ARROYO DE LA LAGUNA
REACH-BASED GEOMORPHIC EVALUATION

NOVEMBER 2023

PREPARED BY
San Francisco Estuary Institute

IN PARTNERSHIP WITH
Alameda County Flood Control and
Water Conservation District, Zone 7

FUNDED BY
San Francisco Bay Water Quality
Improvement Fund, EPA Region IX

SFEI CONTRIBUTION #936
NOVEMBER 2023
A PRODUCT OF **PREPARING FOR THE STORM**

SUGGESTED CITATION

Pearce, S, Beagle, J, McKnight, K, Whipple, A 2023. *Arroyo de la Laguna: Reach-based Geomorphic Evaluation.* Prepared for the US Environmental Protection Agency's Water Quality Improvement Fund. SFEI Publication #936. San Francisco Estuary Institute, Richmond, CA

COVER PHOTO

View looking downstream, Arroyo de la Laguna, Reach 5, Sarah Pearce, SFEI

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SAN FRANCISCO ESTUARY INSTITUTE PUBLICATION #936

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INTRODUCTION

The Alameda County Flood Control and Water Conservation District, Zone 7 (hereafter "Zone 7 Water Agency" or "Zone 7") is one of 10 active zones in the county. Zone 7 is a water wholesaler, in addition to providing flood protection services and groundwater management. The Zone 7 service area encompasses the cities of Livermore, Pleasanton, Dublin, and parts of the Dougherty Valley (unincorporated Alameda County).

The Agency owns 37 miles of channel in the Livermore-Amador Valley (Valley), and increasingly must consider not only flood protection, but also overall stewardship of the channels, including habitat value, water quality, erosion control, and overall downstream effects. The largest channel, Arroyo de la Laguna (ADLL), drains the entire Livermore-Amador Valley, and thus integrates and responds to the collective changes in land and water management that influence water and sediment delivery to the network of channels in the Valley. It is important to note that ADLL has mixed ownership, with a small portion owned by Zone 7, but with many other owners including many private land owners. As population has grown, many anthropogenic modifications to the drainage network have occurred to allow for agriculture and urban development, such as ditching and rerouting of streams, and changing the Valley's ability to sink and store flood flows. In response, beginning well over 100 years ago, ADLL has been adjusting its channel morphology, and is still adjusting today.

Problem statement: The reach of ADLL between the Arroyo Del Valle confluence (at the Interstate 680 crossing) and Verona Road is currently experiencing significant changes to it's channel morphology, namely incision and widening, leading to bank erosion and bank failures. Many of the parcels adjacent to the stream channel are experiencing loss of property and damage or loss of some bank-top structures. The complex history of this reach makes it difficult to determine the current and future condition and functioning. In an effort to understand the ADLL geomorphic processes and channel evolutionary pathway, Zone 7 has partnered with SFEI to create this Reach-based Geomorphic Evaluation report that will serve as a reference for the historical, current, and likely future condition of the reach, and will provide broader context to inform decisions about potential restoration projects.

View looking downstream, Arroyo de la Laguna, Reach 5 • *Sarah Pearce, SFEI*

ADLL provides a unique challenge; because of the channel's location at the downstream end of the Valley, Zone 7 is viewed by some a as the responsible agency for managing the stream corridor. However, as noted above, Zone 7 only owns a small number of parcels along the reach, and can only access and maintain the channel through limited easements. Through it's Stream Management Master Plan (SMMP) which is currently being superseded by a new Flood Management Plan, Zone 7's mission addresses the challenges of balancing flood protection with water supply, water quality, habitat and environment, and recreation and trails objectives for the Valley. Given the disconnect between stewardship and ownership, Zone 7 wishes to better understand the geomorphology of this reach, so that future management decisions can be better informed, and innovative solutions can be enacted that are appropriate for the channel's natural tendencies while also providing multiple benefits.

This report .is intended to assist the Valley community, including its land owners and stakeholders, in making informed management decisions within ADLL based upon an understanding of the channel history, process-based channel response, current channel evolutionary phase, and likely future response, reach by reach. To accomplish this goal, the report contains:

- an overview description of the study area and the channel
- a summary of historical changes to the Valley and to the channel, and the resulting
- channel response, and
- detailed sections for each individual reach that describe current channel features, evolution, processes, and the likely future condition, including recommendations for future management.

This report synthesizes very limited field observations (made in the fall of 2018) and more extensive previous work in the study area. It builds on multiple years of research and investment by Zone 7 and others in understanding the physical characteristics and processes of the watershed, and on upstream and downstream reaches of ADLL. Still, though the assessments and recommendations proposed in this report draw on years of work and relationships, they are to be considered best professional judgement, and additional studies are needed to validate and build upon the ideas presented here.

Finally, while this report aims to help improve management of ADLL itself, this should not be decoupled from the need for continued upstream management of water and sediment, especially with increased urbanization and the changing hydrologic regimes predicted with climate change. This report is part of a larger partnership between Zone 7, SFEI, EPA Region 9, and local landowners, which aims to analyze the flow of water and sediment through the Valley before it reaches ADLL--to understand the potential to sink and store flood flows flows through optimal placements of green infrastructure, and to understand the impact of widening certain stream channels, reconnecting channels to their floodplains and using riparian trees as a part of managing sediment upstream.

While the predictions of future evolution are based upon the current flow regime, we know that the hydrologic future in these watersheds are uncertain, largely due to climate change but also due to continued development. As the Valley continues to develop, increased impervious surfaces will mean that there will be less availability for groundwater recharge, leading to more runoff, and increased wintertime base flows and peak flows. It is possible then that ADLL will continue to adjust to accommodate these increased flows, continuing the cycle of bank failures, widening, and incision. Urban greening is part of the solution to mitigate for the increased runoff and discharge projected to be delivered to the ADLL channel. This will need to be a regionally coordinated and ubiquitous effort across the Valley to have a significant impact which we aim to quantify. For more information, see www.sfei.org/preparingforthestorm.

STUDY AREA

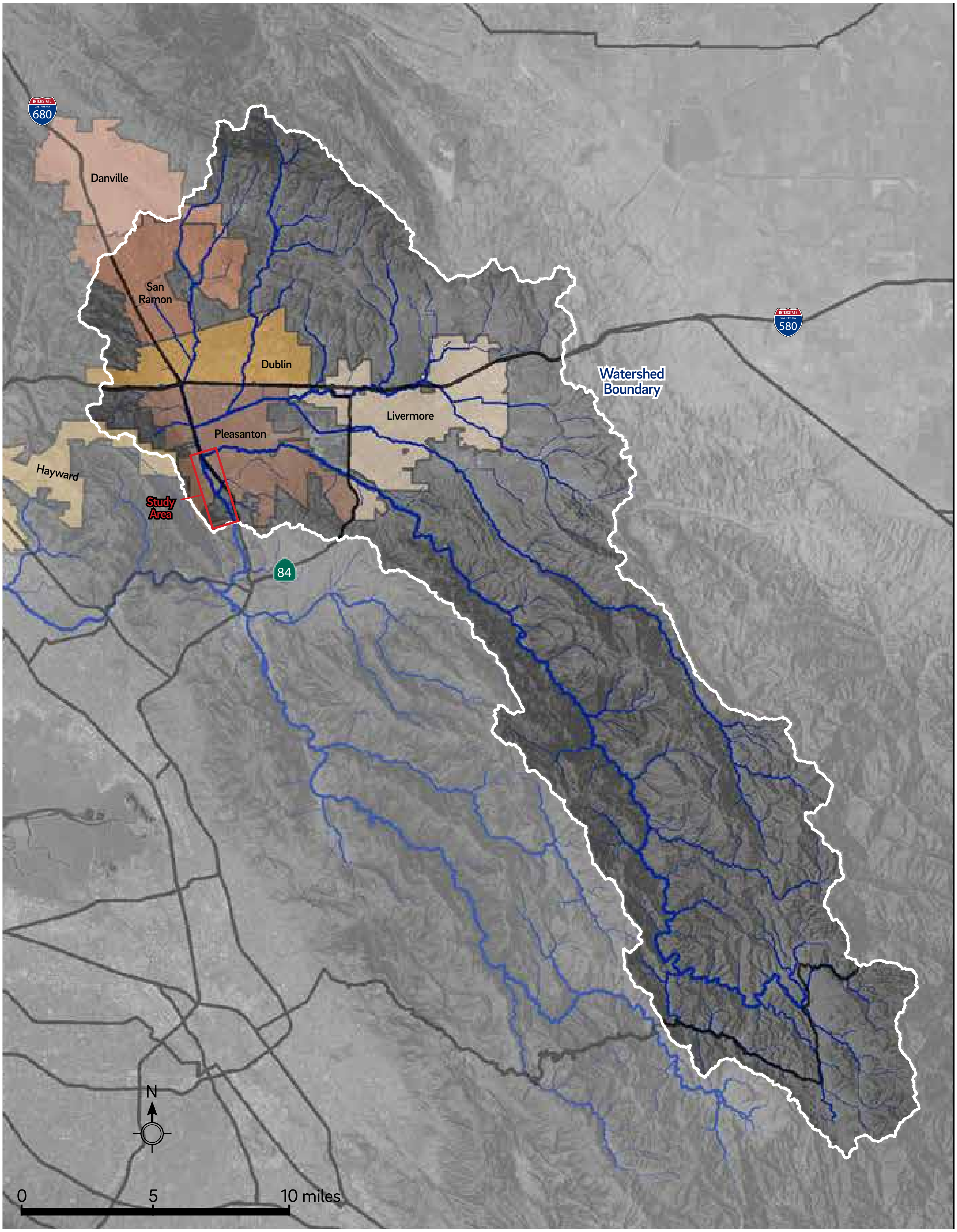
The Livermore-Amador Valley is the broad lowland area containing the cities of Pleasanton, Livermore, Dublin and San Ramon. Numerous streams flow into the Valley from the adjacent hills, however the Valley is drained by a single channel, the Arroyo de la Laguna (ADLL), that flows southward to Niles Canyon, into the Alameda Creek Flood Control Channel, and ultimately out to the San Francisco Bay. At the downstream end of this Study Area, the USGS gage at Verona Road measures the flow from a watershed area of 1,044 km^2 (Figure 1). The physical characteristics of the Valley, as well as its history of change, including population growth, changing land uses, increase in impervious surfaces, and draining and ditching of the Pleasanton Marsh Complex, contribute to the condition and functioning of ADLL today. In this section we provide an overview of the physical setting and characteristics of the Valley, as it pertains to ADLL. A more detailed description of the Valley, its streams and habitats, and its complex history can be found in *Alameda Creek Watershed Historical Ecology Study* (Stanford et al., 2013), in *Landscape Scale Management Strategies for Arroyo Mocho and Arroyo Los Positas: Process-based Approaches for Dynamic, Multi-benefit Urban Channels* (Beagle et al., 2014) and in *A Sediment Budget for Two Reaches of Alameda Creek* (Bigelow et al., 2008).

