roads on one or both sides of the channel and regular vegetation maintenance activities, such as mowing.

3.5.3 San Tomas Creek (Upper)

3.5.3.1 Geomorphic reaches

Geomorphic reaches were not defined for San Tomas Creek because the number of cross-sections surveyed for the project was too small to fully characterize the stream longitudinally, given the diversity of observed conditions. The San Tomas Creek watershed is fairly diverse in terms of channel form, erosion pattern, and vegetation characteristics compared to Ross Creek, where geomorphic reaches were adequately defined and described by only eleven cross-sections. In general, the surveyed portion of San Tomas Creek had less engineered flood control structures than are present in Ross Creek. Also, not all of San Tomas Creek was surveyed due to access limitations.

3.5.3.2 Hydrographic segments

Hydrographic segments were also not defined for San Tomas Creek for similar reasons as Ross Creek.

3.5.3.3 Field Reconnaissance

Not all sections of the San Tomas Creek watershed were surveyed due to limited access in areas of private property. The following observations are among those made during reconnaissance visits in August 2003:

- Definition of geomorphic reaches in San Tomas Creek was not conducted; as the creek often changes physical characteristics (channel geometry, bank vegetation, and presence of dry-season flow) with each culvert/road crossing.
- San Tomas Creek flows into a concrete-lined channel downstream from McCoy Avenue and remains hardened to the Bay. Upstream from McCoy Avenue, San Tomas Creek is either an earthen trapezoid channel or an unmodified, 'natural' channel.
- Most of San Tomas Creek was dry during the August 2003 visits. Patchy areas of creek that sustained flow during the dry season were found in the lower sections of the watershed, where urban nuisance flows from outfalls were the likely source.

3.5.3.4 Channel geometry and channel slope

Several channel geometry parameters were calculated from the cross-section survey data for San Tomas Creek, including top-of-bank (TOB) widths, average depths from TOB, and width-to-depth ratios. Top-of-bank was used as a reference for width and depth measurements because bankfull dimensions, which are geomorphically more meaningful than TOB dimensions in self-formed alluvial channels, were not always present in modified and/or eroded sections of San Tomas Creek. The top of bank for each cross-section was identified in the field where possible, and interpreted from plotted cross-sections when field data did not explicitly designate a TOB. The top of bank can roughly be defined as the uppermost significant break toward a steeper slope that the field crew encountered when conducting the cross-section surveys. Channel geometry and local channel slope measurements are summarized in Table S3-1.

Top-of-bank widths at cross-sections along San Tomas Creek range from approximately 12 to 38 feet. Cross-sections ST-1 and ST-2, which appear to have been widened and deepened for flood control purposes, have the widest channels, with TOB widths greater than 30 feet. Channel depths from TOB range from 2.0 to 11.4 feet at the surveyed cross-sections for San Tomas Creek. The modified cross-sections ST-1 and ST-2 also had the deepest channels. However, cross-sections ST-3 and ST-4, which have also been modified into straight, trapezoidal channels had shallow channel depths from TOB, of about 2 to 3 feet. This is because we designated the TOB as the bench that has formed closer to the bottom of the channel instead of the top of the levee. Top-of-bank dimensions were not calculated for cross-section ST-12 because TOB was not distinguishable. Cross-section ST-12 is the uppermost site surveyed and represents a steep, headwater channel within a canyon.

Width-to-depth ratio (top of channel width divided by mean depth) is a channel geometry parameter that can be used to compare different reaches within the same stream system to evaluate incision and channel widening. Typically, a high width-to-depth ratio represents a wide and shallow channel and a low width-to-depth ratio represents a narrow and deep channel. What constitutes a "high" value compared to a "low" value is dependent on the characteristics of the studied watershed and will vary by region. Width-to-depth ratios for San Tomas Creek vary from 3.1 up to 10.7.

Local channel slopes range from 0.0008 to 0.085 (ft/ft), with channel slopes generally increasing in the up-stream direction. Most measurements of local channel slope were conducted using bed surface elevations following the channel thalweg. Some water surface slopes were measured where there was flow.

3.5.3.5 Bank material

The banks in San Tomas Creek are primarily composed of three different types of material:

- Gravel and cobbles in a sandy, silty, matrix (alluvial deposits)
- Poorly consolidated sand and silt (colluvium or non-gravel bar deposits)
- Moderately-well consolidated sand, silt, and clay with gravel (sometimes engineered fill)

All but three cross-sections had banks composed primarily of alluvial deposits, with varying amounts of gravel and cobbles (ST-1, ST-2, ST-5, ST-7, ST-8, ST-9, ST-10, ST-11, and ST-12). Cross-sections ST-1 and ST-2 had several feet of engineered fill on top of the alluvial deposits. The three remaining cross-sections (ST-3, ST-4, and ST-6) had banks composed of poorly consolidated sand and silt, with little gravel and no cobbles.

3.5.3.6 Bed material

Table S3-2 includes results of the San Tomas Creek bed characterization study. D-50 values ranged from 13 to 32 millimeters, significantly higher than Ross Creek values. D-50 sizes increase upstream. There is some difficulty in directly comparing D-50 values, as the upper cross-sections were sampled using the pebble count method rather than by bed core. The bed material at cross-section ST-12 was not measured because the D-50 was assumed to be too large (cobbles and boulders) for most flows to transport.

3.5.3.7 Vegetation

San Tomas Creek has diverse vegetation characteristics, ranging from only grasses and shrubs to a full, dense riparian corridor. The type and density of bank vegetation often was dependent on location within the watershed, with the upper watershed cross-sections supporting more woody and dense vegetation on channel banks and floodplain areas than the lower cross-sections, which generally supported grasses and shrubs with some scattered trees. Cross-sections ST-5, ST-6, ST-7, ST-8, ST-9, ST-10 and ST-11 supported vines in conjunction with trees and grasses.

3.5.3.8 Erosion rankings

In total, 7 of the 12 cross-sections were assigned a “medium” or “high” erosion ranking, with one additional cross-section bordering between “medium” and “high.” Cross-sections with “medium” or “high” erosion rankings are located throughout the San Tomas Creek watershed, with the exception of the headwaters and locations where the creek has been modified for flood control purposes.

Cross-sections where the erosion ranking was designated “low” typically had banks that were not eroded, eroded but now in a stable configuration, or eroding but at a typical rate and scale of natural channels. Four out of 12 cross-sections were designated as having “low” erosion. Two of these cross-sections (ST-3 and ST-4) are located in a section of San Tomas Creek that has been modified into an earthen trapezoid. These cross-sections show signs of former incision, but current, active erosion is low. Also, cross-sections ST-11 and ST-12, which are located in the headwaters of San Tomas Creek, were classified as “low-erosion” sites.

3.1.1.16 3.5.3.9 Cross-section characteristics

Twelve cross-sections were studied in detail in the San Tomas subwatershed. The cross-sections represent portions of the San Tomas subwatershed, rather than the entire subwatershed. Some sections of San Tomas Creek were not studied due to inaccessibility. Although no continuous geomorphic reaches were established for San Tomas Creek, the cross-sections can be grouped in some instances based on similar geomorphic characteristics and/or geomorphic history.

Cross-sections ST-1 and ST-2

Cross-sections ST-1 and ST-2 are located just upstream from McCoy Avenue and where San Tomas Creek first becomes hardened for a substantial length. This section of creek has been channelized in the past and is currently unstable. At both cross-sections the channel banks are actively eroding, and incision is noted in the thalweg at cross-section ST-1.

Near cross-section ST-2, the left channel bank around a rock gabion structure in the channel has eroded laterally approximately four to five feet. The gabion structure was likely initially installed for toe protection; another suggestion that bank widening has been and continues to be a problem in this section of San Tomas Creek.

Cross-sections ST-3 and ST-4

It is unclear if both cross-sections ST-3 and ST-4 have been channelized in the past based on field evidence alone, although ST-3 most likely has undergone substantial modification and possible straightening. This section of creek has several grade control structures that maintain a fairly gentle slope. A maintenance road is located on the top of the channel bank.

Some minor bank undercutting was evident at cross-section ST-3, but it was deemed minimal. Both cross-sections, ST-3 and ST-4, were ranked as “low-erosion” sites (Figure S3-2). Cross-section ST-4 might be experiencing aggradation due to the location of a grade control structure approximately 500 feet downstream.

Cross-section ST-5

Cross-section ST-5 is located just upstream from Pollard Road. This section of creek appears highly unstable, with active bank erosion and possible incision. There are tree roots exposed along the channel banks. The channel banks are steep although vegetated at the top of the bank and are without maintenance roads. Cross-section ST-5 was ranked as a "high-erosion" site.

Cross-section ST-6

The field crew located cross-section ST-6 at a section of San Tomas that was experiencing active bank erosion. Cross-section ST-6 was ranked as a "medium-erosion" site. This cross-section has steep banks that are eroding at two different levels, a) the bottom layer on the right bank composed of silty and sandy clay with organics is being actively undercut and b) the upper layer on both banks composed of non-consolidated silty and sandy clay has several active failures (bank slumping).

Cross-section ST-7

Cross-section ST-7 is located just downstream from Saratoga Road (Route 9) in a densely vegetated section of San Tomas Creek. Recent incision has occurred in this section of San Tomas Creek of about six to eight inches, which is seen best upstream from the cross-section. Active bank erosion is also occurring at cross-section ST-7 in the form of undercutting and shearing. A retaining structure failed downstream from the cross-section due to a combination of incision and bank widening. Cross-section ST-7 was ranked as a "high-erosion" site.

Cross-sections ST-8, ST-9, and ST-10

Cross-sections ST-8, ST-9, and ST-10 are all located in close proximity to each other upstream from Saratoga Road and near Bantier Way. They are ranked as either "medium-erosion" or "high-erosion" sites. Cross-section ST-8 is located downstream from a large stormwater outfall, whereas cross-sections ST-9 and ST-10 are located upstream from the outfall where the watershed is relatively un-urbanized, limited to large-acreage residential uses

Several faults and geologic contacts are located in this section of San Tomas Creek and represent a significant transition between the tectonically active, headwaters and the alluvial plain (Santa Clara County Geologic Map, 1974). Based on field evidence, it is likely that cross-sections ST-9 and ST-10 have been influenced by a series of historic debris flows and that some of the incision and bank instability noted at these sites are due to these naturally recurrent episodic events.

Cross-sections ST-11 and ST-12

The upstream-most cross-sections of ST-11 and ST-12 are similar in that both are relatively stable and not actively eroding more than what is typical for headwater streams. The bed material carried in the upper watershed of San Tomas is quite large, cobbles at ST-11 and boulders at ST-12 (Figure S3-3). Even less urbanization has occurred upstream from these cross-sections compared to ST-9 and ST-10.

