BASELINE GEOMORPHIC ASSESSMENT OF TOLAY CREEK SONOMA COUNTY, CALIFORNIA

A REPORT PREPARED FOR

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INTRODUCTION

This baseline geomorphic assessment of Tolay Creek Watershed is intended to provide information about geomorphology that may be used to aid Sonoma Land Trust to address active erosion and sedimentation processes. This information is treated within the context of natural processes, land use changes, and potential future restoration activities. In particular, this report addresses an important question: how do physical watershed characteristics and land uses govern geomorphic processes such as erosion and sedimentation in the Tolay Creek Watershed? This question is important to address due to concern that active gully and fluvial incision and bank erosion in the middle reaches of Tolay Creek and channel aggradation in downstream reaches occurred within the past decade.

This work is based on a reconnaissance level investigation including field observations, map and photograph analysis, and discussions with agency staff and local residents knowledgeable about Tolay Creek. The data and results of the reconnaissance reported here is intended to provide a basis for an approach to restoration and management that accommodates geomorphic processes. Results also serve as a basis for a more detailed field work plan to initiate baseline monitoring that would be conducted during a future phase of this investigation.

METHODS

Methods utilized in this work included field reconnaissance, photographic analysis, historic, topographic, and geologic map analysis, review of available hydrologic, geologic, and geomorphic literature, and discussion with agency staff and residents knowledgeable about the watershed.

1. Field reconnaissance of Tolay Creek was conducted during October and November 2008 in coordination with the Sonoma Land Trust and West Coast Watershed (lower watershed), and the Sonoma County Regional Parks Department (upper watershed). The reconnaissance included walking the entire channel from Tolay Lake to Arnold Drive.

2. Topographic map analysis included delineation of the Tolay watershed boundary, measurement of the watershed drainage basin area, illustration of the drainage network, and calculation of channel gradient. Geology is well defined by recent detailed California Department of Mines and Geology mapping in the Sears Point

and Petaluma River Quadrangles and in a recent MS thesis from San Jose State University.

3. A set of five photographic images taken in 1942, 1961, 1981, 1997, and 2007 was assembled to document changes in channel pattern. Channel pattern was mapped during each time period where visible; in some reaches the imagery did not have high enough resolution to differentiate the channel from the surrounding landscape, an in other reaches riparian vegetation obscured the channel. Results are qualitative, as photographs were not ortho-rectified.

4. Tributary erosion processes were characterized using high resolution 2008 LiDAR images along the Rogers Creek Fault zone in the upper portion of the watershed. In the lower portion of the watershed, erosion processes are characterized using the 2007 SLT photograph.

GEOMORPHIC AND HYDROLOGIC CHARACTERISTICS OF THE TOLAY CREEK WATERSHED

Topography and Tributary Drainage Network

Tolay Creek drains the Northern California Coast Ranges in Sonoma County, California (Figure 1). The Creek discharges into a tidally influenced marsh complex at the southern end of Sonoma Valley before entering San Pablo Bay. For the purpose of this report, the watershed outlet is defined as the point where Arnold Drive (Highway 121) crosses Tolay Creek. Downstream of Arnold Drive, in the tidally influenced areas of Tolay Creek, restoration research and monitoring is currently underway by USGS Western Ecological Research Center and others (Takekawa et al., 2002).

Tolay Creek flows from northwest to southeast in a valley situated between and roughly parallel to both Sonoma Creek and the Petaluma River drainages (Figure 1). The watershed boundary is defined by rounded ridges and hilltops with maximum relief of about 900 feet. The highest elevation in the watershed is an unnamed peak on the ridge to the northeast of the creek at 916 ft and the elevation of Tolay Creek at Arnold Drive is about 15 ft. The watershed divide in the headwaters has a relatively low elevation and in some place is somewhat indistinct from the adjacent Petaluma River watershed—with a driveway off of Stage Gulch Road currently acting as one point along the drainage divide (Steve Ehret, Sonoma County Regional Parks Department, Personal Communication, 2008).

The Tolay Creek watershed upstream of Arnold Drive has a drainage area of 8.3 mi^2. The drainage network is composed of all of the tributaries and channels within the drainage basin (Figure 2). Based on 1:24,000 scale USGS topographic maps of the area, Tolay Creek is a third-order channel with a total main channel length of about 6.3 mi. Channel gradient illustrated in Figure 3 shows three zones with distinct slope, here called upper, middle, and lower. The upper basin is wide and includes both Tolay Lake and a reach of Tolay Creek downstream of the Lake. This ~3.0 mile reach has a relatively low slope of 0.0013. The middle basin is narrow and includes a shorter ~1.2 mile reach of Tolay Creek with a steeper slope of 0.0212. The lower basin is relatively wider than the middle basin and includes a ~1.7 mile reach of Tolay Creek with a slope of 0.0069.

Before the 1860's a natural dam impounded Tolay Lake in the upper portion of the watershed. Prior to its destruction, the natural dam surface was about 14 feet higher than the former lake bed (see Figure 9 in Kamman Associates, 2003). Following the initial destruction of the natural dam, the farmers rebuilt a small dam that allowed the farmers to keep water in the lake bottom for longer periods. By keeping the lake bed area moist, they were able to raise potatoes, corn, pumpkins, and squash without irrigation. Planting took place first around the outside margin of the lake, and as the lake dried, the farmers worked toward the middle of the lake. The channel through middle of lake would usually dry by the end of the summer, although wet areas could still be seen. The new small dam created the Tolay Lake of today (Marvin Cardoza, Personal Communication, 2009).

There are 13 tributaries in the Tolay Creek watershed that join the main channel; the spacing of tributary junctions with the main channel is illustrated on Figure 3. Within the middle portion of Tolay Creek, tributary junctions are sites of sediment deposition and woody debris accumulation. The physical complexity at such sites in turn creates important loci of ecological diversity (Benda, et al., 2004). In the upper watershed, tributaries on the northeastern side of the Tolay Creek watershed are longer than those on the southeastern side due to tectonically imposed asymmetry of the watershed. Thus, higher ridges and longer hillslopes exist on the northeast side than on the southwest side of the creek. Other influences of tectonics on the drainage network are described in a subsequent section.

Hydrologic Processes

Sonoma County is characterized by a Mediterranean climate with seasonal precipitation, and storms, erosion, and sediment transport processes are highly episodic. Hydrologic processes in the watershed integrated the upstream tributaries and Tolay Lake downstream to Tolay Creek during wet periods when the lake level was high enough to spill over or around the original dam. Water would have been contributed to the downstream fluvial system as the enlarged lake drained to the elevation of the natural outfall. The extent to which groundwater processes continued to provide base flow to downstream areas after dam overflow stopped is unknown. Presumably, after removal of the natural dam, flow in the downstream portions of Tolay Creek became intermittent or at least drier for longer periods each year. Land use practices as of 2003 included draining water from the Tolay Lake basin using high capacity pumps, because of limited outlet capacity during periods when storm flow to the lake bottom exceeded the ability of the current outlet to convey flow to the downstream portion of Tolay Creek (Kamman Associates, 2003).