Geology

The Livermore-Amador Valley is a fault-bounded down-dropped tectonic basin bordered by the East Bay hills, the Altamont hills, and the Diablo Range. The faults follow the regional northwest-southeast orientation, and generally display right-lateral movement. The San Ramon segment of the Calaveras fault forms the western boundary of the Valley; it currently appears to have low slip rates, however there is evidence of a Magnitude 6.9 earthquake with surface rupture in 1861 (Rogers and Halliday, 2018). The northern watersheds are underlain by the fine-grained Great Valley Sequence, which largely produces clay soils that historically supported wetland habitat (Stanford et al., 2013). In contrast, the southern watersheds are underlain by the Franciscan Formation, which produces coarser, more well-drained soils (Stanford et al., 2013). The southern side of the Valley is characterized by coarse alluvial fans with broad braided channels. Sediment from the numerous streams draining the hillslopes slowly built the alluvial Valley floor. The Valley floor is comprised of a thick accumulation of Pliocene and later sediment with alternating layers and lenses of coarser and finer grain sizes (Stanford et al., 2013). The west side of the valley is bordered by the steep Pleasanton Ridge, which has a number of mapped Pleistocene and younger large landslide complexes which conceal the trace of the Calaveras fault (Majmundar, 1995), and likely have impacted surface drainages through time.

Precipitation

In general, the Livermore-Amador Valley is in the rain shadow of the East Bay hills, and thus receives less rainfall than many locations further west. The amount of precipitation that is


680
Danville
San Ramon
Dublin
Livermore
Pleasanton
Hayward
Study Area
580
Watershed Boundary
84
N
0
5
10 miles

received across the Valley is quite variable, decreasing from west to east. For instance, for the dry period WY 2011 to 2015, the Las Trampas gage (https://raws.dri.edu/cgi-bin/rawMAIN.pl?caCTRA) on the western side of the Valley received an annual average rainfall of 22.0 inches, Livermore Municipal Airport (NOAA) in the middle of the Valley received 11.4 inches, and the Altamont gage (https://raws.dri.edu/cgi-bin/rawMAIN.pl?caCATT) on the eastern side of the Valley only received 7.9 inches (Pearce et al., 2015). However, in average or wet years the precipitation totals can be much higher. For instance, the WY 2017 total for the Danville Library gage was 42.1 inches (http://cdec.water.ca.gov/snow_rain.html). The long-term Valley floor precipitation is best characterized by the Livermore Municipal Airport gage (Livermore gage 044997; WRCC, 2015), which has an average annual precipitation of 15 inches.

Historical Habitat

Historically, the broad and braided Arroyo Mocho and Arroyo Del Valle channels flowed east to west across the Valley, losing definition and sinking into the alluvium before reaching the Pleasanton Marsh Complex (see Beagle et al., 2014 for a map of the Valley habitat). They carried coarse bedload and developed coarse alluvial fans. In contrast, the smaller streams draining the northern watersheds were typically single thread, and lost definition as they flowed out into the Valley. In addition to the numerous largely discontinuous stream channels, the Valley also had two large wetland areas: the Pleasanton Marsh Complex in the west, and the Springtown Alkali Complex in the east. In total, the Valley contained 19,600 acres of seasonal wetland habitat, 600 acres of perennial wetland habitat, and 2,000 acres of willow thicket or swamp (Stanford et al., 2013). The Pleasanton Marsh Complex consisted of intermixed areas of springs, open water, seasonal wetlands, freshwater marshlands, and extensive willow thickets (Stanford et al., 2013). In addition to the Marsh Complex, the Valley supported large areas of grassland habitat across the Valley floor, with only a few small oak groves that were characteristic of other valleys in the Bay Area.

Current Condition

Currently the Valley is home to approximately 270,000 people in the cities of Livermore, Pleasanton, Dublin, and San Ramon (EcoAtlas, 2018 using data from the Fire and Resource Assessment Program of CalFire). Although most of the Valley is urbanized residential and commercial areas (with approximately 40% impervious cover), some portions of the Valley remain as pastureland, while others are now vineyards. The channel network largely consists of natural channels in the hills and channelized trapezoidal flood control channels across the Valley floor. Some of the channels are incised, while others are aggrading and losing capacity. Other reaches, primarily in the location of the historical marsh complex, or where channels were straightened, have chronic bank failure (slumps and rotational failures) during wet years due to the clay composition of their banks. The Del Valle dam was constructed in 1968 on the Arroyo Valle channel, and now regulates flow from approximately 36% of the watershed draining to ADLL at Verona Road.

Figure 1. Arroyo de la Laguna Reach-based Geomorphic Evaluation Study Area, showing Arroyo de la Laguna and the contributing watershed area of the Livermore-Amador Valley.

GEOMORPHIC PRIMER

Stream channels transport water and sediment sourced from their contributing watershed. Their morphology (width, depth, slope, grain size, etc) adjusts to most efficiently transport that water and sediment downstream, without major changes in stream power along the channel length. Following from Lane (1955), geomorphic process in stream channels can be summarized as the idea that streams tend to balance discharge, slope, sediment grain size, and sediment load to form a state of dynamic equilibrium. A perturbation that alters any of these factors will change the balance, and will result in measurable changes in the channel morphology.

Following on from this general concept, Channel Evolution Models (CEM) are conceptual models that have been developed to describe the sequence of geomorphic changes that occur in response to perturbations such as a change in the supply of water or sediment (Schumm et al., 1984; Simon and Hupp, 1986; Simon, 1994; Doyle and Shields, 2000). Perturbations that change water or sediment supply can include rapid urbanization, channelization, deforestation/wildfire, or even tectonically-driven changes in uplift or base level (the level at which its distal portion joins a major body of water (Leopold et al., 1964)). Typically the channel responds by altering the geomorphic processes occurring in the channel, thus altering the channel shape, to return the balance of even stream power and efficient water and sediment transport. However, the channel is not able to instantaneously adjust its entire length, but instead it will typically adjust in a progressive manner along its length through time. For instance, if a channel begins to incise, a wave of incision will typically occur, moving up or down the channel from the perturbation. Channel adjustment can also be phased, with different portions of a channel in different phases of adjustment, potentially adjusting at different rates. These processes continue until dynamic equilibrium and floodplain formation is achieved unless some other perturbation disrupts the process of evolution before it is completed. For example, a channel that is progressing towards a new morphology due to a perturbation caused by a rapid period of upstream land use change could be interrupted by stochastic events such as a 500-year storm, a wildfire, a massive landslide, or an earthquake. These interruptions may cause the channel evolution to be reset to a different phase, or may just cause a temporary pause in the overall evolution.

CEMs are useful for management decisions because they provide a framework for understanding past and present channel process, and allow for prediction of future probable channel response. Later sections of this report will describe the ADLL channel history, current morphology, and predicted future evolution using the CEM framework. However it is important to note that despite their ability to predict probable channel response, CEMs do not predict the amount of time needed for a channel to return to equilibrium because channel response is typically punctuated rather than gradual and can also be interrupted temporarily in response to stochastic events.

Here we describe the six stages of evolution from Doyle and Shields (2000), with an additional seventh stage added by Thorne (1999), as described in Bigelow et al. (2008) **(Figure 2).**

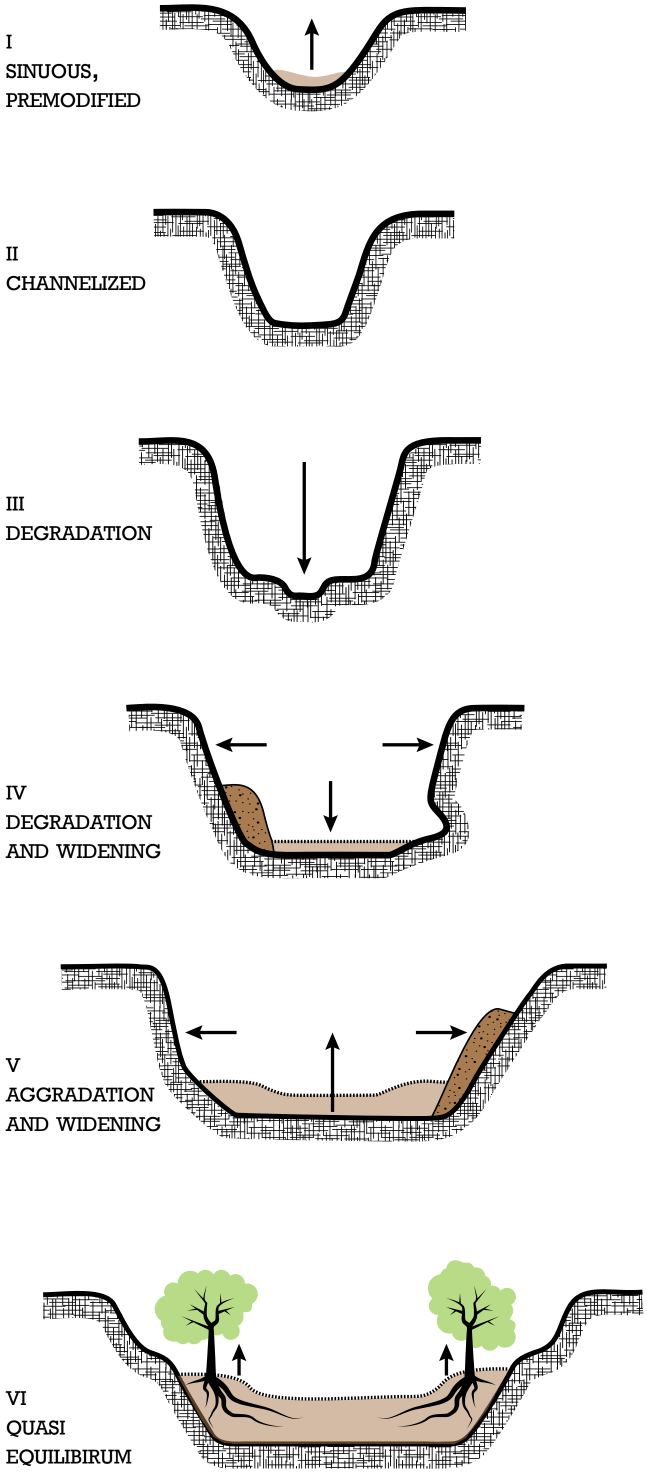


Figure 2. Channel Evolution Model of Doyle and Shields (2000) modified from Simon (1994).

Stage I- Pre-disturbance, includes the premodified channel, representing a channel that is geomorphically stable and in dynamic equilibrium.

Stage II- Disturbance, represents the time period during and immediately after the disturbance occurs.

Stage III- Incision, is when the channel downcuts due to an excess of sediment-transporting capacity relative to sediment supply. This causes steep banks that are at the angle of internal friction, but not yet failing.

Stage IV- Widening and Incision, marks the switch from channel incision to widening and incision. The steep banks are actively failing in this stage. As the channel widens, the flow depth, shear stress, and sediment transport capacity is reduced, and thus some sediment is deposited.

Stage V- Aggradation, is when bed aggradation and the formation of a depositional surface along the banks occurs. When the channel becomes so wide that it cannot transport failed bank material, that sediment begins to buttress the toe of the bank, protecting the bank from further failure. In addition, vegetation grows in this sediment, further speeding bank recovery.

Stage VI- Dynamic Equilibrium, marks a reduction in bank heights due to aggradation, deposition on bank surfaces, and establishment of woody vegetation. The channel thalweg meanders and further reduces channel gradient.

Stage VII- Floodplain Formation, represents dynamically stable morphology with the creation of a proto-floodplain surface.