3.1.1.17 3.5.3.10 Discussion

3.1.1.18 Range of values

The project team compared the values of the data collected for San Tomas Creek to data recorded from other streams, including Thompson and Ross Creeks. Some parameters, such as slope and width-to-depth ratio, appear broadly typical of other stream systems in the region that are affected by hydromodification.

Width-to-depth ratios recorded in San Tomas Creek have a fairly broad range from two to ten, compared to three to four at Ross Creek and two to five at Thompson Creek. This reflects the diverse channel morphologies the project team observed in the field.

3.1.1.19 Dry-season flows

Due to our fieldwork being conducted in the summer and fall months, the field crew was able to observe and evaluate dry season flows along San Tomas Creek. During the survey, which was conducted in September 2003, four of the twelve cross-sections were flowing; ST-2, ST-4, ST-5, and ST-7. The field crew could see where the water table was intercepting the channel bank at cross-section ST-2, but signs of water further upstream (ST-4, ST-5 and ST-7) likely indicate dry season nuisance flows entering the system from stormwater outfalls rather than ground water sources because no seeps were observed and the segments of ponded or flowing water were discontinuous.

3.6 Subwatershed comparison

Field geomorphic surveys are an essential component of developing, testing, and ultimately implementing a set of methods and effective control measures that address hydromodification.

By comparing the geomorphic characteristics of three creeks investigated for the HMP study (Ross, San Tomas and Thompson Creeks), one can better understand what influences channel stability in different physical settings. One can also compare parameters thought to be critical in defining stability (or the ability of channel to resist erosion), such as bed-material size, bank-material composition, vegetation, and others to see if patterns are detected in the different regions of the Basin.

- The single physical parameter that best reflects the stability of a cross-section in these streams is the width-to-depth ratio (top of bank width divided by the average depth from top of bank). Stable channels, or "low-erosion" sites, tended to have larger width-to-depth ratios than unstable channels, ranging from three to ten with an average of approximately 5.5. Unstable channels, or "high-erosion" sites, however, exhibited a much narrower range of width-to-depth ratios of between one and five, with an average of 3.2. Only two unstable cross-sections had width-to-depth values greater than 3.9. Channel width values in isolation were not substantially different between stable and unstable channels.[11]
- In general, similar modes of bank failure were observed in the three test watersheds even though they are located in different geologic/geomorphic regions of the basin. The primary mode of failure being shear erosion at the toe of the bank and bed, which results in incision and over-steepened bank. An array of secondary factors, such as vegetation or lack thereof, can play important roles in bank failure in conjunction with erosion resulting from shear stress. It is meaningful to note that some of the secondary modes of bank failure were more prominent than others in specific watersheds due to differing environmental settings.
    - The key secondary modes of bank failure in the Thompson Creek watershed are a lack of bank and top of bank vegetation in highly urbanized and/or space-constrained reaches and rapid drawdown of flows, which is a product of the flashiness of the hydrograph.
    - Secondary modes of bank failure in the Ross Creek watershed are a result of channel modification in the lower reaches of the creek. These secondary modes of failure are a) a lack of bank and top of bank vegetation (especially woody species) due to the construction of maintenance roads that run parallel to the channel and b) contacts between the former channel and the engineered channel that create zones of weakness in channel banks.
    - San Tomas Creek also experiences bank failure due to a lack of bank vegetation, but is unique amongst the three watersheds because its headwaters are located in the Santa Cruz mountains; an especially tectonically active part of the Basin. The upper portions of San Tomas Creek are periodically subject to debris flows and landslides, both of which affect channel bank stability.

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[11] Hupp and Simon (1991) present a model of channel evolution that describes how channels respond to disturbances, such as urbanization. In their model, incision is the initial mode of channel response followed by channel widening. It is possible that although channel widths do not differ much among the three subwatersheds at present, future widening could occur in channels that are currently experiencing incision.

4 Hydrology

This chapter describes the project team's hydrologic modeling of the Thompson and Ross and San Tomas Creek watersheds. Modeling was conducted for the hydromodification assessment and planning process.

4.1 Modeling Approach

The project team modeled creek flows under pre-urban, existing, and future land use conditions. The watershed models convert rainfall input sequences to estimated stream flow rates at various selected points throughout the project watersheds. The model rainfall input consists of simulated "design storms" and continuous rainfall records. Design storms were developed for various rainfall magnitudes, intended to simulate major flood-causing events, such as the 2-, 10- or 100- year rainstorms. We refer to this type of modeling as "event-based" because only a single rainstorm event (ranging from perhaps 3 hours to 24 hours) is simulated. Alternatively, we may input actual measured rainfall from a nearby gage over a long period of time. This is referred to as "continuous simulation."

Within event-based and continuous simulations, the model incorporates information about the watershed characteristics (topography, soils, vegetation, land use, urbanization, etc.) to estimate how much rainfall is held in the watershed ("losses", including infiltration to the soil, trapping on vegetation or shallow depressions, etc.), and how much precipitation results in surface runoff, eventually reaching stream channels.

The project team chose to model the Thompson and Ross and Upper San Tomas Creek watersheds using the U.S. Army Corps of Engineers' Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) rainfall-runoff model. The U.S. Army Corps of Engineers developed HEC-HMS to supersede the HEC-1 Flood Hydrograph Package. Unlike HEC-1, HEC-HMS allows continuous hydrograph simulation over long periods of time in addition to event-based analysis.

Event-based modeling is useful because it provides a simple method for comparing hydrograph results under different land use conditions for statistically relevant design storms. In addition, event-based modeling is a convenient and commonly accepted approach for evaluating flood risk and design alternatives. Continuous modeling, however, allows for continuous accounting of soil moisture and infiltration and other losses for an extended time period. Therefore, continuous modeling is preferable to event-based modeling when trying to identify the hydromodification effects of development on small, frequent flows and to evaluate their impacts on stream stability.

4.2 HEC-HMS Model

The following sections describe the methods and data sources used to generate input for the HEC-HMS models. The modeling approach generally followed methods and procedures for HEC-1 modeling outlined in Santa Clara Valley Water District's *Hydrology Procedure*s (SCVWD, 1998) as noted below. A previous Thompson Creek hydrology study conducted by Nolte Associates (2000) and a Ross Creek study described in SCVWD's *Hydrology Procedures* also provide background information and estimated flow peaks for model comparison.

4.2.1 Drainage Area Delineation

Project watersheds were subdivided into smaller subwatersheds or catchments to provide a detailed assessment. Using GIS data, the project team delineated catchments associated with storm drain outfalls, storm drain flow direction, and topographic data. Catchments were further delineated to reflect land-use patterns. To the extent possible, individual drainage areas were delineated to separate developed (urban) and undeveloped (rural) areas, as many model parameters are derived from a drainage area's weighted average characteristics and are specific to degree of urbanization. Catchments were consolidated for the pre-urbanization land use scenarios, for which fewer urban areas were present. Figures 4-1 through 4-3 show drainage area delineation of the study watersheds. Tables 4-1 through 4-2s provide catchment size.

4.2.2 Drainage Area Characteristics

The project team identified land cover characteristics and soil types for the study watersheds based on the project's GIS database. The project team overlaid the drainage area delineations on those data to derive soil and land cover characteristics used in modeling each drainage area (Figures 4-4 through 4-6).

Existing hydrologic conditions were modeled using detailed soils and land use GIS data from SCVWD. The land use data were then modified to model hydrologic conditions for future and past (pre-urban) conditions, since GIS data were not available for these scenarios. For future conditions, the percentage of impervious land for each subwatershed under current conditions was increased based on future build-out percent impervious information from the City of San Jose General Plan 2020 (Mattern, 2003). All other land uses for each subwatershed were then decreased in proportion to the increase in impervious area.

The project team reviewed historic aerial photographs and USGS topographic maps to characterize pre-urban land use conditions. These sources provided a representation of the pre-urban distribution of agricultural and woodland/grassland areas for each subwatershed, which was then converted into model input parameters.

4.2.3 Excess Rainfall

HEC-HMS uses soil infiltration rate estimates and other losses described below to calculate excess precipitation that contributes to stormwater runoff. The event-based HEC-HMS model uses the Soil Conservation Service (SCS) method to estimate losses, and the continuous simulation uses the Soil Moisture Accounting (SMA) method (unique to HEC-HMS).

4.1.1.1 SCS Method (Event-based Model, used in Thompson Creek study only)

The SCS method uses a watershed runoff curve number (CN) to represent runoff potential for various soil types and land coverages. To determine CNs, the project team first assigned a soil infiltration potential to each identified soil type by using the NRCS Soil Hydrologic Group designation (A, B, C, or D with soil type A having the highest infiltration potential). Using guidance from *Hydrology Procedures* (SCVWD, 1998) and assuming an average antecedent moisture condition (AMC II), the team then assigned a CN value for each land coverage and soil group combination. Low CNs reflect a high infiltration potential. In regions where the land cover was identified as structures or paved surfaces, the CN value was set to 98, regardless of soil type. The project team then generated a CN for each drainage area using an area-weighted average of CN values present. The project team also used the SCS method to estimate initial abstraction losses as a function of CN (SCVWD, 1998). These parameters are summarized in Table 4-3.

4.1.1.2 Soil Moisture Accounting Method (Continuous Model, used for Thompson Creek, Ross Creek and Upper San Tomas Creek)

The SMA method provides a more complex method for evaluating rainfall runoff processes in a watershed. In this approach, actual measured rainfall over an extended time period is used as input. Losses are computed on a continuous basis, and include evapotranspiration, surface depression storage, and infiltration. The continuous model is designed to model the dynamic effect of soil infiltration and other losses on storm runoff over the course of a long-term rainfall record. Parameters to compute these losses include climatic data, land use conditions, vegetation cover, and soils data. The simplified conceptual schematic of Figure 4-10 illustrates the SMA model:

For each computational time step in the model, HEC-HMS calculates storage in each of the loss categories shown in the schematic, which allows for a continuous accounting of losses and runoff over a long time series. For infiltration, the model initially assumes that water enters the soil at the maximum infiltration rate and percolates out of the soil at the maximum percolation rate. Once the soil layer becomes saturated, the infiltration rate is reduced to the percolation rate. SMA parameter estimation is described in section 4.3.

4.2.4 Hydrograph Generation

Initially, the model determines how much incident rainfall is held in the watershed (losses), and how much will appear as runoff. That which appears as runoff is referred to as “excess precipitation.” The model then determines the time distribution of this watershed-wide excess precipitation, as it flows across the land surface or in shallow “interflow,” eventually reaching culverts or small drainage channels, and finally the main stream channel at the various flow computation points of interest. The resulting time distribution of runoff at a given location is referred to as “hydrograph.”