There are no precipitation data from within the Tolay Creek Watershed, however there are several records from nearby stations. The wet season occurs between October and

May, and the dry season occurs between June and September. At Petaluma Fire Station 3 (046826), average annual precipitation between 1893 and 2007 was about 25 inches, whereas, a shorter record from Mare Island (045333) between 1961 and 1975 reports a somewhat lower average annual precipitation of about 20 inches (Desert Research Institute Regional Climate Summaries; http://www.wrcc.dri.edu/Climsum.html). A long record from the City of Sonoma between 1899 to 1907 and 1931 to 1997 reports an annual average of 29.2 inches (see Figure 4 in McKee et al., 2000). Thus, the average annual precipitation in the Tolay watershed is probably about 20-30 inches.

There are no stream flow gages in the watershed; however, early rainfall history (www.calarchives4u.com/history/sonoma/sect2.htm) suggests that overbank floods occurred in Sonoma County when annual rainfall measured on the order of about 40 inches. Thus, floods in the Tolay basin may have occurred during water years 1841, 1850, 1853, 1862, 1867, 1868, and 1872—or in about seven out of 35 years. During the 82 year period between 1914 and 1996 (see Figure 6 in Kamman Associates, 2003), years with rainfall greater than 40 inches occurred only four times (during 1913, 1940, 1982, 1994), and floods are also documented in Sonoma County during 1955, 1986, and 1995. During this same period, short droughts occurred during 1947-1950, 1959-1962, 1976-1977, and 1987-1994. Field reconnaissance observations during the current dry year documents seasonally dry channel conditions in Tolay Creek downstream of the Lake basin. Even in a dry year, however, water exists in some pools in Tolay Creek, consistent with the 1902 USGS historical topographic map that indicates that intermittent flow characterizes Tolay Creek. Moreover, springs and associated hillslope wetlands, such as wet swales, were apparent. Thus, seasonal and decadal climate variability and both drought years and flood years are important hydrologic characteristics to consider in future restoration planning.

Effect of Geology and Tectonics on Erosion and Sedimentation

The geology and tectonics of the Tolay Creek watershed have a significant effect on geomorphic processes such as erosion and sedimentation. Geologic mapping in the Tolay watershed is detailed and includes recent geologic interpretations of the Petaluma River Quadrangle (Wagner et al., 2002a) and Sears Point Quadrangle (Wagner et al., 2002b) and of the same area north of San Pablo Bay by Allen (2003). Figure 4 shows the geology underlying the Tolay Creek Watershed.

Tolay Creek flows in a basin with ridges formed by Tertiary volcanic and sedimentary rocks and the Jurassic-Cretaceous Franciscan formation. There are no quantitative measurements of erosion rates specific to the watershed; however, this reconnaissance level investigation suggests that these formations are erosive. Much of the hillslope area within the Tolay Creek watershed, especially on the southwestern ridge formed by Tertiary sedimentary rocks is mapped as "mostly landslide" (Wentworth et al., 1997). Geologic mapping (Wagner et al., 2002a and b) shows individual Quaternary landslides documenting unstable terrain that contributes sediment to Tolay Creek on a geologic timescale. For example, in the lower portion of the basin, the numerous Quaternary landslides on the northwest ridge illustrate hillslope instability (Figure 4). Recent high magnitude and high intensity storms such as occurred during 1982 initiated debris flows that were mapped by the USGS (Ellen, et al., 1997). This effort mapped areas highly susceptible to debris flows on the northeastern slope of the Tolay watershed (Figure 5).

The lake basin in the upper portion of the watershed is filled with Holocene basin deposits composed of fine grained alluvium with horizontal stratification that may contain peat (Wagner et al, 2002a). The presence of peat indicates a long geologic history characterized by a wetland environment. Two core samples taken in the upper watershed by Kamman Associates (2003) illustrate layers of fine sediment including mostly clay and silty or sandy clay deposited during the Holocene. The large alluvial fan deposit emanating from the northeastern ridge in this upper basin may have added to the structural controls that created Tolay Lake by depositing sediment atop bedrock that formed the natural dam.

In the middle and lower portion of the Tolay Creed watershed, the valley bottom and lower gradient swales are filled with Holocene alluvium and fan sediment. Fans modify channel pattern by forcing the channel toward the opposite side of the valley. Late Holocene stream terraces are present upstream of Arnold Drive. In the area near the outlet of the basin, there are several types of alluvial deposits. For example, the modern channel alluvium of Tolay Creek is adjacent to older Holocene terraces and alluvial fans emanating from the Upper and Lower Petaluma Formations are adjacent to the terraces. All of these formations are easily erodable and provide a source of sediment to downstream areas through processes including channel migration and incision.

The relatively young fault and fold structures that dominate tectonics in the Tolay watershed are associated with the San Andreas Fault System and include both the Tolay and Rodgers Creeks Faults (Figure 4). The dominant motion on these faults is strike-slip, meaning that the ground on either side of the fault slides past each other. The San Andreas system is a right-lateral strike slip fault: when standing on either side of the fault and looking across at the other side, the other side appears to be moving to the right. However there is also a strong compressional component to the fault motion, termed "transpression," as evidenced by local uplift and folding in the Coast Ranges. The transpression is normal to the northwest trending faults and folding and uplift of younger strata is exhibited adjacent to the fault zones.

Although the dominant regional trend in the Coast Ranges is the transpression that raised the mountain range, localized exceptions occur. Such exceptions create conspicuous valleys where there is no evidence of modern or past river incision—necessitating another explanation for valley formation. One model to explain the existence of these valleys is that they coincide with right-steps (offsets between fault segments) in right-lateral fault systems that cause local crustal extension where small basins form. The upper portion of the Tolay Creek watershed—or the Tolay Lake basin—fits this model. Blake et al., (2002) suggest that the processes that formed small basins within the Tolay/Petaluma River Fault Zone probably occurred before the Pleistocene.

The Rodgers Creek Fault zone trends northwest along the northeastern ridge of the Tolay Creek watershed and the related Tolay Fault zone is located along the slope of the southwestern ridge in the lower portion of the watershed (Figure 4). The Roche-Cardoza Fault cuts across the northeastern hillslope at an angle to both faults. The Rogers Creek Fault is thought to be one segment of the active Hayward-Rogers Creek-Healdsburg Fault system; however older structures are also prevalent in the watershed. The younger faults trend about N30^{o}W and truncate older structures (e.g. the faults between tectonic terranes) that originally trended about N60^{o}W (Blake et al., 2002). Most of the older faults dip steeply to the east and some may have been reactivated or realigned by younger tectonic deformation (Blake et al., 2002).

Regional and local tectonics and the presence of these active and inactive faults exert a major role in structuring the geomorphology of the Tolay Creek watershed. The topography in the watershed is influenced by tectonics with rocks of differing geology, resistance, and erosion rates juxtaposed. Fault zones and numerous splinters of the Rogers Creek, Roche-Cardoza, and Tolay Fault systems have produced sheared or weak zones in rock formations that preferentially weather and erode, and sometimes form conditions for hillslope wetlands. A line of springs is present along the Tolay Fault, demonstrating the influence of tectonics on local hydrology and associated biota. Moreover, as previously mentioned, the watershed is asymmetric, with longer tributaries and higher hillslopes on the northeastern side than on the southwestern side of the basin. This is significant in that the relatively larger drainage areas on the north eastern side produce more of the water and sediment contributed to downstream riparian habitat in Tolay Creek, simply because of their greater extent.