Other Studies

A number of studies have been conducted on the channel network, and various aspects of its sediment transport and geomorphic functioning. This report draws upon the data, analysis and findings of many of these previous reports to support the current and future description of each reach and the recommendations that are put forward. The pertinent studies include:

> The ***Zone 7 Water Agency Geomorphic and Sediment Transport Evaluation*** (Ayres Associates, 2001) looked at sediment supply, in-channel storage, and channel stability. They identified the reach of ADLL from Interstate 680 downstream to Sunol as experiencing erosion. They recommended a number of measures and sediment management tools to better control the sediment transport through the channels.
>
> ***Arroyo de la Laguna Initial Geomorphology Investigation Draft Report*** (Mahacek, 2007) investigated the geomorphology of the reach both through existing reports and field investigations. This study determined that the channel has experienced vertical and lateral channel instability during the historic period of record (approximately 100 years).
>
> ***A Sediment Budget for Two Reaches of Alameda Creek*** (Bigelow et al., 2008) included the ADLL from Verona downstream to the confluence with Alameda Creek in Sunol. While this study provided estimates of sediment erosion from the downstream reach, it also developed the history of evolution and incision using detailed field observations, channel cross sections and longitudinal profiles. It also utilized channel evolution models to describe the history of channel change through time.
>
> ***Watershed Assessment of River Stability and Sediment Supply, Arroyo de la Laguna: Castlewood Drive to Verona Road, Pleasanton CA*** (Stantec, 2011) included a detailed study on erosion and sedimentation issues in the Castlewood to Verona reach, to support Zone 7's StreamWISE program. They collected very detailed geomorphic data on the reach using the EPA's Watershed Assessment of River Stability and Sediment Supply (WARSSS). The report provides detailed mapping and data including a bank stability analysis and a field surveyed longitudinal profile that helped to elucidate patterns within the reach.
>
> ***Sediment supply, deposition and transport in the Flood Control Facilities of Arroyo Mocho and Arroyo Las Positas from 2006-2014*** (Pearce et al., 2015) utilized field sampling of sediment loads and generic erosion potential estimates of sediment yield from ungaged watersheds to create a sediment budget for the watershed upstream of the USGS gage at Verona Road. Although the primary focus was the upstream Arroyo Mocho watershed, an estimate of annual average sediment yield from the ADLL reach between the confluence of Arroyo Mocho and Alamo Canal and ADLL at Verona was made. An average annual 3,100 metric tonnes of sediment is estimated to be contributed from this reach, corroborating the continued incision and bank erosion that was observed during fieldwork to support this geomorphic evaluation.

ARROYO DE LA LAGUNA CHANNEL HISTORY AND CURRENT CHANNEL MORPHOLOGY

Channel History

Before European contact, the groundwater and surface water of the Livermore-Amador Valley drained to the Pleasanton Marsh Complex, a 2,600 acre marsh complex consisting of open water ponds, freshwater marsh, and dense willow thickets (Stanford et al., 2013) (Figure 3). The marsh complex trapped sediment delivered from the upstream watershed, and slowly released water downstream. The head of the ADLL channel started at the open water area within the complex. As it drained the marsh complex (and thus the entire Livermore-Amador Valley), ADLL flowed south through a dense willow thicket. Stanford et al. (2013) describes the historical channel as a broad, flat, multi-thread perennial system that had a shallow gradient (0.2%), a clay bed, and flowed through a narrow valley thick with woody riparian vegetation. An historical General Land Office survey in the summer of 1853 described ADLL near Verona as "main branch (23.1 ft) wide, copious stream, enough to turn mill, sycamore, thicket in creek valley" with several "bayous" (Stanford et al., 2013). An 1851 observation made between Highway 680 and Bernal described the thick woodland along the channel that was "thick as hair" (Stanford et al., 2013). During this time, the ADLL channel downstream from the marsh complex represented CEM Stage I (Pre-disturbance), with a channel pattern that was wide and shallow, with multiple threads (Figure 4).

In the early 1800s the Valley was primarily used for grazing, however by the late 1800s agriculture, namely grain, became the dominant land use. In order to create more arable land, by the 1890s and 1900s, the marsh complex had been drained by constructing a network of ditches through the former wetlands and by pumping groundwater (Stanford et al., 2013). This artificial connection, along with the channelization of previously

Figure 3. Historical extent of the Pleasanton marsh overlaid on modern aerial imagery. This graphic shows the three main habitat types that made up the Pleasanton marsh: a perennial pond (dark blue), freshwater marsh (light blue), and willow thickets extending into seasonally inundated wetlands (green). At its most inundated, the marsh would have covered much of modern day Pleasanton.

discontinuous tributaries in the Valley, rapidly increased the water and sediment supply to the downstream ADLL channel. In addition, the Spring Valley Water Company was also using ADLL to transport water downstream to Sunol Valley, increasing the flow. The company also enlarged and cleared the lower portion of the channel, likely also contributing to the channel disturbance. This time period represents CEM Stage II (Disturbance).

In response to the increased discharge, and thus stream power, the channel began a period of rapid incision, representing CEM Stage III (Incision). Stanford et al. (2013) cites evidence from Williams (1912) that describes channel incision of 3 feet in 10 years since the clearing of the Laguna channel.

After the initial rapid incision, during the 1920s-1940s, the channel continued to adjust by smaller amounts of continued incision, slightly widening and creating some small deposits of sediment. This represents CEM Stage IV (Widening and Incision). Today, we find 1940s vintage trees on previous floodplain surfaces that indicate that there was some channel stability during this time.

The historic series of floods of the 1950s (that had recurrence intervals of 40 to 120 years at the Alameda Creek at Niles gage) deposited significant packages of coarse material across the channel bed and reworked the floodplain surfaces. These unconsolidated fill deposits represent a new perturbation within the channel, represented by CEM Stage II (Disturbance). The extent of the fill deposits appears to increase in the downstream direction.

Following the 1950s floods, the channel quickly cut down through the fill deposits, leaving only remnants of those deposits on channel margins today. This represents CEM Stage III (Incision), and is recorded by the upstream movement of knickpoints on successive surveyed longitudinal profiles. We find that this headward progression of a knickpoint occurred over 30-40 years after the 1950s floods. But instead of the channel simply incising through the 1950s flood deposits and then continuing on to Stage IV, the incision was exacerbated by the increased urban development in the Valley during the 1970s-1990s. The increased amount of impervious surface increased runoff, delivering significantly more water to the streams, and increasing stream power in ADLL. This drawn-out period of incision has caused the channel to deepen enough (often up to 5-10m below the Valley floor) to expose hardpan in some reaches. Hardpan is consolidated older fluvial deposits that are primarily fine-grained, but with some sand or gravel included that have undergone major wetting and drying cycles (often where historical marshes have been drained, oxidized, and compacted; the entire study area is within the historical footprint of the willow thicket and seasonally inundated wetland area of the Pleasanton Marsh Complex). We hypothesize that incision slowed once the hardpan was exposed, causing the channel to switch to a period of widening. However, with time the incision was able to cut through the hardpan and continued to incise, lowering the channel bed elevation and leaving the hardpan now typically 1-3m above the current channel bed.

The 1990s and 2000s were marked by continued incision and widening of the outer banks. In some locations the failure of the outer banks has been quite dramatic, contributing significant amounts of sediment directly into the channel, and threatening property and structures on the adjacent parcels. These threats are exacerbated because additional houses were built on the adjacent parcels during this period. The high flow events of 1997 and 1998 were likely responsible for significant localized change; inspecting the change that occurred between the 1993 and 2002 photographs on Google Earth (the only two available for that time period) shows significant change downstream of Bernal and at the S-curves (see Figures 12 and 16). Based upon the short section of longitudinal profile survey by Stantec (2011), we suggest that there are likely a number of small knick zones that exist along the channel length that represent continued channel adjustment that will likely continue into the future.

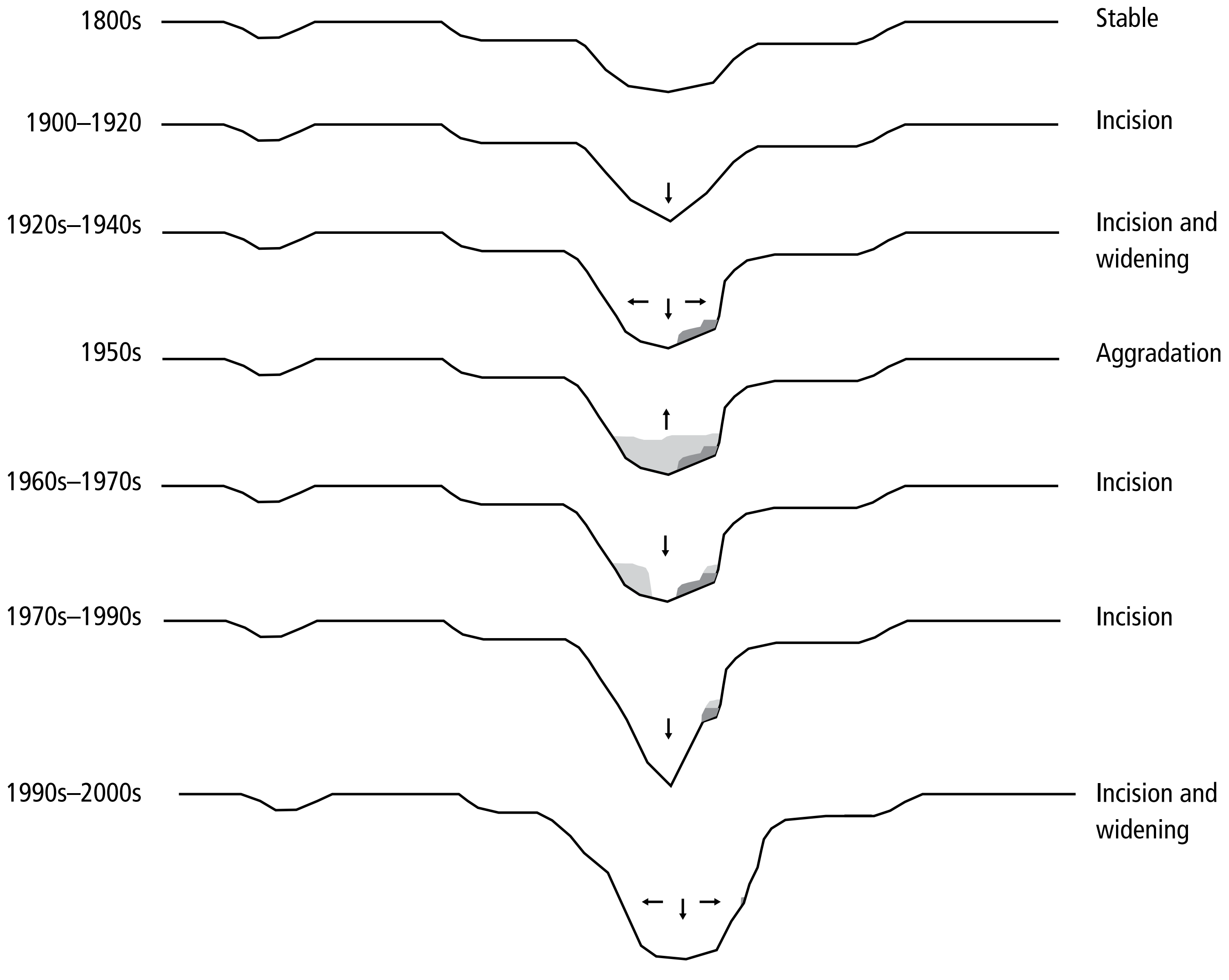


Figure 4. Conceptual cartoon illustrating the generalized response of ADLL through time (adapted from Bigelow et al., 2008). Also see summary Figure 55.