HEC-HMS offers a variety of methods for transforming excess precipitation from any given storm into a runoff hydrograph for each model drainage area. SCVWD’s *Hydrology Procedures* (1998) recommends and provides guidance for using Clark's synthetic unit hydrograph method in HEC-1. Clark's method requires two inputs: time of concentration (T_c) and a storage coefficient (R). We used the District methods to estimate these two drainage area parameters (Tables 4-4 through 4-13*).*

The procedure described in *Hydrology Procedures* (SCVWD, 1998) requires further sub-division of urbanized drainage areas into pervious and impervious areas, and those areas that drain to storm drains. Runoff passing through storm drains is then routed through storage/discharge relationships based on the "Modified Puls" study conducted by the District for Santa Clara Valley storm drains (SCVWD, 1998). Under the SCVWD procedure, hydrographs from pervious and impervious urban areas within a drainage area are routed through the storm drain system, and then combined with the hydrograph for the portion of the drainage area (if any) that does not enter the storm drain system. This routing and combination routine is internal to each drainage area, in contrast to reach routing between drainage areas. As the modeling progressed from Thompson Creek to Ross Creek, it was determined that the urban storage component was unnecessary. Therefore storage components within the HEC-HMS model were only developed for Thompson Creek (Table 4-14)

4.2.5 Reach Routing

HEC-HMS provides a variety of reach routing methods to translate the hydrograph from one drainage area downstream to a point where it can be combined with another drainage-area hydrograph. The project team chose to use the Muskingum method, which uses basic channel (or culvert) dimensions and characteristics to estimate hydrograph translation and attenuation over the routing reach. For existing and future conditions, a combination of surveyed cross-sections, available storm drain data, and information from the District was used to characterize channel dimensions and characteristics for reach routing. For the pre-urbanization scenarios, estimations were established for channel characteristics and flow paths using historic aerial photos. Reach routing parameters are summarized in Tables 4-15 through 4-18.

4.2.6 Precipitation

4.1.1.3 Event-based Model

Synthetic rainstorms were developed to simulate various flood events. Rainfall depths for the 2-, 5-, 10-, 25-, 50-, and 100-year storms (24 hour duration) were estimated using the "return period-duration-specific" (TDS) regional equation provided in *Hydrology Procedures* (SCVWD, 1998). The TDS equation provides a rainfall depth for each storm based on a site's mean annual precipitation (MAP) and coefficients developed by SCVWD from long-term rainfall records. The project team estimated rainfall depth for each design storm for each model drainage area based on the distribution of MAP. Figure 4-11 shows MAP in the vicinity of the study watersheds.

The "balanced hyetograph" routine in HEC-HMS generated storm hyetographs for each return period based on the rainfall depths described above. A storm hyetograph describes the time distribution of the rainfall intensity over the duration of the storm. A balanced hyetograph provides a distribution of the rainfall that maintains the same recurrence event for all time intervals within the storm; thus, a "balanced" 100-year, 24-hour hyetograph will include 100-year rainfall rates for the 0.5-hour storm, the 1-hour storm, and the 3-hour storm imbedded within the total rainfall distribution. This method is useful in simulating runoff in a multi-drainage area watershed model with drainage areas of different sizes, as in this study, since it insures that catchment areas of different sizes will all experience the same recurrence interval storm. This occurs because watersheds of different sizes respond differently to different rainfall distributions: a smaller watershed will produce higher flow rates from a short-duration, intense rainstorm, while a larger watershed may experience higher peak flow rates from a longer duration, less intense storm. The use of the balanced hyetograph allows the inclusion of both shorter duration peaks and longer duration characteristics all within the same design storm.

4.1.1.4 Continuous Model

The HEC-HMS continuous simulation was run using National Climatic Data Center (NCDC) continuous, hourly rainfall data from gage station ID 047821, the "City of San Jose" gage for a 50-year period (records for summer of 1948 through summer of 1999 were used within the model). This gage corresponds to SCVWD station 6086, which was moved in 1986 to a nearby location known as Station 6131 (San Jose Airport). The data collection method was also changed at that time, from a 0.01-inch recording increment to a 0.10-inch increment. This change is reflected in the rainfall record, in that the smallest rainfall event recorded after 1986 is 0.10 inch. Using a process similar to that described for the event-based model, the project team scaled the continuous rainfall record for each drainage area based on drainage-area Mean Annual Precipitation (MAP).

Figure 4-11 highlights the location of the City of San Jose precipitation gage. The City of San Jose gage, although located outside the study area, has recorded a significantly longer period of precipitation than have other gages in the area. It is recognized that measured rainfall at the Airport, scaled by MAP, is only an estimate of rainfall distributed across the study watersheds. Actual rainfall rates vary spatially, and intense rainfall rates (resulting from individual convective cells within a rainstorm) often occur over one area, but may miss another area nearby. Thus, while measured rainfall at the Airport gage represents a valuable estimate of rainfall for the project watersheds, variations during any individual storm are likely.

4.1.1.5 Distributed Precipitation

For design storms and for continuous precipitation records, the project team used GIS to divide each study watershed into categories according to MAP ranges. Precipitation input was then adjusted by category according to estimated rainfall depth. MAP categories were assigned to each model catchment, based on average MAP, and the corresponding adjusted precipitation was linked to each catchment.

4.3 Parameter Estimation Process

To simulate the watershed response to a rainfall event, a variety of parameters must be estimated in the hydrologic model. These estimated parameters affect the size and shape of the storm hydrograph predicted by the model compared to what may result from any individual actual storm. Whenever possible, modelers compare model results to recorded concurrent rainfall and flow data to calibrate the model by adjusting various parameters to reproduce the actual flow resulting from measured rainfall. The project team generally calibrated the models by adjusting SMA parameters and unit hydrograph values.

Initial estimations of SMA parameters were developed in accord with the methodology outlined in Table 4-19. Model calibration refined the parameters within acceptable parameter ranges. A preliminary calibration was performed for the Thompson Creek watershed, which will be refined as additional stream flow measurements are obtained. Historic stream gage data was not available to calibrate the Thompson Creek HEC-HMS model to actual flows in the Lower Silver - Thompson Creek system. However, the SCVWD stream gage on Thompson Creek at Quimby Road has been functional since January 2003, and additional flow data for Thompson Creek is currently being collected as part of a separate project. These sources will provide useful calibration data in the future. Until more data becomes available and the Thompson Creek model is fully calibrated, a level of caution should be extended if model results are to be used in a broader context.

In the absence of calibration data, the project team compared model results to other available peak flow estimates in order to verify the “reasonableness” of model results. Peak flow estimates used in this comparison include those from SCVWD 1998 (“flood quantiles” or regional regression equations), Nolte 2000, and FEMA 1986, as described below. In addition, Thompson Creek peak flows were estimated for a December 2002 storm event using high water marks. Rainfall records from that storm were used in the continuous model. Results from the model were then compared to the estimated peak flows, and used to adjust the model parameters. More recently, measured flow data for the period January-May 2003 has become available. Additional collection of data will allow for a more detailed calibration of model parameters.

A continuous record of stream gage data was not available to calibrate the continuous simulation of the HEC-HMS model to actual flows in the Lower Silver - Thompson Creek system. The project team therefore used the results of the event-based model to verify that the continuous model produces reasonable results. To obtain comparable “peak flows” from the continuous model, we initially ran the model to provide 50 years of estimated flow records. The peak flow rate for each year in the record was then identified. Estimates of the 2-, 5-, 10-, 25-, 50- and 100-year return period flow rates were obtained by performing a statistical flood frequency analysis of the ordered flood peaks, using the same method that is used for actual gaging station flow records. This analysis was conducted with the model parameterized for the existing land use condition. Peak flows were then compared to those estimated by the event-based model for the same return periods and land use scenario.

Initial estimates of SMA model parameters, specifically the infiltration parameters, were then adjusted to produce peak flow rates that were in reasonable agreement with the event-based model.

Given the limitation of available calibration data, the Thompson Creek continuous model input parameter refinement process has primarily focused on matching observed and simulated flow volumes. The process, to date, has been a model "verification" as opposed to "calibration." Future calibration of the Thompson Creek model may include flow volume, peak flow rates, and hydrograph shape as calibration criteria.

4.4 Methodology for Hydrologic Analysis

4.4.1 Flow Frequency Analysis

4.1.1.6 Annual Flow Frequency

Recurrence intervals of simulation results are represented by ranked annual peak flows based on USGS Bulletin 17B guidelines for distributions fit to a log-Pearson Type III frequency distribution. Under the 17B guidelines, the distribution was weighted with generalized skew coefficients applicable to the study area. The USGS model PEAKFQ was utilized to calculate the skew and the subsequent recurrence intervals for the data sets.

4.1.1.7 All-Event Flow Frequency

Traditional hydrologic analysis has focused on low frequency/high flow events, as these tend to be of primary interest for flood hazard prediction. Typically, storms between the 10 and 100-year event are simulated. However, one of the key changes that occur as a result of hydromodification is the dramatic increase in the frequency of runoff from smaller storms. In pre-urban conditions, many of these rainstorms would produce no runoff at all, with all of the precipitation trapped on vegetation, in shallow depressions, and infiltrating into the soil. The large areas of impervious surface associated with urbanization, connected directly with storm drain culverts, results in more frequent runoff, and considerably faster travel times than in the pre-urban state. Frequent small storms, with return periods of 2 years or less, are influential events for long-term sediment movement. Recurrence intervals were calculated for all flows events obtained from the continuous simulations using individual event separation, as opposed to annual peak flows only. We refer to this methodology as "all-event flow frequency." Flow frequency relationships calculated using the annual peak methodology described above do not capture the smaller, frequent storm events of interest to the project team.

For this analysis, the peak flow rate from each individual storm was computed, stored and tabulated from the continuous simulation record for the three land use scenarios (pre-urban, existing, and future land use conditions). To extract events from model output, the beginning and end of flow events were marked by the rise and fall of flow above a threshold level. Peak flows from each event were ranked in descending order and assigned a monthly return period, T, as follows:

$$T = (N + 0.2) / (M – 0.4)$$

such that N is the number of months simulated, and M is the event rank (adopted from James *et al.*, 2002). The return periods are the probability that particular events will be observed within an average month. Note that this technique does not account for seasonality of precipitation events, or probability of an event happening during a "wet" vs. "dry" month. In that context, an event assigned a three-month return period might be more appropriately referred to as an event that occurs four times per year on average.