Tributary patterns are influenced by faults within the Tolay Creek watershed. For example, one unnamed tributary flows to the northwest along the Rogers Creek Fault zone in a northwestern direction, opposite to the flow direction in downstream reaches of Tolay Creek, before bending back toward the southeast and flowing into the Tolay Lake basin (see Figure 2). Another geomorphic feature related to tectonic activity is sag ponds, ponds that are found on fault zones. Numerous sag ponds are present on the northeastern drainage divide, along the Rogers Creek Fault zone including Gravelly Lake and Lee Lake.

LAND USE CHANGES

Local history in the Tolay Lake area is known to span 8,000 years (Sonoma County Regional Parks Department; www.sonoma-county.org/PARKS/pk_tolay_history.htm). Native American occupation in the Tolay Lake area extended until the early 1800's (Steve Ehret, Sonoma County Regional Parks Department, Personal Communication, 2008). Over the millennia, the lake was considered to be a spiritual center that drew Native Americans from across California (Goerke, 2007).

In the upper portion of the watershed, significant modifications to support agriculture included destruction of the natural dam impounding Tolay Lake sometime between about 1865 and 1885, ditching and draining the lakebed, and creation of the channelized upper Tolay Creek in the former lake area where there was probably not a single channel prior to European settlement. Dredging of a channel to drain Tolay Lake appears to have been accomplished by 1914, as Tolay Creek is shown as a single channel and no lake or wetland is indicated within the lake basin on the 1914 USGS topographic map. Channel straightening of Tolay Creek and other tributaries flowing into the lake basin appear to have occurred after 1914 but before the time of the earliest photographs of the area taken in 1942. Downstream of Tolay Lake, channel dredging occurred many times, and dredged materials were used for a variety of activities that required fill. One such activity included disposal of dredged sediment along the creek as levees as documented in a 1970 plan for about 3,500 feet of the channel downstream of the causeway across Tolay Lake (Soil Conservation Service, 1971; data provided by Sonoma County Regional Parks Department). The plan called for excavation of a trapezoidal channel that widened and deepened the existing channel where width increased from 40 to 54 feet and depth increased by 6 to 8 feet to a constant 10 feet. The slope of the newly dredged channel was expected to be 0.00138—similar to the current gradient in the lake basin (Figure 3). The plan specifies that disposition of excavated material would be directed by owner. Field reconnaissance suggests that one use of dredged sediment included using material for levee construction along the dredged channel. Dredging of about one to two feet of soft sediment in the channel downstream of Tolay Lake took place about every 8-12 years, with the dredged channel profile being defined by a relatively hard layer (Marvin Cardoza, Personal Communication, 2009).

In addition to the modifications on the valley floor, land use changes on hillslopes began in the area with early European influence and grazing of the hillslopes and establishment of the Sonoma Mission in 1832. A wave of American settlers immigrating to the area in 1840-1845 obtained land grants; the largest confirmed in Sonoma County was the Petaluma grant. The Petaluma grant included 75,000 acres of arable land between Sonoma Creek to the east, San Pablo Bay on the south, and the Petaluma River on the west—thus including the entire Tolay Creek Watershed. Currently, land uses within the watershed are still dominated by grazing with a small portion of the watershed planted with vineyards. There is a10-acre vineyard near the causeway across the modern Tolay Lake area; the majority of vineyards are in the headwaters on private property. Other areas recently planted with vineyards are within the lower portion of the Tolay Basin. Grading, vegetation changes, and irrigation practices in vineyards may modify hillslope hydrology and erosion processes. In areas where the ground is left bare, runoff and sediment production supply to downstream fluvial system generally increases. Changes in hydrology associated with vineyards may also initiate gullies in adjacent swales.

Small dams on tributaries were constructed to store water for use during the dry season. Numerous dams are present on small tributaries in the watershed and the resulting reservoirs and water diversions support the agricultural activities and modify hydrology in the watershed. Because most of the dams are small and agricultural diversions are not usual during storms, the majority are not likely to significantly influence high flows in downstream portions of Tolay Creek whereas dry season flow could have smaller magnitudes and shorter durations. An exception is one dam that creates a 245 AF impoundment that may affect the flow of storm waters in the Tolay Lake basin (Ehret, Sonoma County Regional Parks Department, Personal Communication, 2009).

Roads present in the watershed include Mangel's Ranch Road that connects the upper and lower portions of the watershed and closely follows the middle portion of Tolay Creek. Historically, there were various alignments of the Lakeville Highway; one alignment crossed the upper portion of the Tolay Creek basin near the lake (Sonoma County Atlas, 1897; map provided by Sonoma County Regional Parks Department). Existing and remnant tributary crossings in the watershed play an important role in concentrating drainage. Today, a few tributary road crossings act as a grade control where there is significant incision downstream of the crossing and a step to a higher tributary bed elevation upstream. Two potential causes of such steps include: 1) headward migration of incision from the main Tolay Creek channel until it meets the structural control imposed by the road crossing; and 2) the road acts as a dam trapping sediment transported from tributary headwaters upstream of the road crossing so that flowing water has a greater capacity to erode sediment downstream of the road.

Development associated with Infineon Raceway in the downstream portion of the watershed includes a parking lot and access road immediately upstream of Highway 122 that spans the Tolay Creek floodplain and adjacent slope. In addition there is an overflow parking lot downstream of Arnold Drive in the former tidal marsh.

The main landuses in the tidal marshes downstream of Arnold Drive include restoration, grazing, and some agriculture (mostly hay). There is one recently planted vineyard on the alluvial fan surface north of Tolay Creek immediately downstream of Arnold Drive.

EFFECT OF NATURAL PROCESSES AND LAND USES ON EROSION AND SEDIMENTATION

The long history of grazing, other agricultural practices (e.g. ditching, dredging, channelization), dams and water diversions, and road construction probably have influenced erosion and sedimentation rates and altered the hydrology and morphology of Tolay Creek. There are no sediment transport data available; however it is likely that sediment sources and sediment transport regimes differ corresponding to both land use activities and to geologic and tectonic influences on hillslope source areas, tributaries, and the downstream main channel.

Active tributary erosion is prevalent throughout the watershed. In the upper portion of the watershed, erosion and depositional processes are greatly influenced by the presence of the Rogers Creek Fault zone along the northeastern ridge and to anthropogenic activities on hillslopes and in the low gradient lake basin. Sediment sources along the Rogers Creek Fault zone visible in the recent LiDAR image (Figure 6) illustrate numerous erosion processes in the upper portion of the watershed. First, hillslope instability is evident in unchanneled zones upslope from channel heads, where hummocky topography is an indicator of past and recent debris slides that contribute sediment to first order tributaries. Some debris slides are associated with debris flow tracts, illustrating the mechanism responsible for transporting sediment from hillslopes the drainage network. Second, gullies form in many locations within these and other unstable areas, providing a conduit for sediment to quickly reach channels during storms. The channelized zone of many tributaries begin downstream of wet swales filled with Holocene alluvium; such hillslope wetlands are vulnerable to erosion by headward migration of tributary erosion and from upstream changes in hydrology due to roads or vineyards. Third, bank erosion along the interface of the hillslope with first order channels is prevalent (e.g. as along the small channels forming the headwaters of Cardoza Creek). Coarse and fine sediment contributed to small first-order channels moves episodically downstream during storms.