ADLL Today

Today the reach of ADLL from Verona upstream to Interstate 680 is in a state of complex response, due to its history and continuing changes in water and sediment delivery from upstream. ADLL in the Study Area flows through residential areas, including some large and high-value properties, alongside an active railroad line, along the Castlewood Country Club golf course, through Zone 7 property with an adjacent maintenance road, and along a City of Pleasanton dog park and open space property. Although the Study Area is fairly suburban, much of the channel length has an adjacent land use that could be viewed as an opportunity within the context of a long term restoration plan.

Although we observe different CEM Stages within the Study Area (described below), as a whole the Study Area is currently in CEM Stage IV (Widening and Incision). The variation in evolutionary stage is likely attributable to multiple factors, including the typical geomorphic progression of a channel in phases, as well as the length of time since passage of the headcut(s), purposeful bank hardening, hard structures (e.g. weirs, riprap across the bed) on the bed, exposure of hardpan and other geologic units, and the effect of bridge footers.

The extended period of incision (from the 1970s through to today) has significantly deepened the channel causing the current channel bed to be anywhere between 5 to 12 m below the valley floor elevation. Often the outer banks are vertical or near vertical (Figure 5). This incision has exposed various geologic units in the banks and on the bed, whose properties are likely having an effect upon the style and rate of erosion. Observation of failing outer banks can be made throughout the reach (Figure 6). Some locations fail as block failures, with blocks of material calving off. In some locations, the bank material appears to be weathering and eroding as dry ravel; this material likely collects on the banks/at the base of the banks until a high flow is able to transport it downstream. In addition, some locations of rotational failure of the banks (e.g., bank slumps) are observed. Trees rooted at the top of the banks are providing root strength and soil stability, but many have been recruited into the channel after the banks have been undercut (Figure 7). As the outer banks continue to fail, property along the top of bank is eroded away, in some cases eroding backyards, and in other cases putting houses, fences, decks, sheds, tennis courts, swimming pools, and railroads in danger. An analysis of structures located within 2.5 times the local bank height from the top of bank reveals that 5 primary residences, 8 secondary

Figure 5. Example reaches with near vertical banks.

Figure 6. Examples illustrating block style failure; dry ravel style failure; bank slump failure.

Figure 7. Oak tree in danger with exposed roots and undercut bank; tree recently recruited into channel.

structures, and four backyard amenities (pool, shed, fountain, tennis court) are within this distance. Four roads cross the channel within the reach: Verona Road, Castlewood Drive, Bernal Avenue, and Highway 680 (forming the upstream boundary of the Study Area). All of the bridges fully span the channel, but the Bernal Avenue bridge has earthen footers that impinge within the channel cross section.

For most of length, the channel is narrow and deep, indicative of the history of incision that has occurred. The channel is a mix of pool/riffle morphology and deep pools or glides. Most of the channel is bed is composed of fine gravel, sands and silts, although some locations have larger boulders of either failed bank material or displaced riprap. The upstream portion of the study reach has incised and exposed a layer of hardpan (indurated gravels in a finer matrix) (Figure 8). Due to continued incision, the hardpan is often found approximately 1-3 m above the current bed elevation. In addition, the incision has exposed pockets of blue clay material at the base of the banks, likely deposited in the historical Pleasanton Marsh Complex. There are remnant deposits of sediment from the series of 1950s floods that exist 2-3 m above the bed elevation (Figure 9). The channel is currently depositing sediment in bars that are between 0.5 and 2 m above the bed elevation.

In many locations, landowners have attempted to harden the channel banks to prevent or slow erosion. Riprap is the primary material used, although one section has articulated concrete mat material (see Reach 1). Placement ranges from a narrow line of riprap placed at the toe of the bank to coverage of the entire bank on both sides of the channel. Riprap has also been placed on the bed of the channel to cover an exposed sewer pipeline crossing.

(left) Figure 8. Exposed hardpan (Reach 4).

(right) Figure 9. Depositional feature, likely the 1950s flood package, and detail of the deposit.

REACH ANALYSIS

In addition to previous knowledge of the creek and a number of reconnaissance visits, the entire length of the Study Area was observed by the field team on July 10th and 12th, 2018. Water levels in the creek on these days were representative of typical summertime low flow conditions. The objective of the two field days was to make observations of the creek in order to define distinct reaches, characterize the current and likely future processes occurring within those reaches, and analyze the risks, opportunities, and management recommendations specific to each reach to support this report.

The following criteria were established to define reaches:

- A change in the dominant visible geomorphic process currently occurring,
- Significant differences in channel pattern or morphology,
- Significant differences in bank height, erosion, or hardening,
- Breaks in slope as evidenced in longitudinal profiles or visible in the field.

Based upon these criteria, the study area was divided into six reaches, with Reach 1 at the downstream end of the Study Area, and Reach 6 at the upstream end (Table 1 and Figure 10).

Table 1. Reach locations and distances.

Reach	Downstream boundary	Upstream boundary	Reach distance (m)
1	Verona Road	Slightly upstream of a small tributary confluence on the left bank in the golf course	1,250
2	Slightly upstream of a small tributary confluence on the left bank in the golf course	Downstream edge of full riprap banks, approximately 50 m downstream of Castlewood Drive	165
3	Downstream edge of full riprap banks, approximately 50 m downstream of Castlewood Drive	Upstream edge of full riprap banks	250
4	Upstream edge of full riprap banks	Confluence with Line B.2.1	475
5	Confluence with Line B.2.1	Bernal Avenue	1,830
6	Bernal Avenue	Interstate 680	735

Figure 10. Location of the six reaches within the Study Area. Flow is from north to south.

In the section below, we begin at the downstream end of the study area and move upstream, describing each reach in detail, including the observed current channel evolutionary stage and the hypothesized likely future stage, propose additional studies or data that could be collected, and describe the risks, opportunities and management recommendations that exist. Representative channel cross sections along with a field photograph of the cross section location are shown to illustrate conditions within each reach. Figure 11 shows a summary of the entire Study Area, but each reach section should be referenced for additional detail.

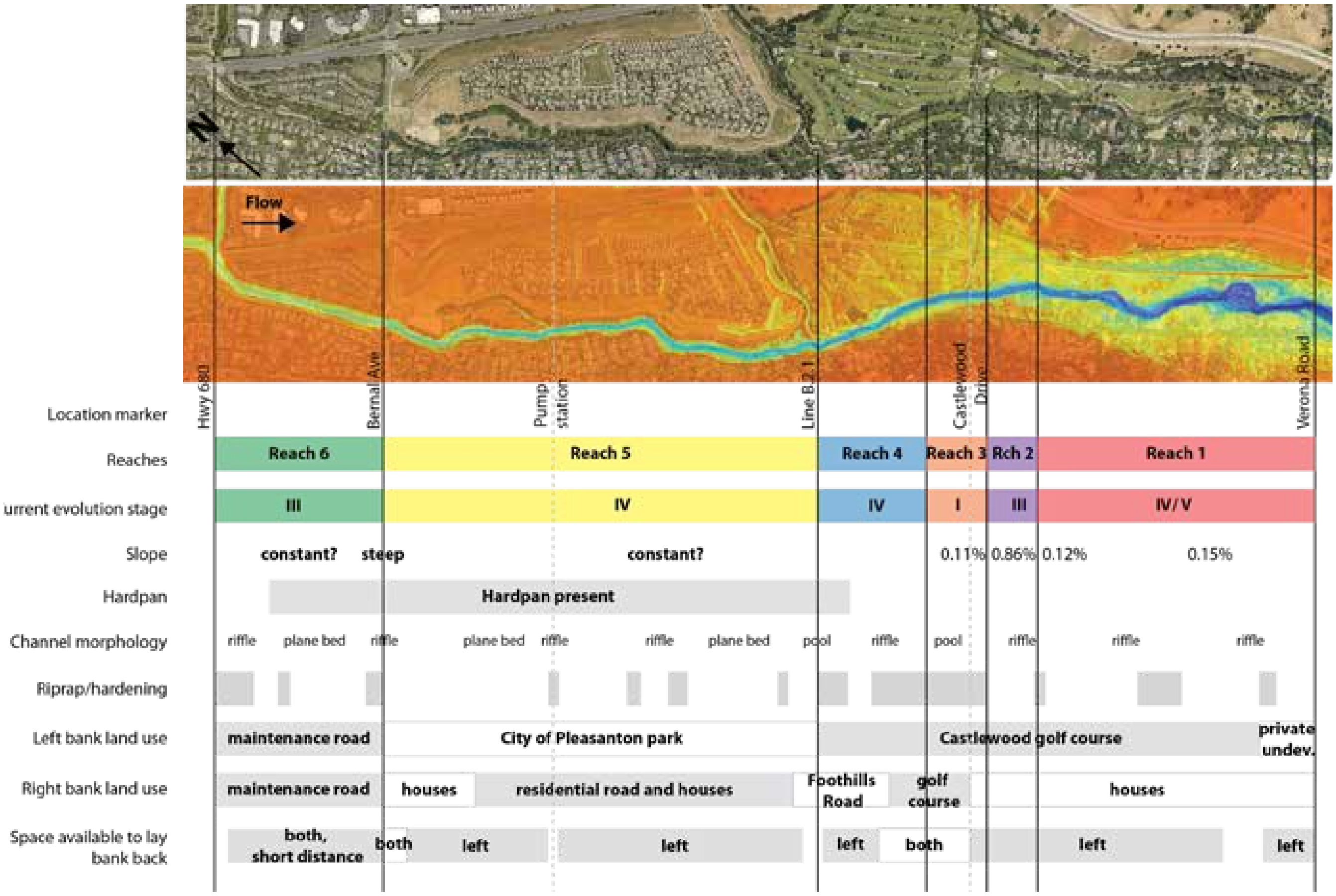


Figure 11. Summary graphic of the Study Reach, showing the aerial photo, LiDAR data, and location of important features throughout the reach. Flow is from left to right. Warm colors on the DEM represent high elevations, while cool colors represent low elevations. See sections below for additional detail. Actual channel bed slope values for the entire reach would be valuable; unfortunately a field-surveyed longitudinal profile only currently exists for Reaches 1 and 2.

REACH 1

Description

Reach 1 is the most downstream reach of the Study Area, extending from Verona Road upstream to approximately 1,250 m upstream of the confluence of a small tributary drain entering on the left bank in the golf course. This reach has two distinct morphologies within the reach: erosive S-shaped meander bends and relatively straight but still erosive reaches in between the meander bends.