4.4.2 Regional Regression Flow Estimates

The project team compared peak flows generated by the model to peak flows predicted by the regional regression equations provided by SCVWD (1998). The regional equations provide a method for estimating peak flows for a variety of return periods, based on contributing sub-watershed area, MAP and other parameters (SCVWD, 1998). The equations are derived from analysis of long-term historical stream gage records for the region, and are generally assumed to represent undeveloped watershed conditions.

It should be noted that the regional regression equations, the event-based modeling approach, and the continuous model represent three completely independent methods of estimating the larger magnitude flood events.

- The regional regression equations are based on actual gaged flow records for undeveloped watersheds, then "non-dimensionalized," based on annual precipitation and watershed area.
- The event-based model uses District-selected parameters, with a "design" rainstorm. The rainstorm volume is derived from observed frequency curves, but the temporal distribution (hyetograph) is "artificial", based on experience.
- The continuous model approach attempts to simulate a gaging station flow record (using measured rainfall only). The simulated flow record is then statistically analyzed to estimate flood frequency.

The inclusion of all three of these methods provides some measure of the uncertainty inherent in hydrologic analysis.

4.5 Thompson Creek Watershed

4.5.1 Continuous Model Results

This section presents data from the continuous model for pre-urban, existing and future land use conditions. Due to the large amount of data generated by the model for each land use scenario (50 years of flow estimates at half-hour intervals for multiple locations), summary results for junctions J-5 and J-12 are presented in this section to demonstrate representative model results for the upper and lower portions of the Thompson Creek watershed, respectively.

Figures 4-12 and 4-13 show the results of a flood-frequency analysis of continuous model results for the three land use conditions at the two representative locations. Figure 4-13 shows results for the lower portion of the watershed, reflecting aggregated hydromodification effects of development throughout the watershed. These results demonstrate the fact that the watershed is largely built-out in the lower reaches, so that the projected hydromodification between the current and future conditions is much less than what has occurred from the 1960's ("pre-urban" condition) to the present. The upper reaches of the watershed are partially developed at present, although additional development is planned in those locations for the future. Potential impacts due to increased imperviousness in the upper reaches may be significant.

A comparison of 10-year peak flows at J-12 demonstrates an important aspect of hydromodification. As shown in Figure 4-13, the 10-year peak flow for the pre-urban condition (approximately 1500 cfs) now occurs approximately every 2.5 years under existing conditions, according to the continuous model results. This represents a dramatic increase in the frequency of flows of this magnitude, which has implications for stream stability, as discussed in another chapter. The increased flow frequency is less dramatic between current land use conditions and future, but is still potentially significant.

Model results for J-5 (Figure 4-12) show a less dramatic difference between pre-urban and existing conditions, since the upper part of the watershed is not yet built out. However, a similar comparison peak flows show that the 10-year peak flow under pre-urban conditions now occurs approximately every six years under current conditions, according to the model results.

Recurrence intervals calculated using annual peaks from the continuous model are compared with the all-event flow frequency in Figures 4-14 and 4-15. Estimated peak discharges from the two methods compare favorably for return intervals of five to 10 years and above. However, peak discharges calculated using annual peaks do not capture the smaller, frequent storm events of interest for this project.

As seen in Figures 4-16 and 4-17, the percent increase in discharge, for a given return period, is relatively small when comparing existing to future conditions. The change from pre-urban to existing or future conditions is significantly larger, particularly for small, more frequent storm events. For the events with a very low return period (3 months or less), the percentage increase between pre-urban and existing (or future) is enormous. This demonstrates the important role that imperviousness has on runoff generation.

Although historic measurements of flow in Thompson Creek were not available, some flow data collected between January and May 2003 were made available for use in assessing initial model performance. The continuous model was compared with gaged streamflow for the period of January-April 2003. Balance Hydrologics provided flow data for Thompson Creek near Quimby Road and Yerba Buena Creek near the confluence with Thompson Creek. Measured precipitation for this same period was obtained from the San Jose Airport raingage, and scaled by MAP, was used as the model input (Figure 4-18).

The primary form of model assessment was a comparison with predicted and measured streamflow volume for both individual storm events, and the rainy season as a whole. This process indicates if the model is generally separating out rainfall runoff and losses within the watershed. Calibration of individual storm hydrographs and peak flow rates for small storms is difficult, due both to the complexities of the watershed response at that scale, and also, the difficulty of accurately extrapolating the rainfall data from outside the watershed to the response at different watershed junctions. Therefore, the Project Team compared simulated volumes of flow, rather than individual hydrograph peaks, to measured volumes at the gages.

Measurements from the Quimby Road gage were compared with simulated flows at junction J-11 of the model. Discharges measured at the Yerba Buena gage were compared with the combined simulated flows from STO-8 and R-12. Figures 4-19 and 4-20 show cumulative volumes of flow as measured by the stream gages and as computed within HEC-HMS. Cumulative precipitation is also shown within the figures. Simulated discharge is consistent with measured discharge for Thompson Creek at Quimby Road. However, at the Yerba Buena site, model results over-predict discharge volumes. Overall, it is important to recognize that only about 6- to 10-percent of the rainfall in the watershed appears as stream runoff. This is a relatively small percentage, based on our experience in other watersheds throughout the region (where typically, 15- to 25- percent of the total rainfall appears as runoff). The majority of rainfall is held in the watershed, then later either lost via evapotranspiration, or flows to the Bay through subsurface layers as groundwater. The continuous model provides a good simulation of these overall watershed dynamics.

Individual event volumes were calculated for several flow events. Table 4-20 lists computed and measured volumes for events occurring January 9-10, February 16, February 25-27, and March 15-16, 2003. Figures 4-21 and 4-22 graphically present the volumetric comparisons. In general, measured discharge volumes for Thompson Creek at Quimby Road correspond to approximately 4-6% of the event precipitation volumes. The continuous model calculates flow volumes that compare reasonably well to the measured values. Measured streamflow at the Yerba Buena site is generally less than 1.5% of the precipitation volume. Simulated volumes at Yerba Buena compare well considering that the model is not yet calibrated.

Based on initial simulations using spring 2003 rainfall data, it appears that with the present parameterization, the continuous model tends to over-predict runoff and most peak flow rates. Therefore, after calibration, the simulated flows will most likely decrease. It is important to note however, that the relative differences between pre-urban, existing and future conditions are unlikely to change very much as a result of calibration.

4.5.2 Event-Based Model Results

The project team compared peak flows generated by the event-based model to peak flows predicted by the regional regression equations provided by SCVWD (1998). The regional equations provide a method for estimating peak flows for a variety of return periods, based on contributing sub-watershed area, MAP and other parameters (SCVWD, 1998). The equations are derived from analysis of long-term historical stream gage records for the region, and are generally assumed to represent undeveloped watershed conditions. Event-based results were also compared to flow estimates provided in Nolte 2000.

Figures 4-23 and 4-24 compare simulated event peak discharges as a function of yearly recurrence intervals at two HEC-HMS nodes (junctions J-5 and J-12). Discharges are shown for simulated pre-urban, existing, and future development scenarios plotted with discharges calculated from the regional equations. Estimates from Nolte 2000 are also shown for comparison in Figure 4-24. The line representing the historical flood quantile (regional regression) shows good correlation with simulated pre-urban conditions. This relationship is reasonable as the regional equations were developed based on gaging station data from primarily undeveloped watersheds.

Figures 4-25 through 4-28 show additional event-based model results for past, existing and future land use conditions at each segment of Thompson Creek, and for the upper portion of Yerba Buena Creek (refer to Figure 4-1 for junction locations). Peak flows for a variety of return periods are plotted together for the three land use scenarios. This comparison demonstrates the effect of urbanization on peak flows across the spectrum of return periods, with the most dramatic impact being on the smaller, more frequent storms.

A summary of model results (peak flows and discharge volumes) is presented in Table 4-21, for relevant locations on Thompson Creek and Yerba Buena Creek. In addition, model results at J3 and J12 for selected return periods are presented in Figures 4-29 through 4-32.

4.6 Ross Creek Watershed

4.6.1 Continuous Model Results

Continuous discharge records from two Ross Creek stream gages were used to calibrate the HEC-HMS model. Gage #21 is located on Ross Creek at Blossom Hill; Gage #51 is located at Cherry Avenue. Gages #21 and #51 correspond to HEC-1 model nodes J-5 and J-1, respectively (Figure 4-2). Due to the large quantity of data generated in the Ross Creek model, this section will limit the results discussion to results from junctions J-5 and J-1. Junction J-5 represents the upper watershed, which is largely undeveloped under existing conditions. Junction J-1 is inclusive of the upper and lower watershed and includes the urbanized areas of the watershed.

Figures 4-33 and 4-34 show the results of a flood-frequency analysis of continuous model results for the three land use conditions at the two representative locations. The Ross Creek Watershed, similar to the Thompson Creek Watershed, is largely built-out in the lower reaches. The effect of watershed hydromodification is much more significant when comparing pre-urban/existing conditions than when comparing existing/future land use conditions.

Due to increased urbanization, and the resulting increase in impervious area, the frequency of flows at a given magnitude have increased. As illustrated in Figure 4-34, the 10-year pre-urban peak flood event was approximately 500 cfs. According to the model results, under existing conditions, a flow of that magnitude is expected to occur almost every year. A 500 cfs magnitude event is expected to occur slightly more frequently under future land use conditions. As seen in Figure 4-33, the 10-year pre-urban peak of 250 cfs occurs, on average, every 1.3 years under existing conditions. The increase in flow frequency is a significant influence on watershed stream stability.

Recurrence intervals calculated using annual peaks from the continuous model are compared with the all-event flow frequency in Figures 4-35 and 4-36. The two methods are comparable for events larger than the 3-year return period. However, computation of an annual flow frequency does not capture the smaller, sub-year, events that are important for long-term stream stability.

Figures 4-37 and 4-38 present the percent increase in discharge, for a given return period, for the multiple land use scenarios. As expected, the change from pre-urban to future land use conditions represent the largest differences in peak flow. The hydrologic peak flow comparison resulting from changing existing land use to future conditions is relatively small.

The pre-urban and existing condition models for Ross Creek were calibrated against the observed data for two flow gages within the Ross Creek watershed. In the upper portion of the watershed, the flow record for Ross Creek Gage 21 at Blossom Hill Road was used to calibrate the model at junction J-5. Flow data was available from 1946 till 2003 for Gage 21, and the period from October 1950 through March 1952 was used for the pre-urban condition calibration of the model at J-5. The hydrograph results for the pre-urban condition calibration at J-5 are shown in Figure 4-39.

The flow record for Ross Creek Gage 51 at Cherry Avenue was used to calibrate the lower portion of the Ross Creek watershed model at junction J-1. Flow data was available for this gage from 1956 through 2003, and the period from October 1956 through May 1958 was used for the pre-urban condition calibration of the model at J-1. The hydrograph results for the pre-urban condition calibration at J-1 are shown in Figure 4-40.