An 1823 account from Altimira's diary (provided by Steve Ehret, Sonoma County Regional Parks Department, Personal Communication, 2008) reports "little groves of oaks between gullies and hilltops," suggesting that gullies (or some type of channel) were already part of the landscape at that time. However, in general, the rate of sediment transport in watersheds such as Tolay Creek are likely to have increased due to changes in hillslope hydrology associated with long-term grazing and vegetation changes (see: Trimble and Mendel, 1995). Moreover, the current absence of vegetation (that would provide large woody debris that in turn could trap sediment for longer periods) may also increase transport rates. Sediment transport is interrupted by the numerous small dams in the watershed (see Figure 2) that trap sediment from upstream areas. A corresponding reduction in sediment delivery to downstream channels could increase incision rates.

Sediment contributions from the southwestern hillslope are likely to be delivered to the drainage network by similar processes as from the northeastern hillslopes. However because the drainages are smaller with shorter stream lengths, the volume of sediment contributed is expected to be less than on the northeastern side of the watershed. In the lower portion of the watershed, the upstream-most point of erosion in tributaries visible on the SLT photograph is illustrated (Figure 7) in order to show potential linkages between and tributary erosion and land uses such as roads and vineyards. Although land uses such as these may accelerate erosion, baselevel changes (described later in this section) may also play a role.

Prior to land use changes and channelization, the majority of sediment and woody debris that entered the Tolay Lake basin from tributaries was likely to be deposited locally on fans at the margins of the valley or in the lake itself, except perhaps during high magnitude floods that carried sediment past the natural dam. The upper portion of Tolay Creek was channelized prior to 1942 (channelization is apparent on 1942 aerial photographs) and has a relatively low gradient within the lake basin. No quantitative data regarding current sedimentation rates in the upper watershed are available; however presumably there was a need for dredging to maintain drainage and the channelized conditions, suggesting that some sedimentation occurred.

Historic changes in channel pattern in the watershed suggest that channel pattern present in the earliest photographs from 1942 have persisted to the present—with migration in the lower portion of the creek within the range of uncertainty present due to the low resolution and distortion apparent in some of the historical photographs. Downstream of Arnold Drive, Tolay Creek is confined in a straight channel before discharging into the tidally influenced Napa-Sonoma Marsh slough channel system. Straightening of the channel in the upland marsh transition area likely occurred at about the same time as construction of the railroad, in 1878, with the trestle over Tolay Creek fixing the channel location.

In contrast to the anthropogenic activities that created the straight leveed channel in the former lake basin, the major influences controlling channel character in the middle and lower portion of the watershed currently appear to be differences in channel slope and valley width. In the middle portion of the watershed, a narrower and steeper reach exists downstream of the lake outlet. In this reach, Tolay Creek generally transports sediment and wood contributed from adjacent tributaries and hillslopes. The channel profile illustrated in Figure 3 suggests that overall this middle reach of Tolay Creek is steep. However, field reconnaissance indicates local variations in the channel gradient and width with alternating steeper and gentler segments. The steeper segments appear to be narrow and incised with actively eroding, nearly vertical banks, coarse sediment bed material, and abundant large woody debris. In contrast, the more gentle segments are wider; containing relatively fine grained sediment deposits with a somewhat marshy appearance. Local residents and others knowledgeable about the Tolay basin suggest that the active incision and bank erosion is recent, since the mid 1990's.

In the downstream portion of Tolay Creek, the valley widens, and there is a floodplain or fans adjacent to the channel. Sediment in this lower reach is derived from upstream erosion processes, adjacent tributaries, and local bank erosion and reworking of the floodplain and fan sediment deposits. At the same time that incision and erosion was occurring in the middle portion of Tolay Creek, local residents suggest that deposition occurred downstream in the lower portion of Tolay Creek.

These recent changes in erosion and sedimentation could be the result of both upstream changes in hillslope hydrology that could have increased runoff and downstream changes in baselevel in the Tolay Creek Watershed. Baselevel is defined as the elevation to which a fluvial system can erode (Schumm, 1993). Lowering of the baselevel may have caused headward migration of incision in Tolay Creek in two separate locations. First, destruction of the dam that formerly impounded Tolay Lake lowered the baselevel of the upper portion of the watershed—by a maximum of 14 feet (based on the estimate of the dam surface elevation relative to the lake bed described previously). Over time, the longitudinal profiles of tributaries upstream of the dam are likely to have changed as sediment eroded upstream through headward migration of a knick point, the location where velocity and shear stress are greatest. Sediment eroded from tributaries would have been transported and deposited downstream. The rate change of in tributary longitudinal profiles depended on sediment supply from adjacent hillslopes, sediment transport rates, the character of the upstream bed and bank material, and on the presence of large wood or other vegetation that may have locally stabilized the bed. Field observation suggests that hillslopes adjacent to tributaries in the upper portion of the Tolay Creek watershed are actively eroding, indicating ongoing dynamic adjustments in elevation and slope.

A second location where baselevel lowing may have caused headward migration of incision in Tolay Creek is in the lower portion of the watershed. The USGS topographic Map for Sears Point indicates some subsidence on Tubbs Island upstream of Highway 37—the former west bank of Tolay Creek—although subsidence was not as extensive in this area as it was downstream of Hwy 37. Assuming that a historic MHHW elevation of about 3.45 feet NGVD corresponds to the historic marshplain elevation prior to construction of the highways, levee construction, and the initiation of agricultural activities that led to marshplain subsidence, current land surface elevations of -1.0 ft NGVD (shown on the 1968 photo revision of the 1951 topographic map) suggest that about 4.5 feet of subsidence has taken place in this area near the mouth of Tolay Creek. Thus, baselevel lowering due to subsidence in tidal marshes downstream of Arnold Drive by about 4.5 feet may have initiated incision and headward migration erosion in the lower and middle portion of Tolay Creek during the period during the century following the extensive human modifications to the tidal marsh when subsidence was initiated. Some baselevel lowering may have been related to historic dredging that occurred at the mouth of Tolay Creek near San Pablo Bay. Additional information from nearby Skaggs Island, where levee construction began 1892, estimated ongoing regional subsidence at a rate of about 0.75 inches/year to one inch/year (WESTNAVFAC-ENGCOM, 1981; Metcalf and Eddy, 1971; both reported in the Western Division Naval Facilities Engineering Command, Skaggs Island Master Plan).