The S-curve meander bends represent nodes of widening and inset floodplain building. As the channel enters these nodes, it changes from single thread to multi-thread, and often becomes coarser, supporting long riffle lengths. These areas of the channel have vertical or near vertical outer banks that fail both as block failures and as dry-ravel failures. The channel meander bend is actively migrating, compressing in a downstream direction. Comparison of a time series of aerial photographs clearly illustrates the changes that have occurred (Figure 12), indicating that the brunt of the erosional pressure has been directed at the downstream outer bend, where a house and a swimming pool are close to the top of bank. Because of Zone's 7's 2017 restoration and bank set-back project at 3 Verona, the downstream portion of the downstream S-curve location has been reconstructed, stabilized by willow and other riparian plantings, and has been holding sediment at the toe of the slope providing some protection. Because it is likely not economical to lay back the banks in locations with high-value real estate near to the stream, measures that focus upon providing stability at the toe of slopes (e.g. protection from scour during high flows, and protection from constant wetting/drying) should be considered. The outer banks are generally 7-9m high (with some locations 12 m high), so that when they fail, a significant amount of sediment is delivered directly into the channel. Field surveys by Zone 7 have been estimated that approximately 27,000 yds3 of sediment has been contributed from bank retreat at two properties in the downstream S-curve alone between 2005 and 2010. In addition, failures

Figure 12. Time series of aerial photographs illustrating the migration of the channel meander at the downstream S-curve.

have recruited many large riparian trees that were growing at the top of bank, and many more are currently on the verge of being recruited. Once the trees are in the channel as LWD, some become embedded, or partially buried by sediment, and act as small temporary grade control structures, that cause localized scour and deposition.

In addition to the active widening, these meander bend reaches also are characterized by active inset floodplain building (Figure 13). Wide areas of sand, gravel and cobble are being deposited between the actively migrating low-flow channels. These inset surfaces support growth of young (often <10 years old) woody vegetation (e.g. cottonwoods and willows). These growing inset floodplain areas appear to be very dynamic, and have complex flow dynamics and provide for complex habitat.

The channel bed riffles in this reach are visible on field-surveyed longitudinal profiles (Stantec, 2011) as steeper reaches, as compared to up and downstream reaches (Figure 14). It is not clear if the bed coarsening is due to deposition of transported bedload due to loss of stream power in the wider reach, or if the locally-sourced failed bank material is unable to be effectively transported, and thus acting as a "slug" of sediment.

The relatively straight reaches adjacent to the two S-curve nodes have tall vertical banks that are actively failing, and threatening many properties. A number of land owners in this reach have placed riprap, articulated concrete mats, or filter fabric to help stabilize the toe of the slope, with varying success (Figure 15). Limited indicators of downcutting were observed underneath the concrete mats. These straight reaches have a more shallow gradient than the adjacent S-curve reaches, and have a well defined pool-riffle sequence, with many low bar deposits. In addition, discontinuous remnant 1950s flood deposits are observed, which are coarse packages of fluvial material forming a surface approximately 2-4 m above the current channel bed. In places, a wider floodplain surface is developing, which is fairly ecologically complex, with a number of swales and young woody vegetation (e.g. cottonwoods and willows).

The current land use adjacent to channel is variable throughout the reach (Figure 16). In general the left bank is either Castlewood Country Club property (golf course) or undeveloped land. The right bank is largely residential properties. Specifically at the downstream S-curve, the left bank is primarily open space recently transferred to Zone 7 ownership and the berm for the BNSF railroad trestle.

Figure 13. Examples illustrating active inset floodplain building.

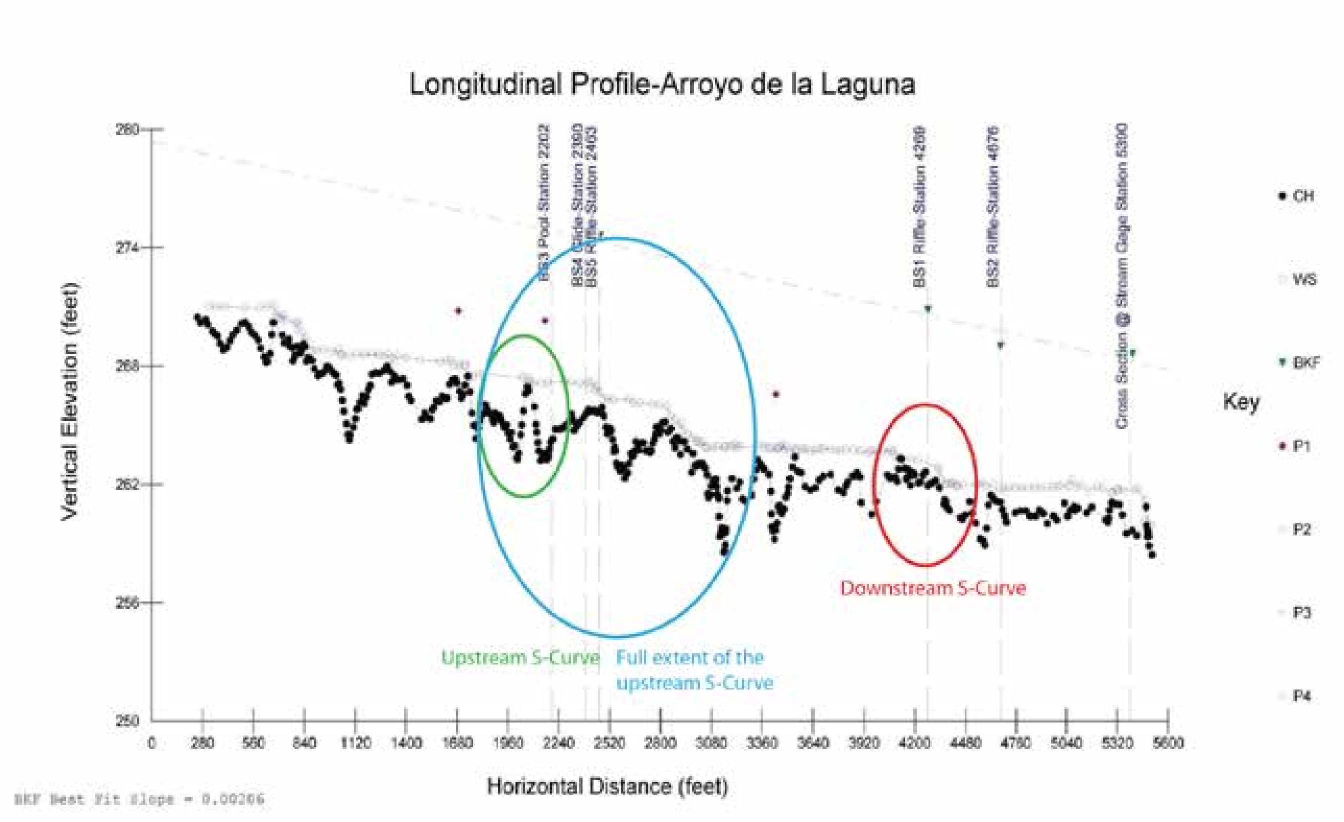


Figure 14. Field surveyed longitudinal profile (Stantec, 2011) showing the steeper gradient in the downstream S-curve (red oval). The upstream S-curve is shown in the green oval, with the larger extent of the S-curve shown in the blue oval, also displaying a steeper gradient.

Figure 15. Failing articulated concrete mat.

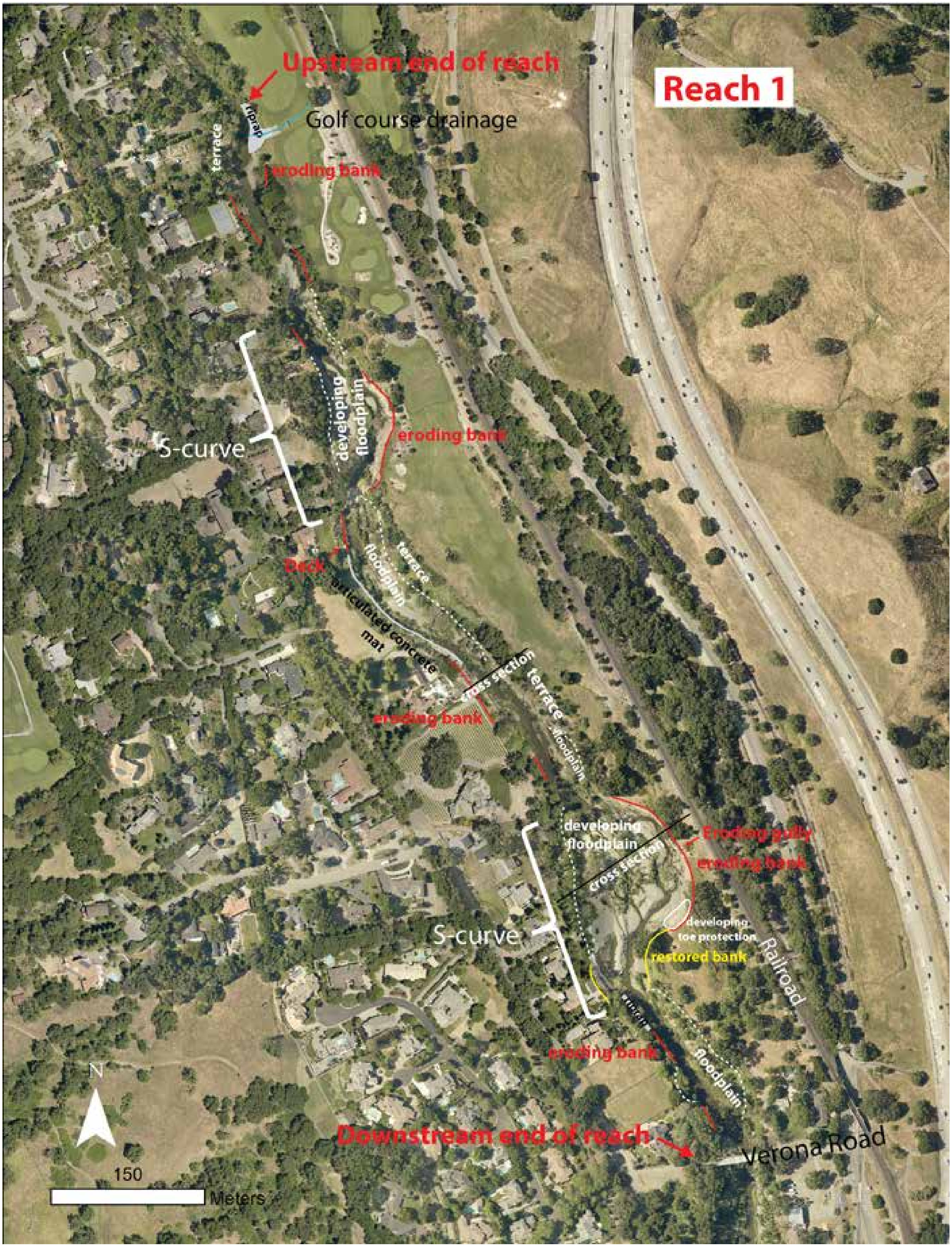


Figure 16. Channel map of Reach 1.

Two representative channel cross sections show the S-curve meander bend and the relatively straight reach morphology. Figure 17 illustrates an S-curve meander bend, with tall vertical banks with blocks of failed material at the toe, a main channel, and multiple other smaller channels. The developing bars and floodplains are visible at distinct elevations relating to various recurrence intervals of flows. Figure 18 illustrates a representative straight reach morphology between S-curves.