For the existing condition model for Ross Creek, junctions J-5 and J-1 were both calibrated for the period from November 2000 through March 2003, using flow data from Gage 21 and Gage 51, respectively. The hydrograph results for the existing condition calibration at J-5 and J-1 and are shown in Figure 4-41 and Figure 4-42, respectively.

Tables 4-22A through 4-22D list the numerical results for each of the four calibration periods discussed above. The total volume for the flow gage record and the simulation are shown, as well as the total volume for the flow gage minus all flows less than or equal to 1 cfs. This analysis was added to account for the effects of baseflow in the flow gage record. The model results for total volume were compared with this decreased volume, so as to not over predict flow volume in the model, which did not simulate baseflow. The percent error from observed volume is presented the tables, and due to the variability of hydrologic modeling, a deviation of 20 percent is considered a strong correlation. The average discharge for each condition was included for comparison. The RMS error function value for the model results when compared to both the gage data and the adjusted gage data are presented in the tables.

The degree of correlation between the observed and simulated flows was measure using the peak-weighted root mean square (RMS) error objective function. This function is identical to the calibration objective function included in computer program HEC-1 (USACE, 1998). It compares all ordinates, squaring differences, and it weights the squared differences. The weight assigned to each ordinate is proportional to the magnitude of the ordinate. Ordinates greater than the mean of the observed hydrograph are assigned a weight greater than 1.00, and those smaller, a weight less than 1.00. The peak observed ordinate is assigned the maximum weight. The sum of the weighted, squared differences is divided by the number of computed hydrograph ordinates; thus, yielding the mean squared error. Taking the square root yields the root mean squared error.

Therefore, this function is an implicit measure of comparison of the magnitudes of the peaks, volumes, and times of peak of the two hydrographs. The function is defined as follows:

$$Z = \sqrt{\frac{\sum_{t=1}^{n} (Q_0(t) - Q_S(t))^2 \frac{Q_0(t) + Q_A}{2Q_A}}{n}}$$

$$Q_A = \frac{1}{n} \sum_{t=1}^{n} Q_0$$

Where Z is the objective function, $Q_0(t)$ is the observed flow at time t, $Q_S(t)$ is the computed flow at time t, and Q_A is the average observed flow. The objective function is evaluated for all times t in the objective function time window.

4.7 San Tomas Creek Watershed

4.7.1 Continuous Model Results

Continuous discharge records from two gages on San Tomas Creek (above Williams Road) were used to calibrate the HEC-HMS model for the portion of the watershed studied. This portion of the watershed is just upstream of lower watershed that has concrete lined channels. Gage #24 is located on Upper San Tomas Creek just upstream of Williams Road; Gage #29 is located at Elwood Drive, see Figure 4-3. Due to the large quantity of data generated in the Upper San Tomas Creek models, this section will limit the discussion to results from these junctions.

In the lower portion of the watershed, the flow record for stream Gage 24 was used to calibrate the Pre-urban condition and the Existing condition models at junction J-6. Flow data was available from September 1955 to September 2004, and calibration was performed for the period from June 2002 through June 2003.

For the upper portion of the watershed, the flow record for stream Gage 29 was used to calibrate junction J3e of the Pre-urban condition model and junction J1 the Existing condition model. Flow data was available from October 1945 to October 1968 and calibration was performed for the period from October 1960 through October 1962.

5 Stability Assessment

This chapter summarizes the results of applying the stability assessment to the Thompson Creek, Ross Creek and San Tomas Creek sub-watersheds. These results from Ross and San Tomas Creeks, which are in the Central and Western portions of Santa Clara Basin, are compared to the Thompson Creek on the eastern portion of Santa Clara Basin.

The comparison answers the following question:

- Are the Thompson Creek, Ross Creek and San Tomas Creek results significantly different enough from each other to warrant a separate hydromodification standard, criteria and threshold, or can a single Basin wide standard be defined that applies to all watersheds in the Basin?

Sections 5.1 and 5.2 provide a summary of the background information related to the conditions and assumptions of the method. Section 5.3 describes the mechanics of the method. Section 5.4 describes how well the method works compared to the observed field conditions and presents the tools to be used for management decisions. Section 5.5 applies the method to future conditions and summarizes the results. Section 5.6 summarizes the findings of the Stability Assessment and Section 5.7 briefly states the conclusion on developing a Basin wide standard.

5.1 Overview

Increases in impervious surfaces caused by urbanization and the associated changes in runoff can increase erosion in streams. Development creates large percentages of impervious surfaces that are interconnected via rain gutters, storm drains, and open channels discharging into the creeks. The modification of stream flows due to increases in impervious surfaces and connectivity is considered the most significant cause of channel erosion in urban stream channels (Hammer, 1972; Booth et al. 1997; Doyle et al 2000; Bledsoe et al 2001). This modification to stream flows is termed as hydromodification. In addition to hydromodification, urbanization encroaches onto floodplains and channels, can change sediment sources and supplies, and alter vegetation patterns and densities that influence stream stability.

The stability assessment methodology is based on the premise that a balance among flow energy, sediment supply, and channel resilience must be maintained in order for the stream network to remain stable (Ontario, 2003). By applying this method and establishing management criteria, the intent is to maintain stream sediment transport and erosion processes, not to eliminate them.

Using continuous simulation, the method integrates the excess shear stress applied to the channel boundary over the total time (duration). Excess shear stress is defined as the amount of applied shear that exceeds the critical shear stress for initial motion of bed material or erosion of bank material. This integration is done over a rainfall record of 50-years in this analysis. The assessment method measures erosion potential by using an index representing the effective work done by flow energy in excess of the amount required to transport the available sediment load.

To gain confidence that the method is a reliable predictor of stream channel erosion and instability, the method is used to compare model predictions to observed field conditions classifying the current eroded state of the stream channel (low, medium or high). An empirical relationship is derived that relates model predictions to the probability of having unstable channel conditions. Through this relationship, a threshold is defined that predicts the on-set of channel adjustment and erosion, which is then used to evaluate the effectiveness of management strategies. Chapter 5 discusses this relationship, compares and contrasts the results between the Ross Creek, San Tomas Creek and Thompson Creek subwatersheds.

Natural processes such as weathering, landslides, debris flows, and hill slope erosion supply sediment to the valley floor and stream channels. This material is transported downstream, broken down into smaller material, deposited, scoured, and continually reworked. The hydraulic energy of stream flow imposes a shear force that mobilizes the erodible soils and rock and helps shape the stream channel network. Over time, channels evolve to approximately stable equilibrium conditions that balance the imposed flow energy and sediment load with the channel boundary materials' ability to resist erosion. The processes of runoff and sediment transport interact with the boundary materials establishing cross-sectional geometry, longitudinal slope and planform. As vegetation co-evolves with the channel, it too influences channel stability and shape.

Minor episodic storms (including El Nino) small fires and landslides can also affect sediment characteristics of stream channels. Such minor episodic events occur at a frequency of one in 5 to 20 years in the Santa Clara Basin and can establish a new set of stream conditions and vegetation patterns that gradually return to the pre-event geometry over time. Major episodic events (large fires, major earthquake fault movement) may establish new set of stream conditions. Major episodic events do not occur every 100 years.

The stability assessment primarily addresses changes in watershed runoff patterns and does not specifically address changes in sediment or vegetation patterns. The methodology measures changes and impact from urbanization. It does not measure or recommend management measures for episodic effects associated with fires, seismic events or landslides. These influences would be accounted for under the geomorphic/ historic assessment, and characterization of the watershed and stream system.

5.2 Channel Stability and Equilibrium

5.2.1 Channel Stability and Thresholds

To test and verify the method, the stability assessment requires stable "*baseline*" conditions to compare to the existing conditions. Stable baseline conditions are being represented by pre-urban watershed conditions and modeling. Both the hydrologic modeling and the stream hydraulic modeling were completed using 1940s and early 1950s conditions on Ross and San Tomas Creek watersheds, and 1960s conditions on Thompson and Lower Silver Creek watersheds.

A stable channel is loosely defined as one that neither aggrades nor degrades, but instead maintains its average cross-section, planform, and profile features over time and within a range of variance. Several researchers have defined the equilibrium concept as one where the spectrum of discharges, slope, and channel geometry are adjusted to provide just the right energy to transport the sediment load supplied to the system (e.g., Knighton 1998).

Stream systems in equilibrium can tolerate a certain amount of variation in its flow and sediment loads through natural self-regulating mechanisms. A stable channel can tolerate short-term disturbances without significant change. A disturbance of sufficient magnitude and duration that exceeds the ability to self-regulate causes the channel to begin changes, which is defined as the "threshold of adjustment". Under such conditions, streams can migrate, widen or incise into underlying materials. Stream systems may never truly be in perfect equilibrium, but over the short time period of observation, stream systems tend to maintain consistent measurable characteristics, or if disturbed, streams tend to return to approximately their previous state.

The intent of the assessment method is to identify the threshold of adjustment where channels begin to incise or widen and the forces that cause this adjustment, accelerating the natural erosion and sediment transport processes. This threshold of adjustment is proposed as the measurable limit of allowable change in the watershed and used for management purposes.

5.2.2 Work Concepts

In addition to the equilibrium concept, there also is a range of flows that are considered most important in defining channel form, adjustment and controlling the rate at which sediment is transported through the stream system (Leopold et al. 1964). Leopold et al. (1964) showed that a large percentage of the "work done" is performed by frequent flow events of moderate magnitude defined as "geomorphically significant flows" in this report. Research has shown that urbanization significantly alters the frequency and duration of geomorphically significant flows (Hammer 1972, Hollis 1975). Bledsoe and Watson (2001) reported that the frequency of these flows increases by factors of 2.5 to 5 for watersheds with 18 percent impervious cover. MacRae et al. (1992, 1993) showed that the greatest increase in channel erosion results from increases in the small and moderate sized flow events – referred to as sub-bankfull flows. These small but frequent flow events have the energy to move sediment and erode stream bank material, and cumulatively have more influence over channel erosion and adjustment than infrequent larger storm events. Additionally, they can weaken the bank and therefore contribute to more extensive and severe slumping during larger storm events.

5.3 Methods

5.3.1 Effective Work Index

The stability assessment is based on measuring the magnitude of effective work index (*W*) by flows that exceed a specified critical value for the streambed or bank material. *W* is an index that represents the total work done on the channel boundary integrated over time. Note that the index includes a velocity term to accurately represent W in units of Work. The Thompson Creek study was updated to include the index as shown below in Equation 1 and illustrated earlier in Figure 2-2.