Despite subsidence in the downstream marshes that lowered local baselevel, recent observations suggest that the lower portion of Tolay Creek is undergoing aggradation, not incision. Tom Huffman (CDFG, Personal Communication, 2008), reported that in 1992 it was possible to walk under the Railroad trestle about 0.5 miles downstream of Arnold Drive. Since then, significant sedimentation from the Tolay watershed was deposited during two storm years: 1998 and 2006 (January) so that sediment is now near the level of the tracks (suggesting on the order of about 4-5 ft of recent local aggradation). High flows and sediment yield from the Tolay Creek Watershed during these storm years influenced areas downstream of Arnold Drive, including filling or washing out culverts, filling in and overtopping low levees, and replacing the single thread channel with shallow sheet flow. Thus, geomorphic processes during these recent floods appear to have raised the baselevel in the marsh at the outlet of the Tolay basin.

Significantly, during the same recent storms that deposited sediment and raised the baselevel at the outlet of Tolay Creek near Arnold Drive—incision occurred in the middle portion of the watershed. Incision, and associated bank erosion and channel widening may have occurred during these storms due to high magnitude runoff and discharge from upstream. Alternatively, erosion in the middle portion of the watershed could be a lagged response to downstream changes in baselevel—which then provided the sediment for transport to downstream areas that has been documented. Similarly, other causes for sedimentation in the tidal marsh downstream of Arnold Drive should be considered, including the effect of a reduction in tidal prism and hydrologic connectivity to San Pablo Bay upstream of Hwy 37.

SUMMARY

This reconnaissance level assessment of geomorphic processes in the Tolay Creek Watershed describes the influence of land use changes on erosion and sedimentation processes. The work presented here is based on field observations, map and photographic analysis, and available reports and information. More detailed field work is warranted to document current spatial extent of erosion and sedimentation, local variability of channel conditions, and rates of change. Selecting reaches for long-term field monitoring and initiation of baseline data collection is an essential component of future adaptive assessment and management, restoration, and educational efforts.

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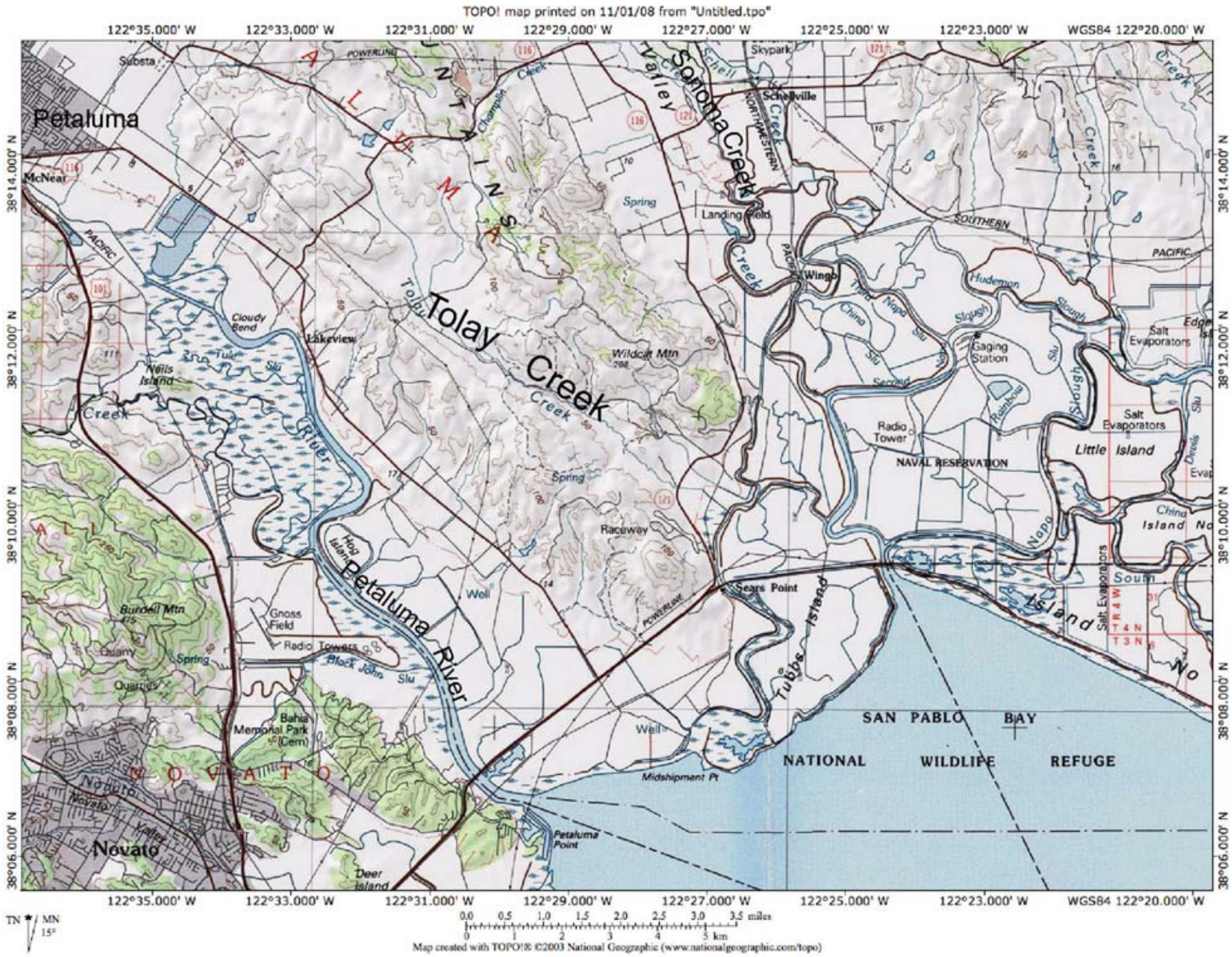


Figure 1. Location Map of Tolay Creek.