Current Evolution Stage

Currently Reach 1 is in CEM Stage IV (Incision and Widenting). However, the S-curve meander bend locations are showing evidence of entering Stage V (Aggradation). See summary Figure 55 for additional context.

Likely Future Evolution Stage

In the near-term future, the reach will likely remain in CEM Stage IV (Incision and Widening) and continue to widen the cross section, building floodplain. Ultimately the reach will widen enough and transition into CEM Stave V (Aggradation).

The S-curve meander bend locations will likely see the fastest rate of change on the downstream and outside portion of the meander bends. It is possible that each meander bend could continue to migrate downstream until it encounters resistance (e.g., purposeful revetment to protect a structure such as a house or railroad), or alternatively, the channel could cut the meander off, leaving a wide off-channel habitat area. In either scenario, we expect the channel to continue to adjust in an effort to smooth this steeper portion of its longitudinal profile. The widening in these locations will shift the evolution into CEM Stage V (Aggradation) helping these locations to stabilize.

Additional data/studies to do

Due to the dynamic nature of this reach, data on the longitudinal profile and channel cross section will be invaluable for monitoring change through time. A channel bed longitudinal profile and a few permanent cross sections should be established and monitored every 5 years, or after large flood events (e.g. greater than a 5 year recurrence interval). Locations without structures on the top of the banks should be studied more carefully to see if the opportunity exists to widen the cross section in those locations. Locations where material exists at the toe of slopes could be documented and monitored, in an effort to understand what type of toe material provides the greatest amount of protection (e.g. bars, woody vegetation, bank failure material deposits, etc) and under what flow conditions.

Similar S-curves exist in the ADLL reach downstream of Verona, where the channel has had a longer period of time to evolve. Building from previous work (Bigelow et al., 2008) and a time series of aerial photographs, these S-curves could be studied to learn about how they evolve and the rates of migration. This exercise would use the premise “space for time” and assumes that lessons learned downstream would be applicable here.

Additional hydraulic modeling that focuses upon shear stress on the banks, to assess which banks are most likely to fail in the near future, could also be valuable to determine if additional projects should be implemented.

Additional research could be conducted to determine if the channel pattern is mimicking the regional tectonics. We hypothesize that the flow pathway of ADLL may be mimicking the right-lateral component of the Calaveras Fault, with the nodes of S-curve erosion occurring at the

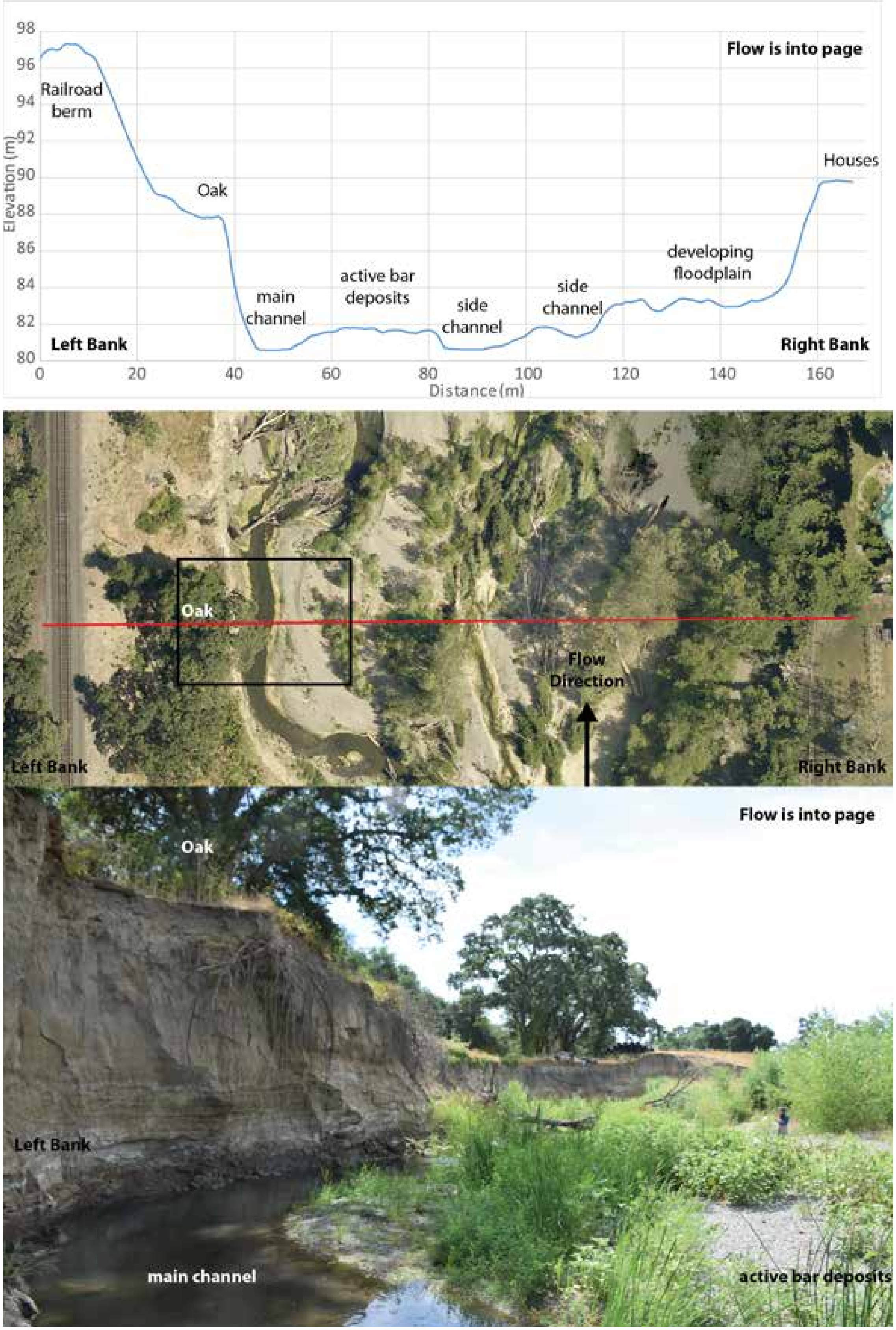


Figure 17. Representative channel cross section at an S-curve meander bend, looking downstream. The red line on the aerial photo indicates the location of the cross section. The black rectangle shows the area shown in the field photograph (looking downstream).

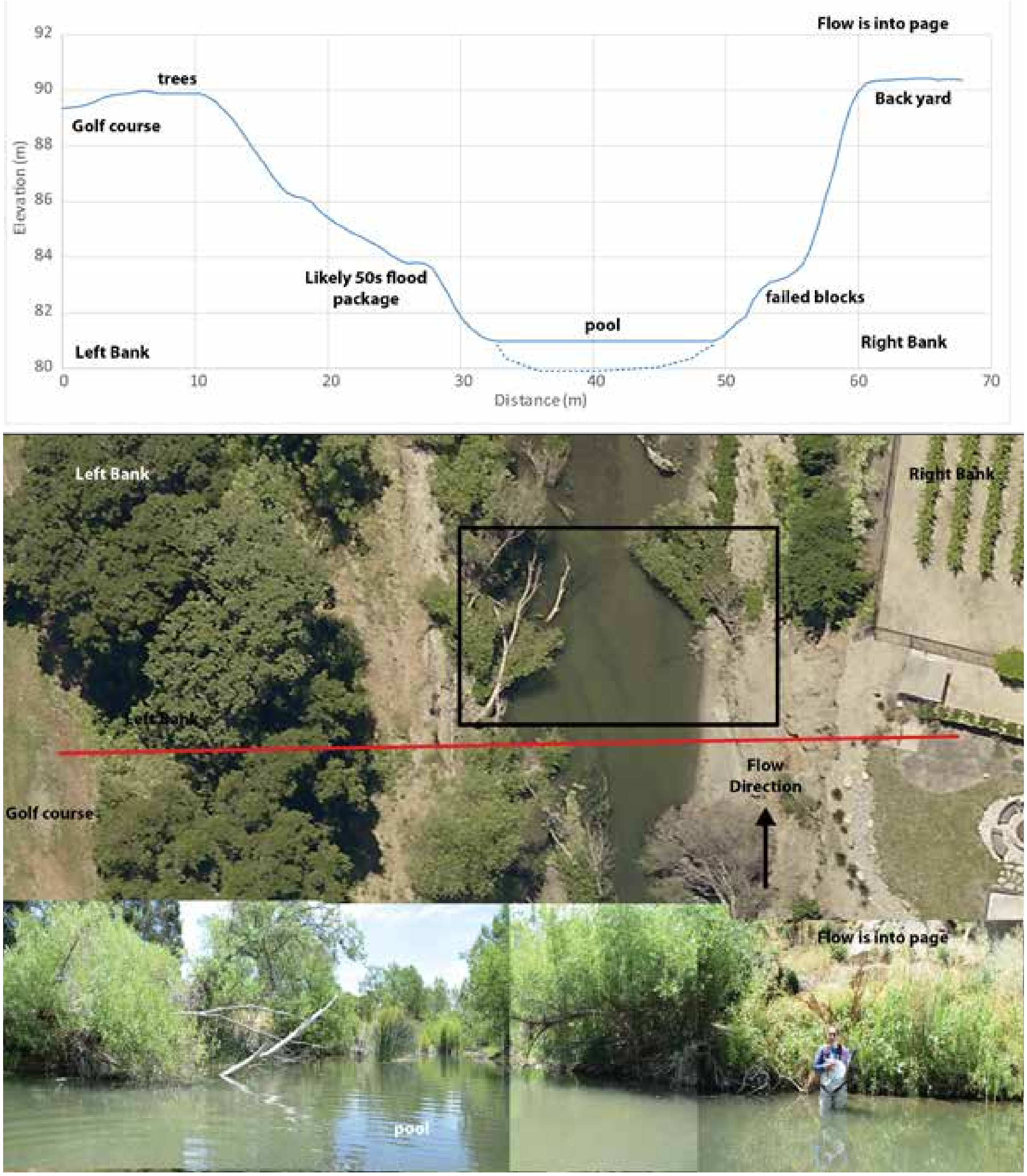


Figure 18. Representative channel cross section for the relatively straight reaches between S-curve locations (looking downstream). Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation. The black rectangle shows the area shown in the field photograph (looking downstream).

transition points in flow direction from SE to SW (Figure 19). While the stream pattern is not superimposed directly upon the location of faults, it does appear to be mimicking the regional NW-SE strain orientation. This pattern is most clear in Reach 1, likely due to the more advanced evolution, however it occurs the entire length of study area. Of note, the S-curve locations downstream of Verona also follow this pattern. If this hypothesis is true, and knowing that we can't control tectonic movement, then perhaps additional management focus can be placed on the upstream flow direction transition points, as we know they might be future potential nodes of erosion. Thus, following this hypothesis and based upon flow direction and the steepness of the longitudinal profile, we expect the upstream S-curve in Reach 1 to be the next large node of erosion.