This effective work index is defined as follows:

$$W = C \cdot \sum_{i=1}^{n} (\tau_i - \tau_c)^{e} \cdot V \cdot \Delta t \qquad (1)$$

where:

W = index of total effective work done over the length of flow record per square foot of bed or bank (ft-lbs/sq-ft).

C = a constant to convert equation to dimensional or dimensionless units of work, dependent on exponent *e*

n = number of flow records in a histogram of flows

τc = critical shear stress that initiates bed mobility or shear erosion (lbs/sq-ft).

τi = applied hydraulic shear stress, computed as ρgdS (lbs/sq-ft).

e = exponent that captures the exponential rise in stream power with flow (determined to be between 1 and 2.5, selected as 1.5 for watersheds in Santa Clara Basin)

V = mid-channel velocity (ft/sec)

Δ*t* = duration of flow (in seconds) for each flow record

For τi ,

d = depth of water (ft), S = longitudinal slope (ft/ft),

g = gravity constant (ft/sec2)   ρ = density of water (lb/ft3)

The time increment (Δ*t*) is determined by generating a histogram of flows from the continuous hydrologic simulation results, which are hourly data. For each flow range (Bin), the histogram provides the count or duration of time that flows are within the designated flow range. For the average flow within a Bin, the depth, velocity, and shear stress are computed. Equation 1 is solved for each flow Bin, where the excess shear term is multiplied by the velocity (V) and duration (Δ*t*) to compute the incremental effective work done by that specific range of flows. When equation 1 is summed over the 50-year flow record (histogram), the result (*W*) is a measure of the total effective work done on the stream channel boundary.

5.3.2 Determining Critical Values

Critical values of the streambed and stream bank provide a measure of the stream's resistance to erosion. Critical values for bed material reflect the onset of sediment transport. Critical values for bank material reflect the onset of erosion of the bank, especially for weak stratigraphy layers. Streams (or boundary material) with larger critical values have more resilience to hydromodification. Chapter 3 described the physical properties of the observed streambed and bank materials, which are used to determine the critical values for the channel boundary. The bed was characterized by particle size distribution and depth. Stream banks were characterized by composition (percent clay, silt, sand and gravel).

For the different bed material sizes, critical values of shear stress and velocity for bed mobility were estimated using two methods: Shield's equation and from permissible velocity tables published in ASCE Manual No. 77 (1992). Table 5-1 lists the range and average of estimated critical velocities and shear stresses using each method for comparison. Ultimately, the average ASCE values were used in the stability analysis to maintain consistency between the values selected to represent the critical shear for bank material.

Table 5-1. Range of Critical Shear Stress and Velocity for Measured Bed Material in Thompson Creek

Study Area	D50 (mm)	Bed Slope	Critical Bed Shear Stress (a) (lbs/ft^2)	Critical Bed Shear Stress (b) (lbs/ft^2)	Critical Velocity (a) (ft/s)	Critical Velocity (b) (ft/s)
Thompson Creek Range	3.2 to 10	0.002 to 0.018	0.05 to 0.16	0.09 to 0.27	1.5 to 2.8	2.4 to 3.5
Average	6		0.09	0.14	2.1	2.8
Ross Creek Range	14 to 30	0.004 to 0.019	0.22 to 0.48	0.21 to 0.61	3.3 to 4.4	3.9 to 5.2
Average	20		0.29	0.35	3.9	4.3
San Tomas Creek Range						
Average						

a) Source: Computed using Shields Equation. Dimensionless parameter used = 0.047

b) Source: ASCE Manual No. 77, page 334, Figure 9.5.

The ability of a stream bank to resist erosion depends on soil materials, stratigraphy, vegetation density, root strength, the degree of cohesion, bank height, and slope. Boundary material also influences vegetation assemblages which in turn provide resistance to bank erosion. Stream channels bounded by clays, compacted silts, and loess are often more resistant to erosion and respond more slowly to hydrologic changes than channels bound by loosely consolidated sands and gravels.

The ASCE Manual No. 77 was used to estimate critical velocities and shear stress for the channel banks, including both the upper stiff clay layers and the lower weaker layers with sands and gravels. Table 5-2 lists the critical values selected for the different bank materials found in the Thompson Creek and Ross Creek subwatershed. The composition of the bank soils was estimated qualitatively in the field.

Table 5-2. Selected Critical Velocity and Shear Stress Values for Bank Material

Material Type	Critical Velocity (V_c ft/sec)	Critical Shear Stress (τ_c lbs/ft^2)
Riprap	8.0	1.6
Hardpan	6.0	0.67
Compacted Clays	5.0	0.5
Stiff Clays	4.0	0.32

Alluvial Silts	3.5	0.23
Firm Loam	3.5	0.23
Silty Loam	3.0	0.17
Sandy Loam	2.5	0.12

5.3.3 Hydraulic Computations

Hydraulic calculations convert the flow rates estimated by the hydrology model to flow depth, velocity, and shear stress based on cross-section geometry and slope. Channel hydraulics are computed using normal flow assumptions. Each cross-section is treated independently from the others; thus backwater effects are not considered. The computations are completed following the Army Corps of Engineers HEC-2 method, where conveyance (K) is computed and summed between individual survey points. A HEC-2 (HEC-RAS) model was not developed. The depth, velocity, and shear stress used in the stability assessment are taken from the main channel not including overbanks or floodplains. The central channel velocity and shear stress more correctly represent the actual values imposed on the channel bed and toe of banks where shear erosion is occurring.

The following equations are used for the hydraulic analysis:

$$Q = 1.49 \cdot K \cdot \sqrt{S}$$

$$K = \sum \frac{AR^{2/3}}{n} \qquad R = \frac{A}{P}$$

where

K = Conveyance

R = Hydraulic radius

P = Wetted perimeter

Conveyance is computed for each element of the flow area defined between two cross section survey points. The total conveyance (*K*) is then determined by summing the conveyance between individual elements. Once *K* is known, the discharge is computed. The computation begins by computing the flow area (A) and wetted perimeter (P) for a know depth of water, followed by computing *K* and then discharge (Q).

For the stability assessment, hydraulic tables were generated for each cross section by incrementing stage in 6-inch increments up to the maximum surveyed elevation. This stage-discharge table includes hydraulic radius, flow velocity, bed shear stress, flow area, and a composite roughness coefficient. The stage-discharge table was used in conjunction with the histograms to predict the hydraulic variables (by interpolation) given the model flows.

5.3.3.1 Selecting Roughness Coefficients

Roughness coefficients, required for hydraulic calculations, were first estimated in the field and then adjusted in the office using photographs taken at each individual cross-section. Coefficients were estimated using Cowan's method as described in Chow (1959) and others. Cowan's method sums individual roughness elements of the stream boundary. For example, bed material and form, irregularities in the banks, variations in cross-section, obstructions, and vegetation density are elements considered to derive the overall roughness coefficient. For the hydraulic computations, coefficients were selected to represent low flows in the mid-channel, bankfull flows, and flood flows, and vary by elevation and location.

5.3.4 Erosion Potential

The effective work index for stable stream channels under pre-urban conditions (or drainage areas as close to undeveloped as possible) is compared to unstable channels under urbanized conditions. The comparison, expressed as a ratio, is defined as the Erosion Potential (Ep) (McRae, 1992, 1996) and illustrated earlier in Figure 2-3.

$$Ep = \frac{W_{unstable}}{W_{stable}} \tag{2}$$

$W_{unstable}$ = work index for a stream section determined to be unstable

W_{stable} = work index for a stream section determined to be stable

The Ep is used to develop the empirical relationship between Ep and the observed stability of stream channels.

Predicting the erosion potential for future development projects and for management purposes, the Ep ratio would be written as:

$$Ep = \frac{W_{post}}{W_{pre}} \tag{3}$$

W_{post} = work index estimated for proposed development

W_{pre} = work index measured for the pre-development condition

The concept here is that during implementation of the HMP, the baseline pre- condition is the *Existing* condition. The existing condition may, or may not, be stable. When existing conditions are not stable because of current development, implementation of the HMP requires that Ep not increase and make the observed erosion worse.

5.3.5 The Erosion Potential Chart

The measured Work Index and Ep values for pre-urban and existing land use conditions are compared to the field classified erosion condition (stable/low and medium/high). The numeric value of each parameter is plotted on a vertical chart by group and is referred to as the Erosion Potential Chart. Groups with indistinguishable measures are combined; groups that are distinguishable suggest potential thresholds for management purposes. Earlier results from Thompson Creek showed the above groupings to be appropriate.

As with any environmental data, there is always variation in results and some level of uncertainty in mathematical expressions that attempt to predict environmental conditions. Predicting the on-set of erosion and channel instability is a complex matter. Overlap in groupings illustrates the uncertainty in the effective work index and Ep. The Erosion Potential Chart will be described in more detail under Results.

5.3.6 Logistic Regression

5.4 Results

The results are presented for the Thompson Creek Watershed, and then for the Ross Creek and San Tomas Creek watersheds. The Ross Creek and San Tomas Creek results are then discussed in comparison to the Thompson Creek. Sub-section 5.4.1 provides a discussion on percentage of watershed imperviousness specifically as it relates to Segment 5 in Thompson Creek and for East Ross Creek where field observations noted a transition from stable channel conditions to unstable conditions. The literature frequently reports observed channel and riparian impacts once the percent of imperviousness reaches a certain level (frequently stated as 10%). Sub-section 5.4.1 tests these conclusions in the Santa Clara Basin. Sub-section 5.4.2 summarizes the result of the effective work computations and compares the computed index to the observed field classification for erosion. Close agreement would indicate that the effective work index can predict the likelihood that a stream channel would be stable or unstable. Sub-section 5.4.3 discusses results for the Erosion Potential (Ep) and sub-section 5.4.4 discusses the logistic regression results, which are used to derive the threshold of adjustment.

5.4.1 Percentage of Watershed Imperviousness

Booth et al. (1990, 1997) reported finding a good correlation between the onset of channel instability and recent increases in percent imperviousness. According to Booth, western Washington lowland streams display the onset of degradation at a consistent level of development, and instability is observed when the effective impervious area increases to 10 percent or more.

The project team compared the percentage of impervious area for cross-sections in Thompson Creek and Ross Creek. Figure 5-1T and 5-1R presents an illustration showing the cross section location, contributing sub-catchments, and percent impervious area, for Thompson Creek and Ross Creek, respectively.

In Thompson Creek, the project team compared the percentage of impervious area for cross-sections TC5-4, TC5-5, TC5-6 and TC5-7 in Segment TC5 under existing conditions. In Ross Creek, the project team compared cross sections in East Ross (ER-1, -2, and -3) as well as one on the main stem of Ross Creek (RC-8).