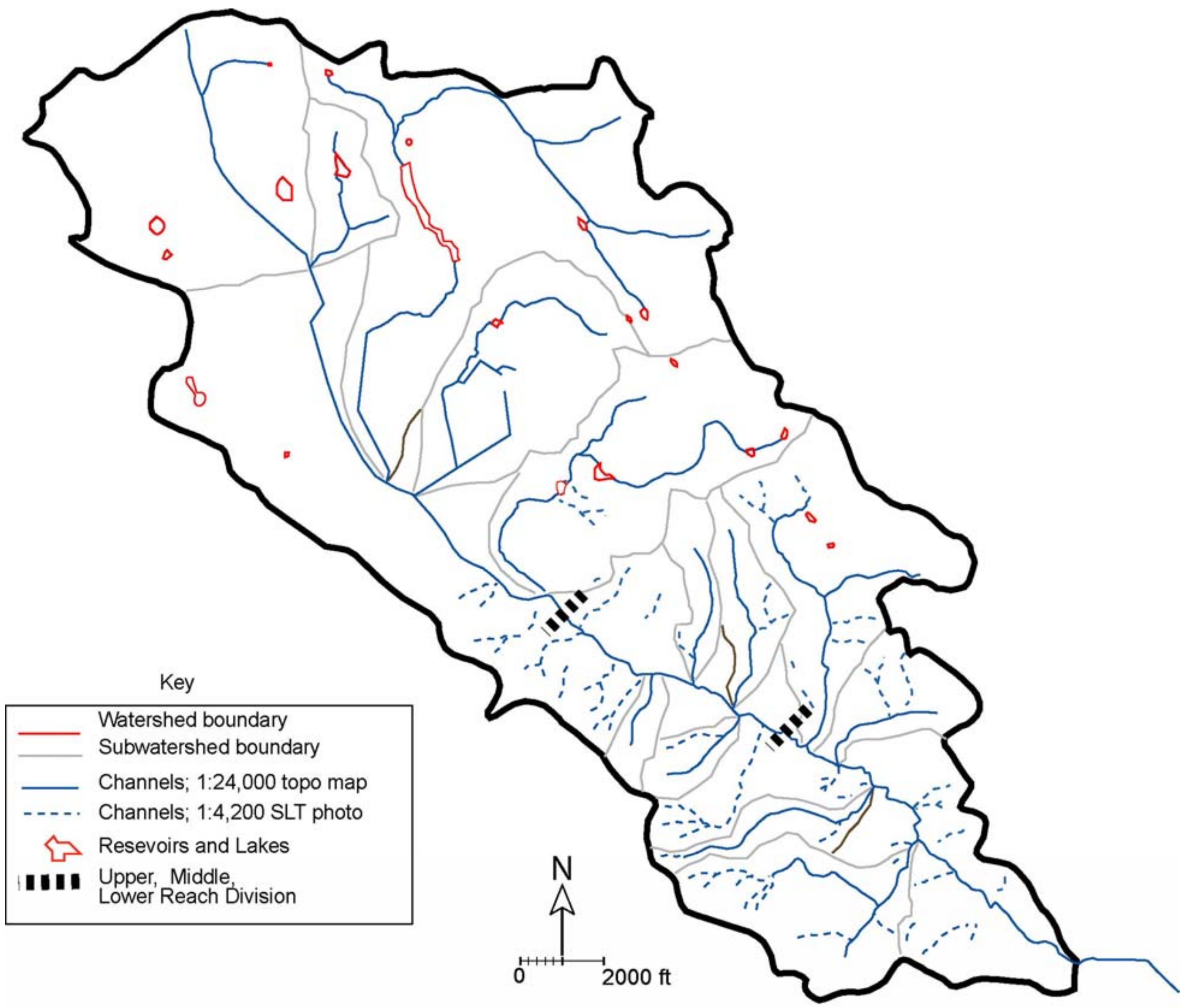


Figure 2. Tolay Creek Watershed and Drainage Network.

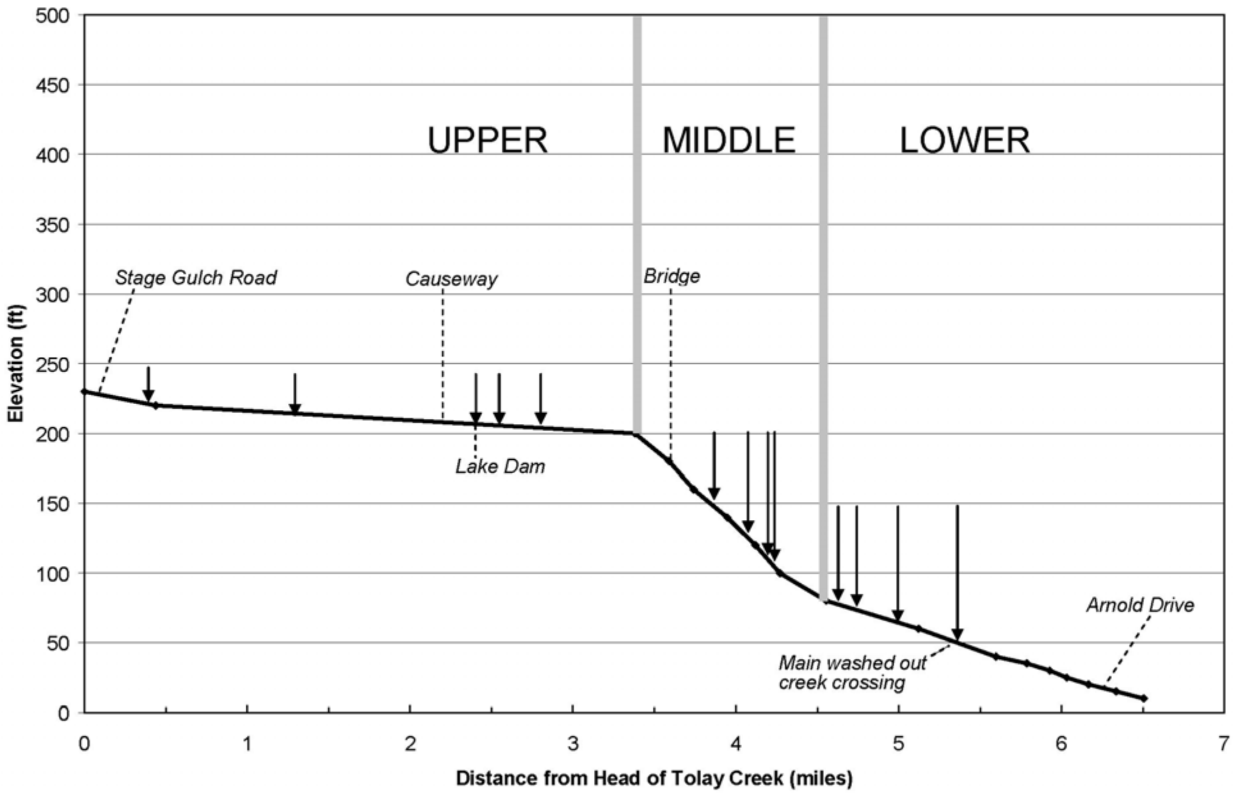


Figure 3. Longitudinal Profile of Tolay Creek Showing Breaks in Slope Distinguishing Upper, Middle, and Lower Portions of the Watershed. Profile constructed from USGS topographic maps. Arrows indicate location of tributary junctions.