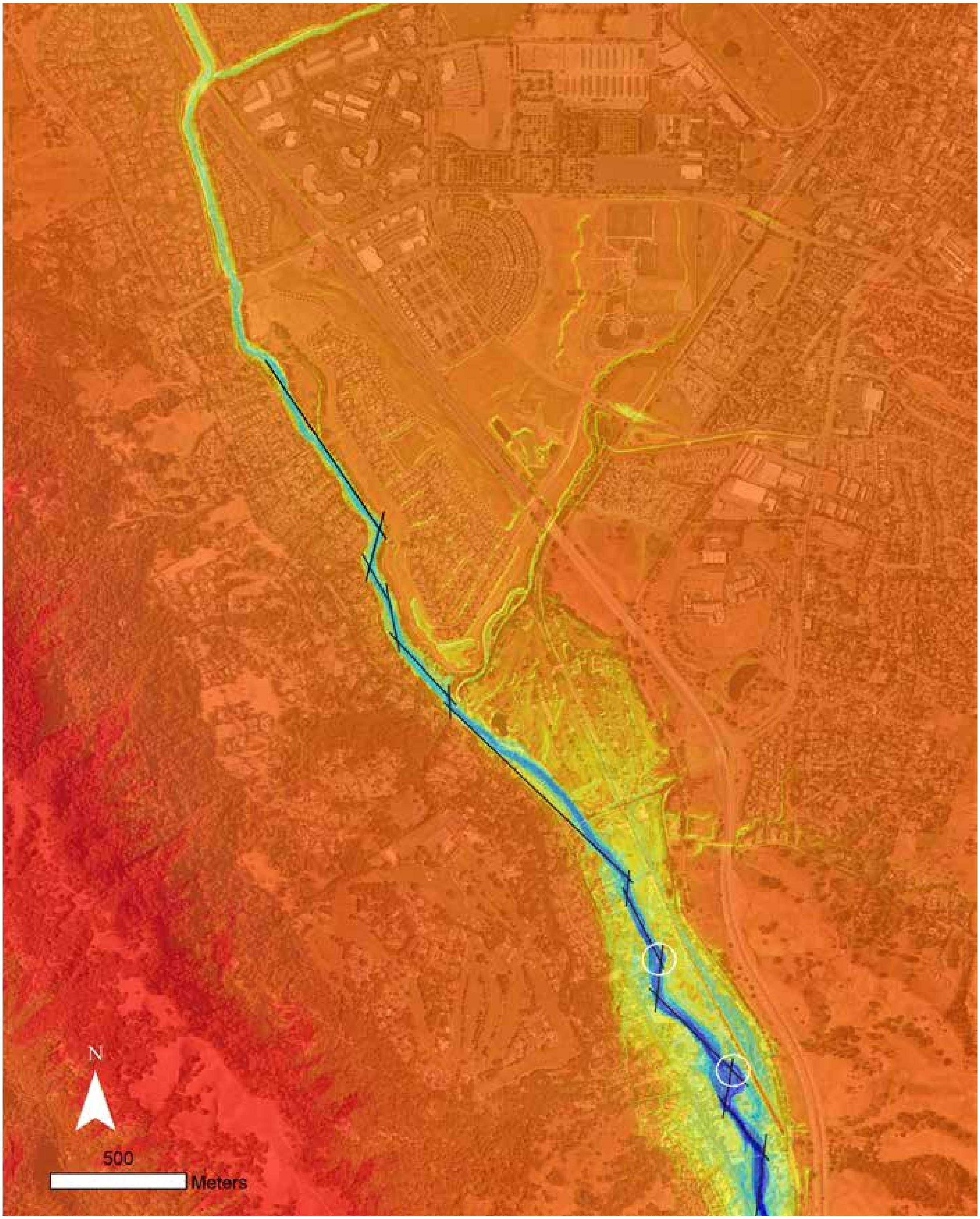


Figure 19. DEM for the ADLL study area, with generalized flow direction (north to south) of the channel superimposed (black lines). The lower right corner shows Reach 1, with nodes of erosion (circles on the downstream and upstream S-curve locations) indicating the transition points in flow direction.

Risks and Management

To summarize our findings by reach, we identified notable risks, opportunities, and potential management actions applicable to this reach in the near term (Figure 20). Risks include: the continued failure of outer banks that may ultimately damage property or structures, increased recruitment of large riparian trees into the channel as widening and deepening continue, the continued faster-paced migration of the downstream S-curve and slower-paced migration of the upstream S-curve, eventual undermining of the railroad trestle at the downstream S-curve, the potential reworking (e.g., channel migration, bank erosion, sediment deposition) of existing restoration/stabilization projects, and the potential headward migration of the steeper gradient associated with the two S-curves. And at a larger scale, continued development of the upstream urban areas without a focus upon the timing and volume of runoff produced will likely increase the volume of water delivered to ADLL during storms, thus increasing the stream power and the likelihood that the channel will continue to erode and incise.

However, this reach holds opportunities especially given the potential for large-scale restoration projects that are able to slow/halt the erosion of the outer banks and protect the adjacent properties. We recommend focusing on the opportunity presented by the left bank being composed primarily of Zone 7 and Castlewood Country Club property, and under-utilized open space to work with the expected future evolution. In particular, providing the channel additional width at the S-curve locations could lead to the development of a large, functioning node(s) of floodplain, and the creation of complex habitat areas, critical for ecological function and improved wildlife habitat. Specific locations where small drainages are routed into the channel can be addressed so that they do not exacerbate local bank erosion. And finally, the 3 Verona project should be monitored, with lessons learned applied to other areas in this reach.

Because of these risks, we recommend many actions for this reach. Locations where the channel might be widened proactively should be identified. Locations where the toe of slope has deposited material can be focused upon to stabilize that material and reduce the future erosional stress on the toe. Tree planting can focus on the top of banks, behind the current trees that are in danger of being recruited, allowing for some shading and root strength when/if the existing trees are recruited. We recommend addressing key data gaps in order to anticipate locations of future bank failures, and create an "anticipatory management plan" (Beagle et al., 2016) that focuses upon the threat to the railroad so that bank failures can be planned for over the long term.

Figure 20. Risks and opportunities within Reach 1. Existing conditions created by the 3 Verona bank reconstruction project are highlighted by the yellow lines.


Reach 1
Upstream end of reach
Riprap
Golf course drainage
Consider laying back bank
Encourage toe protection
Risk of tree recruitment
Encourage toe protection
Risk of tree recruitment
Consider laying back bank and adding toe protection
Risk of property erosion
Monitor failing mat, risk of erosion
Consider laying back bank
Encourage toe protection
Monitor, plant trees
Risk of tree recruitment
Address eroding gully
Develop complex habitat node
Plan for potential railroad grade erosion
Plan for meander cutoff
Encourage toe protection, monitor existing toe material
Monitor restoration project
Monitor
Railroad
Downstream end of reach
Verona Road
N
150
Meters

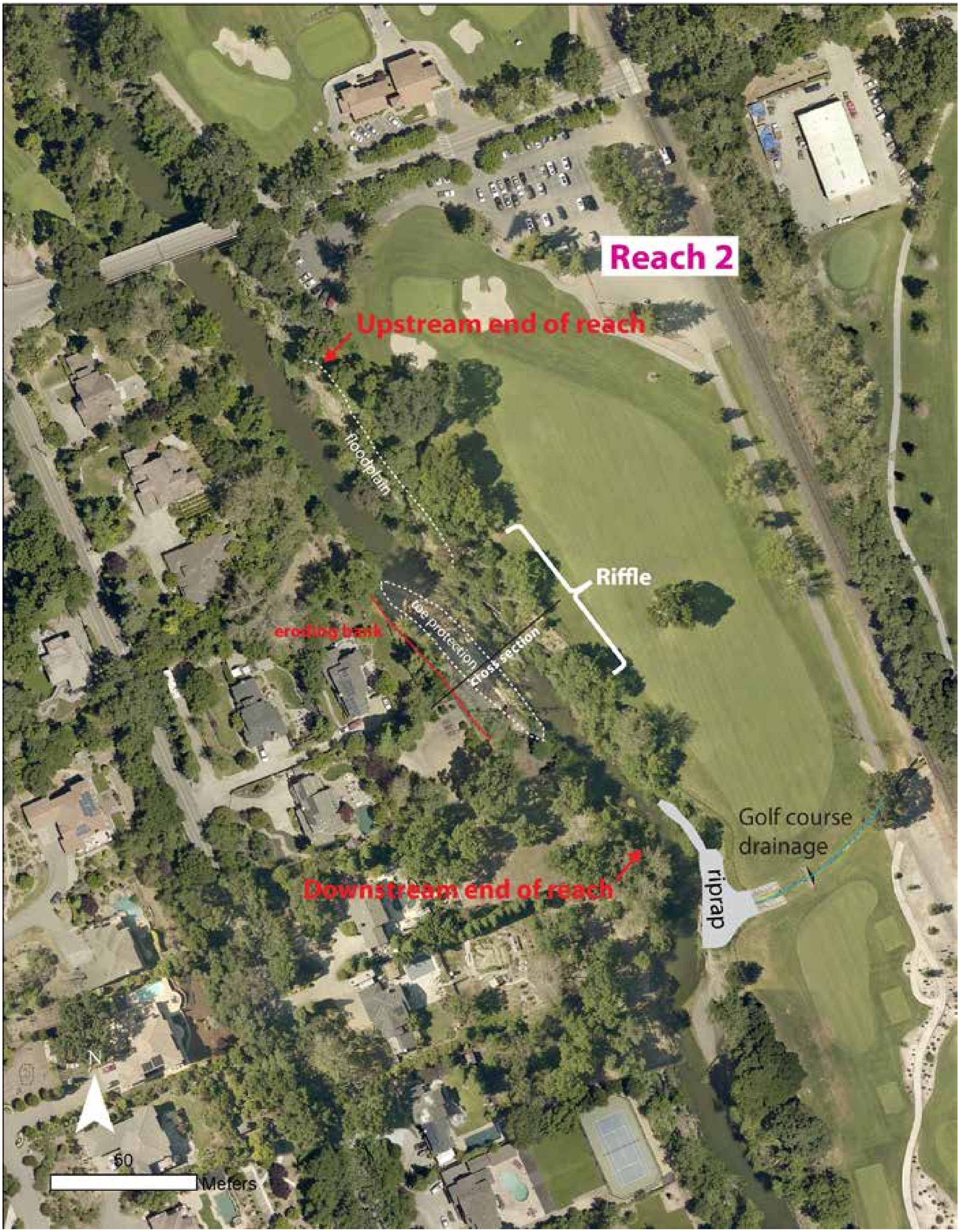


Figure 21. Channel map of Reach 2.