The percent of impervious area associated with cross-sections in the upper parts of the watersheds, where the cross-sections transition from stable to unstable conditions is shown in Table 5-3 and in Figures 5-1T and 5-1R.

Table 5-3. Summary of Percent Impervious Area in Transition Segments of Thompson Creek and Ross Creek subwatersheds

Ross Creek	Current % Impervious	Erosion Rate Classification	Thompson Creek	Current % Impervious	Erosion Rate Classification
ER-3	1.2	Stable	TC 5-7	1.6	Stable
ER-2	5.8	Medium/High	TC 5-6	6.9	Low
ER-1	8.9	High	TC 5-5	9.4	High
RC-8	18.7	High	TC 5-4	11.1	High

The percent of impervious area associated with cross-sections TC5-4, TC5-5, T5-6, and T5-7 are 11%, 9%, 7% and 1.6%, respectively. The field study classified erosion along cross-sections TC5-4, TC5-5, TC5-6, and TC5-7 as “high,” “high,” “low”, and “stable”, respectively. Furthermore, cross-section TC5-5 is just beginning to show the signs of instability, where the bed has recently incised six-inches, reach wide.

The percent of impervious area associated with cross-sections RC-8, ER-1, ER-2, and ER-3 are 19%, 9%, 6% and 1.2%, respectively. The field study classified erosion along these sections as “high”, “high,” “medium/high”, and “stable”, respectively. According to the field crews, cross section ER-2 is mostly medium.

Given the results for both Ross Creek and Thompson Creek, it appears that a similar relationship between percent imperviousness and stream channel instability might exist in the Santa Clara Basin as that found for Western Washington by Booth. The transition between stable and unstable conditions occurs between 5 and 10 percent impervious.

5.4.2 Testing the Assessment Method’s Ability to Predict Observed Instability

5.4.2.1 This section first discusses the effective work curves, which suggests which flows are responsible for doing the most work on the channel boundary, and when compared between pre-urban and existing, illustrate how urbanization changes these important flows.

5.4.2.2 Effective Work Curves

Thompson Creek

Figure 5-2T present effective work curves and cumulative effective work curves for the pre-urban watershed conditions for a sub-set of cross sections in Thompson Creek. These results represent the stable baseline condition upon which the existing and future conditions are compared and used to evaluate potential instabilities. Figure 5-3T presents the computed effective work curves and cumulative effective work curves for cross-sections in Segment 5 under existing conditions.

These curves illustrate which flows are doing the greatest amount of work on the stream channel and are responsible for the greatest amount of channel incision and toe erosion. For the urbanized cross section TC5-1, -2, -3, -4, and -5, flows between about 15 cfs and 80 cfs are responsible for greatest percentage of the erosion and instabilities in this segment. This is observed by the larger magnitude of the effective work index between 15 cfs and 80 cfs. For cross sections TC5-6 and TC5-7, with little development, there is much less influence of small to moderate sized storm on the overall effective work. The important geomorphically significant flows begin at about 15 cfs but extend to 250 cfs and 190 cfs for TC5-6 and TC5-7, respectively. These curves illustrate the effect urbanization has on increasing the frequency and duration of small to moderate sized storms and its affect on *Work*, and is consistent with results presented by others in the literature (Hammer 1972, Hollis 1975, Bledsoe and Watson 2001, MacRae et al. 1992, 1993).

Ross Creek

Figure 5-2A presents effective work curves for select cross sections for the pre-urban, existing, and future watershed condition for Ross Creek. The pre-urban results (late 1940's and early 1950's), when the watershed was agricultural and undeveloped, represent the stable baseline condition upon which the existing and future conditions are compared and used to evaluate potential instabilities. These curves illustrate which flows are doing the most work on the stream channel boundary. As observed with Thompson Creek, the small to moderate magnitude flows have the greatest influence on channel shape and erosion potential. For example, under pre-urban condition for Ross Creek, flow from 25 cfs to about 240 cfs accounts for 90% of the total work done. This range of frequent flow events constitutes the geomorphically significant flows for Ross Creek.

The change between the existing curves and the pre-urban curves illustrate which urban flows are doing the greatest amount of work on the stream channel and are responsible for the greatest amount of channel erosion. The work done at cross section RC-8 for example increases the most dramatically when compared to the other cross sections. The maximum work done under pre-urban conditions is about 200,000 ft-lbs/sq-ft at 40 cfs, which increases to 640,000 ft-lbs/ sq-ft under existing conditions.

Figure 5-2B present the cumulative work curves for Ross Creek, sections RC-3 to RC-8. These curves illustrate which flows are contributing the most to the overall total work done on the stream channel. The figure also shows the magnitude of the 2-year, 5-year, and 10-year peak flows. This figure illustrates how much work is done for flows of different magnitudes. For example, 70% to 80% of the work is done by all flows up to the 2-year peak flow. Between 92% and 94% of the work is done by flows up to the 10-year peak flow. Provision C.3.f.iv of the permit requires the HMP to specify the range of storms for which the HMP applies. From Figure 5-2B, the Project Team is recommending that flows be managed from zero up to the pre-project 10-year peak flow.

Figure 5-3 presents effective work curves for the pre-urban, existing, and future watershed condition for East Ross Creek. These curves show similar trends as well as some differences. ER-1 and ER-2 both show increases in work in the low to moderate flow range. However, ER-3 actually shows decreases in work and in the range of flows. It may be that the construction of impervious surface upstream from ER-3 creates the bimodal hydrograph phenomenon where runoff from the impervious surfaces travels faster and exits the catchment before the remaining forested catchment area is able to contribute to flows.

Figure 5-4 presents effective work curves for the pre-urban, existing, and future watershed condition for RC-1 and RC-2. These two cross sections are located in a portion of the channel that was excavated where no stream channel existed naturally to route flows to Guadalupe River. These two cross sections illustrate results for an earthen engineered channel with an erodible boundary. The maximum work for the existing conditions is not too much different than the maximum work under the pre-urban conditions. The existing curves are a little broader than the pre-urban curves. These cross sections show signs of significant past erosion. At present, they have low to medium erosion presently. Figure 5-4b illustrates what the work curve would look like using existing flows and the design cross section. This curve suggests that much more work was done on the channel in the past than what is predicted today. This is consistent with the field observations that these cross section show signs of past erosion with about 2-feet of incision and bank erosion. Today, these cross sections are wider and deeper and may be reestablishing a state of equilibrium.

Like Thompson Creek, the work index computed in Ross Creek increases more so for smaller flows than larger ones. However, the effective work in Ross Creek does not increase as dramatically in the low flow range as predicted for Thompson Creek. Effective work in Ross Creek exhibits a more or less uniform increase (percentage wise) within the low to moderate flow range (roughly 25 cfs to 500 cfs). These results may reflect the hydro-geomorphic nature of Ross Creek. Ross Creek is mostly perennial, larger lot sizes per dwelling, and larger bed material than Thompson Creek. The upper watershed is forested and has lower perviousness, unlike Thompson Creek whose watershed is mostly grass lands and more pervious.

5.4.3 Evaluation of the Field Designated Erosion Classification

Figure 5-5 plots the total effective work index with erosion classification for Thompson Creek. Estimates for pre-urban conditions are also shown for comparison. The total effective work index is computed by the model and the erosion classification is determined in the field for existing conditions. The distribution of stable/low versus unstable – medium/high along the total effective work index suggests a strong correlation between the computed work index and the field designated erosion classification.

Figure 5-6 compares the total effective work index (W) with the erosion classification for existing conditions based on field observation in Ross Creek. Unfortunately, all but two cross sections were classified as medium/high, which makes it difficult to make strong statements regarding correlation to field observations. Considering the two cross sections in the stable/low classification, RC-7 is just upstream of a grade control structure installed in 1958, and ER-3 is predicted to have a decrease in work due to shifts in the flow histograms.

The range in magnitude of the effective work index for Thompson Creek is greater than what is computed for Ross Creek. To understand this better, it is necessary to look at a number of factors:

1. Critical shear stress in the two watersheds: For the same total shear stress applied, the critical shear stress at Ross Creek is higher, thereby resulting in a lower value of total effective work. The critical shear stress on Ross Creek is higher because of larger D50 of the bed material. The D50 is larger because of differences in the geomorphology, the mountain ranges and perennial nature of flow in Ross Creek, which does not allow as much of the fines to settle out. Tables T3-3 and R3-3 lists the D50 values for Thompson and Ross creeks
2. Age of development and channel response: Another possible explanation is the difference in the time period of adjustment since intense development has taken place. Possible explanations for these differences include cross section differences (channel geometry and slope have had more time to adjust), watershed size and flow magnitudes (Thompson Creek has twice the watershed area and flows), and stream geomorphology differences (Ross Creek has larger bed material). Considering sections RC-1 and RC-2, there is evidence that the erosiveness of flows through this reach has decreased over the years as the channel expanded. Ross Creek has had roughly 20-years longer to adjust to development (from the 1960's & 1970's) than Thompson Creek (high rate of development continuing from 1980's to present). Further analysis of more cross sections would likely show the same pattern.

5.4.4 Erosion Potential (Ep)

Figure 5-7 presents the Erosion Potential Chart for Thompson Creek. As with Figure 5-5, there is a strong correlation between computed Ep and the field-designated erosion classification. Those sections classified as having medium/high observed erosion characteristics plot on the chart above those classified as stable/low with only two outliers.

Figure 5-8 presents the Erosion Potential Chart for Ross Creek. As with Figure 5-6, there is a suggested correlation between the predicted erosion potential and the field-designated erosion classification. Those sections classified as having medium/high observed erosion characteristics plot on the chart above those classified as stable/low (even with only two points). The minimum value of the medium/high group is 1.6. RC-

7 is just upstream from a grade control structure installed in 1958 as part of the channel improvement projects. ER-3 is reduced as described earlier.

Figure ST5-8 the Erosion Potential Chart for San Tomas Creek, which plots very similar to Ross Creek. San Tomas has four cross sections that are classified in the stable/low category and five that are classified as medium/high. San Tomas, however, includes a medium/high section with an Ep ratio of 1.1. Four cross sections in San Tomas (ST-7, 8, 9, and 10) were not used because they were located near an active fault line and the area was determined to be naturally highly erosive. ST-7 is located immediately downstream from an outfall, which is causing localized scour, so it too was not included in the final pooled analysis.

By comparing the results for Thompson Creek, Ross Creek and San Tomas Creek, the Ep values at which cross-sections transition from stable to unstable rates of erosion are similar. This should allow for pooling the data for logistic regression analysis on watersheds in different parts of the Santa Clara Basin.