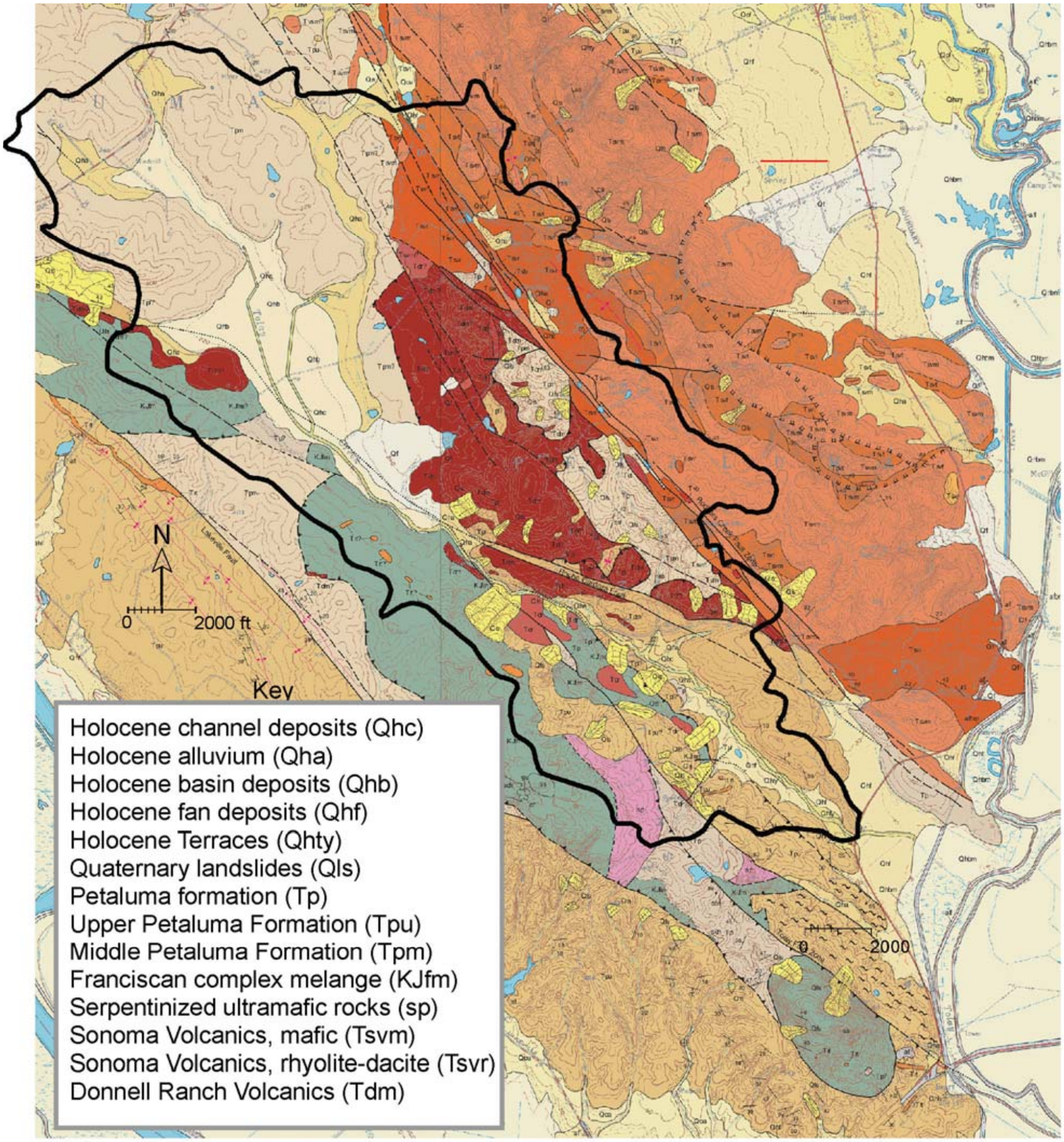


Figure 4. Geology Underlying the Tolay Creek Watershed (Wagner et al., 2002a and b).

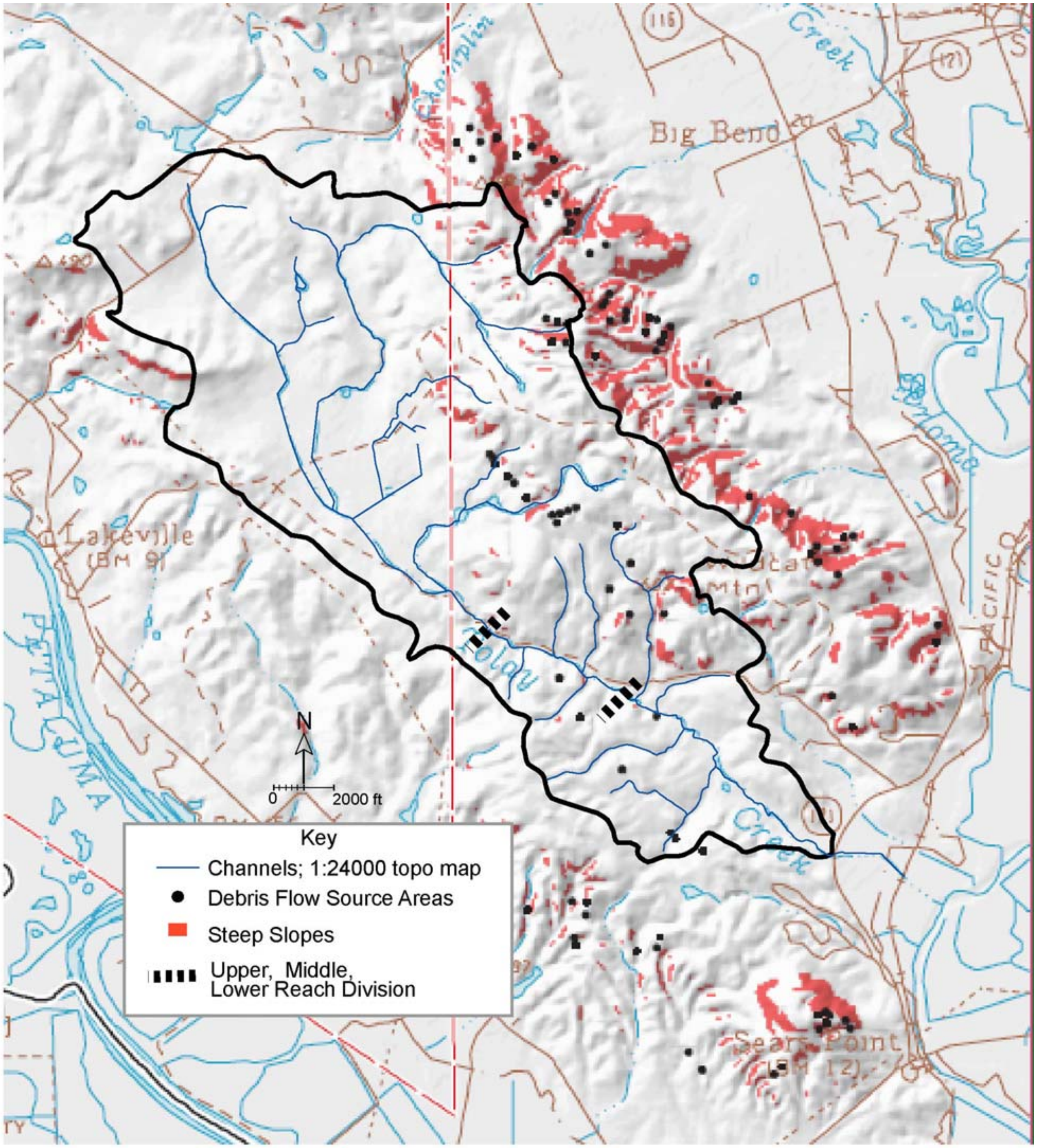


Figure 5. Debris Flows Initiated During 1982 Storm (modified after Ellen et al., 1997).

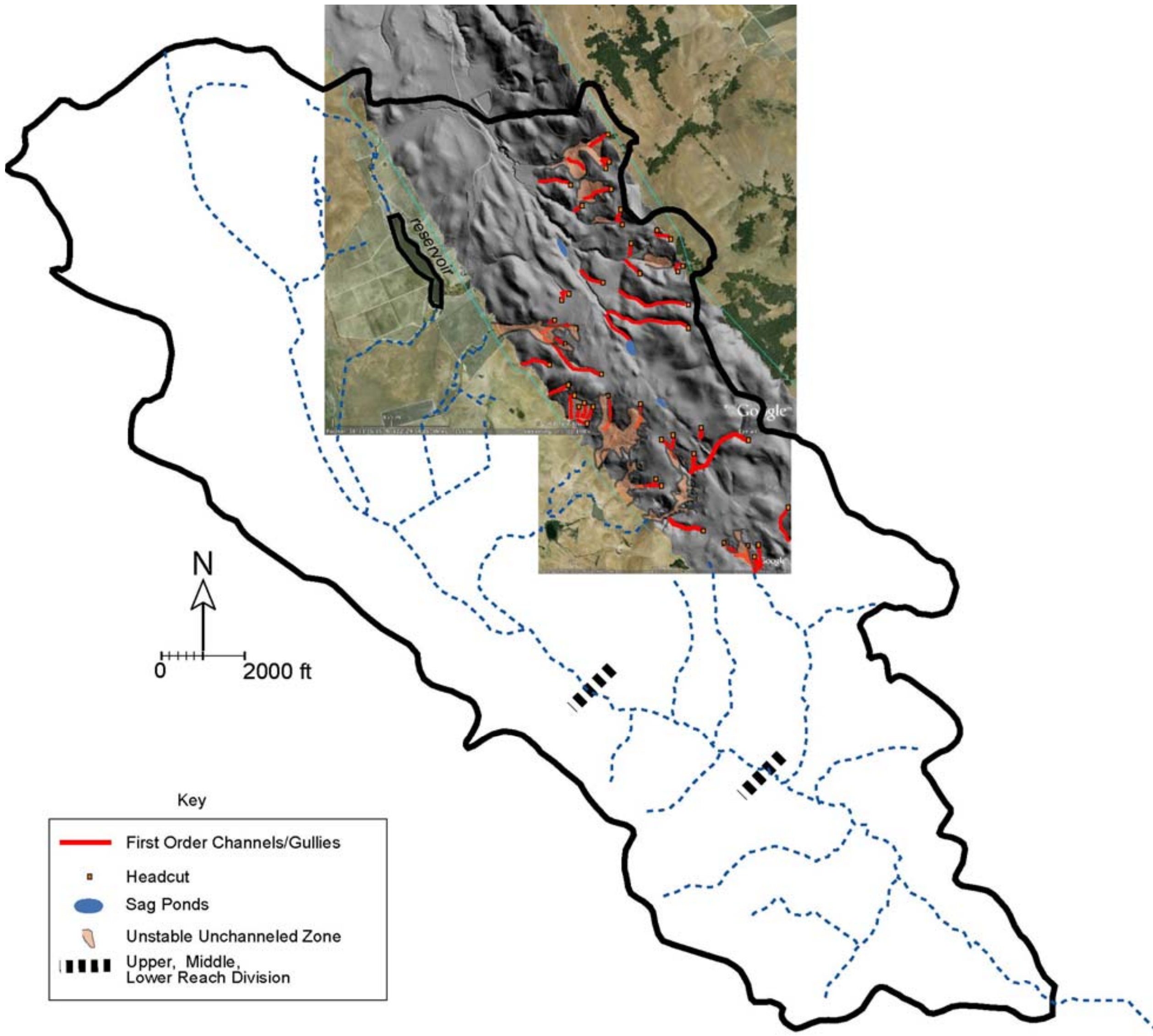
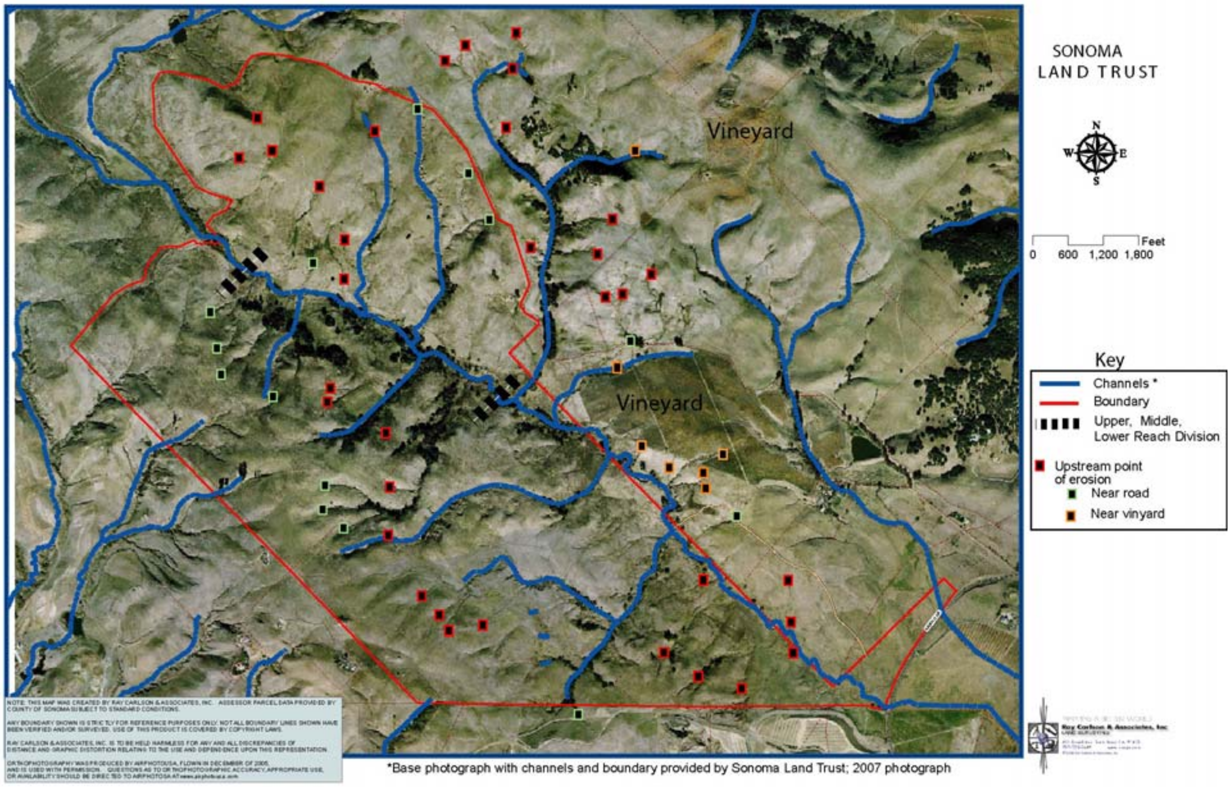


Figure 6. Sediment Source Areas Along Rogers Creek Fault Zone. Fault zone is indicated by grey-scale color.



*Base photograph with channels and boundary provided by Sonoma Land Trust; 2007 photograph

Figure 7. Preliminary Map Showing Locations of the Upstream-most Point of Active Erosion. Potential linkages between tributary erosion and land uses such as roads and vineyards based on aerial photo should be field verified.