5.4.5 Selecting a Threshold for Management\

5.4.6 Analysis of Critical Flow (Qc)

This section describes the determination of the Critical Flow (Qc) for Thompson Creek and Ross Creek. Critical flow is defined as the stream flow (cfs) that produces the critical shear stress (τc) and initiates bed movement. Table 5-5 lists the estimated critical flow at cross sections near locations where flood frequency results were generated.

Critical flows for Thompson Creek range from 3 cfs to 40 cfs depending on the location listed. The average critical shear of 0.14 lbs/sq-ft is used for most all sections. According to the sediment sampling data collected in Thompson Creek, estimated critical flows is estimated to range from 1 cfs to 18 cfs. Critical flows for Ross Creek range from 15 cfs to 25 cfs depending on the location listed. In Ross Creek, critical shear values ranging from 0.23 to 0.38 lbs/sq-ft depending on location were used in the analysis.

In order for the critical flow to be useful to dischargers, the critical flow in the stream must be partitioned or related to an on-site project based variable. For this analysis the in-stream critical flow was related to the pre-urban 2-year peak flow (Table 5-5). Because computations involving sediment data, critical shear values, and roughness coefficients are highly variable and subjective, the critical flow was generalized as being 10% of the 2-year peak flow.

Table 5-5. Summary of 2-year Peak Flows and Estimated Critical Shear Stress Values

Subwatershed and Location	Pre-Urban 2-Year Peak Flow (cfs)	Cross Section	Critical Flow (Qc) (cfs)	Percent of 2-Year Peak
Thompson Creek J-1	56 (a)	TC5-7	10	18
J-5	189 (100)	TC5-1, 5-2 & 5-3	3, 5, 7	2, 3, 4
J-12	530 (500)	TC1-1, 1-2	40, 40	8
Yerba Buena	69	YB-6, YB-7	5, 4	7, 6
	57	YB-2, YB-4	3, 10	5, 18
Ross Creek J-1	209 (b)	RC-1, RC-2	25, 25	12

J-5	139	RC-6, RC-8	20, 15	14, 11

a) Thompson Creek 2-year peak flows were generated from synthetic design storm hydrographs as described in Chapter 4. Flows in parenthesis are estimated from the 50-year continuous model records where flood frequency data were generated.

b) Ross Creek 2-year peak flows were generated from the 50-year continuous model records. Design storm hydrographs were not generated for Ross Creek.

5.5 Predicting Erosion Potential under Future Build-Out Conditions

5.5.1 Thompson Creek

Table 5-6 presents the results for total effective work index and erosion potential under future conditions (build-out per the current San Jose General Plan 2020) for select stream sections. The percent increase in the work index from existing conditions is also presented. These results suggest that future development will increase the current erosion potential by an average of 26 percent.

The important change to note is that Ep for cross-sections TC5-6 and TC5-7 shifted from about 1 to an Ep of 1.3 and 1.2, respectively. Future development increases the probability that cross-sections TC5-6 and TC5-7 will become unstable. If this reach of Thompson Creek were to become unstable, then erosion of the bed and bank would contribute sediment to downstream reaches.

Table 5-6: Percent Increase in the Erosion Potential under Future Build-Out Conditions

Cross Section	Ep		
	Existing	Future	% Increase
TC1-6	5.4	6.7	24%
TC2-1	2.4	3.3	37%
TC2-3	3.7	4.8	29%
TC2-6	9.7	12.2	26%
TC2-9	4.1	5.3	31%
TC2-10	2.0	2.6	30%
TC3-5	10.4	11.6	12%
TC3-7	2.8	4.0	45%
TC5-2	4.0	5.4	35%
TC5-3	4.6	6.0	33%
TC5-4	8.2	10.5	30%
TC5-5	5.2	6.8	31%
TC5-6	0.9	1.2	10 %
TC5-7	0.9	1.3	12 %

5.5.2 Ross Creek

In this section, the results for the future build-out condition of Ross Creek and East Ross Creek in the Ross Creek sub-watershed are presented and discussed as an example of changes that can be experienced with future development. Sub-section 5.5.2.1 summarizes the result of the effective work computations and compares the computed index to the observed field classification for erosion. Sub-section 5.2.2.2 discusses results for the future condition Erosion Potential (Ep).

5.5.2.1 Effective Work

Figure 5-2, presented earlier, shows the effective work curves for the pre-urban, existing, and future watershed condition for Ross Creek. The change between the existing curves and the future curves illustrate which additional urban flows will do the greatest amount of work on the stream channel and be most likely responsible for the increase in erosion in the future build-out condition. The work done at cross section RC-8 for example increases from pre-urban to existing to future conditions, when compared to the other cross sections. The maximum work done under future conditions is 920000 ft-lbs/ sq-ft, a 44% increase from existing conditions.

Figure 5-3, as presented earlier, shows the effective work curves for the pre-urban, existing, and future watershed conditions for East Ross Creek. These curves show similar trends as for Ross Creek. ER-1, ER-2, and ER-3 all show increases in the low to moderate flow range from existing to future condition due to the projected increase in impervious surface area within East Ross Creek.

Figure 5-4, as presented earlier, shows the effective work curves for the pre-urban, existing, and future watershed conditions for RC-1 and RC-2. While these cross sections are wider and deeper today, and may be reestablishing a state of equilibrium, the future condition curves do predict an increase in the effective work on these engineered channels which could correspond to additional erosion as the channel continues to adjust to a new state of equilibrium.

5.6 Findings

5.6.1 Effective Work

- The predicted effective work index (*W*) is capable of distinguishing between stable stream sections (pre-urban, stable/low existing conditions), and unstable stream sections (medium/high existing conditions).
- In all watersheds studied, the more frequent small to moderate magnitude flows have the greatest influence on channel shape and erosion potential.
- The critical discharge (Qc) upon which bed material begins to move in quantity is about 10 to 15 cfs for Thompson Creek and 20 to 25 cfs for Ross Creek. In both instances, it is 10 percent of the peak 2 year flow.

5.6.2 Erosion Potential (Ep)

- The Ep methodology is capable of distinguishing stable/low eroding conditions from medium/high eroding conditions for San Tomas Creek, Ross Creek and Thompson Creek subwatersheds (including East Ross Creek and Yerba Buena Creek).
- The Ep ratio between the subwatersheds is similar such that the Ep data for Thompson Creek, San Tomas Creek and Ross Creek can be pooled together to evaluate the threshold of adjustment.

5.6.3 Threshold of Adjustment

5.7 Implications for a Watershed Wide Standard

The Ep ratio for watersheds studied are not significantly different to warrant separate hydromodification standard, criteria and threshold. Differences in the physical conditions between watersheds are accounted for in the assessment methodology.

9 Method Limitations and Uncertainties

9.1 Physical Processes Not Accounted For

Streams are also impacted by historical land use practices such as grazing, agriculture, and mining; the development of infrastructure such as bridges, flood control and water supply facilities; and buildings located in the floodplain. Natural events such as fires, droughts, and landslides caused by seismic activity can also impact streams. Although no less important, the effects of these factors are not addressed in this document.

Several modes of failure are recognized as contributing to channel bank failure in the Thompson Creek subwatershed. The primary failure mechanism addressed by this HMP method is shear erosion along the channel bed and at the toe of the bank, which results in incision and over-steepened banks. Secondary failure mechanisms are often a function of the incised channel form and include slumping due to over-steepened slopes and/or lack of vegetation and root structures. Also, due to the flashy nature of flows in Thompson Creek, rapid reductions in water level during the recession portion of the hydrograph can also cause bank failure.

Urbanization can also change sediment sources and supplies, alter vegetation patterns and densities, and affect flood plains. The sediment load, its particle size range, input timing and longitudinal distribution contribute to the development of geomorphic surfaces and in-stream deposits that form the foundation for riparian and aquatic habitat. The episodic nature of storms and dry and wet cycles (including El Nino), fire and earth flows affect sediment characteristics of stream channels. Episodic events temporarily establish a new set of stream conditions and vegetation patterns that gradually return to the pre-event geometry over time. The stability assessment primarily addresses persistent changes in watershed runoff patterns and does not specifically address changes in sediment or vegetation patterns. However, these influences would be accounted for under the geomorphic/ historic assessment, and characterization of the watershed and stream system.

In the implementation phase of the HMP, development will likely occur in watersheds that have dams and reservoirs, or gravel mining, water diversions, etc. that can also cause channel incision and widening. The development of the HMP method was intentionally tested on subwatersheds without these factors to identify true urbanization impacts and develop control measures that address hydromodification as defined in this report. When HMP control measures are applied to development in watersheds with other stream impacting factors, the impacts associated with hydromodification is adequately mitigated. This does not mean however that the other factors will not cause channel instability and adjustment.

9.2 Analysis of Model Errors

Chapter 4 discussed the accuracy of the hydrologic model in predicting low flows and larger peak flows when compared to other methods, including measured flow data. This section discusses how these model discrepancies are likely to affect the stability assessment. The results of the HMS model tested are briefly summarized below:

- The HMS model was compared to a regional regression equation developed for predicting 2-year to 100-year peak flows form open space. The regression equation was developed for flood control purposes. The model results for the pre-urban land use scenario were shown to under-predict peak flows estimated by the regression equation.
- The HMS model was compared to high water marks measured in the field after a December 2002 storm. The continuous model accurately predicts the December 2002 peak flows for the upper reaches (mostly open space) and predicts slightly high in the lower reach (mostly urbanized), although not out-of-bounds. The regression equation also over-predicts the measured high water marks. This error has been attributed to streambed infiltration
- Measured flow data was collected for storms between January and April 2003. The modeled flow volumes were compared to the measured stream flow volumes. The continuous model accurately predicts stream flow volume in the lower reaches (urban) and over-predicts volume in the upper reaches (open space). The event-based model over-predicts the continuous model and measured data.

It should be noted that runoff volume is more important for hydromodification than peak flows. Erosion and channel adjustment is affected by the frequency, duration and volume of long-term stream flows. Infrequent peak flows have little effect on the overall hydromodification problems.

These results suggest that the continuous HMS model is over-predicting runoff volume from open space, which becomes negligible once the runoff volume from the urban area becomes significant – likely around cross-section 5-5 in Segment 5 (for existing conditions). It appears that the most significant error is in predicting runoff for the pre-urban land use scenario, since the model seems to over-predict runoff volume from open space. This is not a significant issue under existing conditions, or for the upper reach stable cross-sections where the Ep ratio would tend to cancel the errors.

Given the above discussion, the stability assessment may be under-predicting the magnitude of the erosion potential (Ep) for most cross-sections tested. In other words, the pre-urban Work Index (W) would be smaller than our current estimates, which would than increase the estimated Ep values.

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