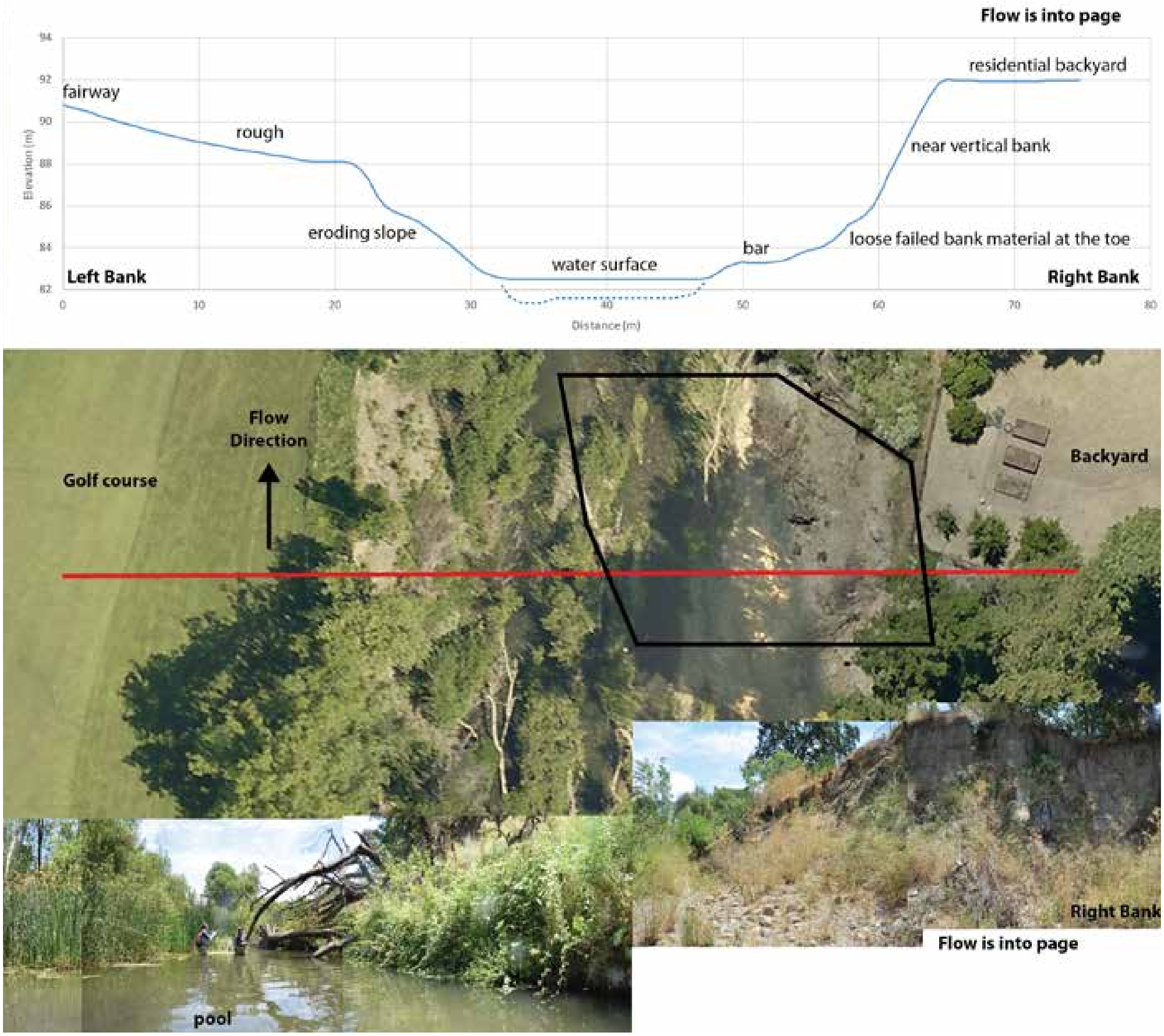
REACH 2- KNICK ZONE

Description

Reach 2 appears to encompasses a knick zone, or a zone where a knickpoint (or significant change in channel bed grade) is present and is likely currently headwardly eroding along the channel length (Figure 21). The primary characteristic of this relatively short reach is the steeper gradient and coarser grain size, compared to the adjacent upstream or downstream reaches. The gradient change is observed in the field, accompanied also by a change in substrate, and distinctive bed morphology. The reach is a long, steep, coarse grained riffle that has a multi-thread channel pattern with active depositional bars. The bars support growth of dense young willow trees (Salix lasiolepis) that further increase the channel complexity (Figure 22). The channel outer banks are vertical through this reach. The outer right bank appears to be failing episodically, primarily by dry-ravel failure of the fine-grained valley fill material. The toe of the outer banks is protected by either bars or failed bank material deposits, which prevent lower flows from exerting shear stress forces upon the bank.

The representative cross section for this reach shows the near vertical outer bank on the right bank side, with the at-risk residential property at the top (Figure 23). It also shows the loose failed bank material piled up at the toe of the slope, and the low bar that has deposited (Figure 24). The left bank shows the slope that is failing more as a rotational-style failure, and the lower terrace surface that now has the fairway rough of the golf course. Unfortunately the detail of the channel (mid-channel bars) do not come across in the LiDAR data.

Figure 22. Photograph looking upstream at the downstream end of the steep riffle, and surrounding willow trees on the bar surfaces.



(above) Figure 23. Channel cross section cut from the LiDAR data and annotated with field notes, and the matching field photograph. Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation. The black polygon shows the area shown in the field photograph (looking downstream).

(right) Figure 24. Right bank at cross section showing near vertical bank and failed material at the base.

Current land use along the banks in this reach includes the Castlewood Country Club golf course along the left bank, and residential along the right bank. On the left bank there is approximately 20 m between the top of the bank and the first cut of the fairway on the golf course. On the right bank, the downstream property has about 3 m between the top of the bank and a fence, while the upstream property has 5-10 m between the top of bank and the backyard landscaping.

The relatively steep gradient through this reach is captured in the 2011 field-surveyed longitudinal profile (Stantec, 2011) (Figure 25). The gradient in this short reach is 0.86%, while is it 0.12% for the reach downstream and 0.11% for the reach upstream. We hypothesize that the riffle in this reach represents the current location of a knick zone. Previously, as this knick zone migrated upstream, it caused the channel to deepen, widen, and erode some of the adjacent terrace width, causing the difference in channel morphology downstream of the knick zone, as compared to upstream. However, further study is needed to evaluate this hypothesis and assess the key drivers for the bed gradient and channel morphology. Quantifying upstream migration of the knick zone will confirm that is truly is a knick zone rather than just the deposition of a slug of sediment as the channel exits the upstream confined riprap reach or from the adjacent banks, or just the expression of a resistant geologic unit.

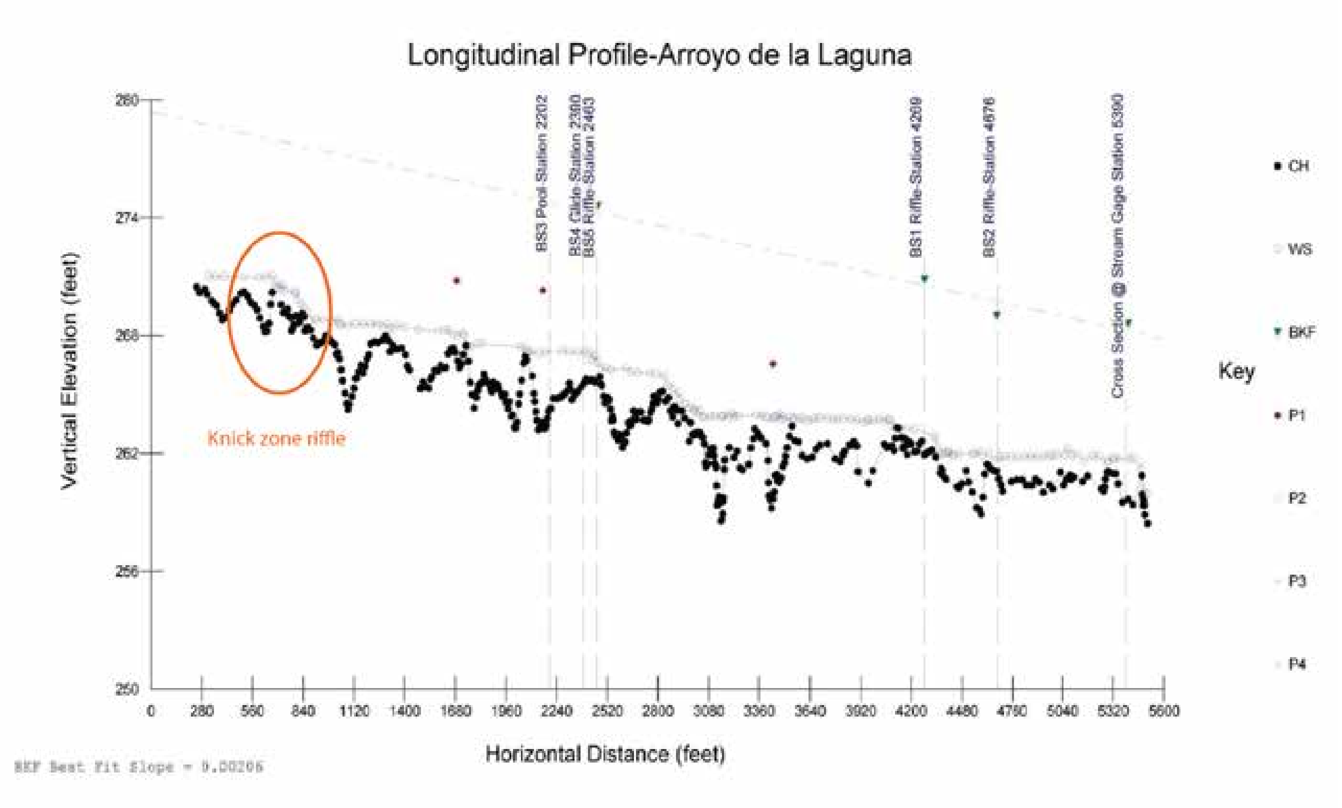


Figure 25. Field surveyed longitudinal profile (Stantec, 2011) showing the steeper gradient in the riffle of the knick zone.

Current Evolution Stage

This reach is currently in CEM Stage III (Incision). See summary Figure 55 for additional context.

Likely Future Evolution Stage

In the future we expect the channel to progress to CEM Stage IV (incision and widening). The primary concern is that the knick zone will continue to migrate upstream into Reach 3 in an effort to smooth the overall gradient, and potentially destabilize that reach. After this occurs, we expect this reach to widen by continued failure of the outer banks. The channel should become single thread, and deposit high bars/low floodplains along the channel margins, similarly to the downstream reaches.

Additional data/studies to do

Resurvey a longitudinal profile for comparison with Stantec's previous profile, and consider resurveying every 10 years or after large flood events. Monument several cross sections (within the reach, and immediately upstream of the reach, before Castlewood Drive) and re-survey every 5 years (or so) or after larger flood events to document channel change. Document rate of bank retreat using aerial photographs, or re-surveys. Using a series of aerial photographs, estimate a rate of bank retreat, particularly for the reaches with adjacent houses, to better understand the magnitude/timing of the erosion risk. Conduct additional research to determine the rate of bank erosion (for both banks) occurring in within the footprint of the future Castlewood Country Club bank repair project.

Risks and Management

In this reach, the right bank is nearly vertical and failing via dry-ravel failure, and continued or increasing bank failure actively threatens residential backyard property and out-buildings (Figure 26). An aerial photograph analysis reveals 1 primary residence within 80 ft (2.5x the bank height) of the top of bank in this reach. A refined understanding of bank erosion rates will help inform risk management scenarios, however, the channel will likely deepen and widen after the knickpoint moves through, which will further destabilizing the banks, increase rates of bank erosion, and lead to loss of property.

However, because the left bank is golf course property, there are opportunities for proactive management. On the left bank, there is approximately 20 m of space between the top of bank and the fairway. This reach (and upstream of this reach) could be a location where the bank is laid back, with minimal impacts to golf course function, thus widening the channel width. The golf course is currently planning to proactively set back a 150m length segment of the left bank, with placement at the toe of the right bank. The project is being done in collaboration with Zone 7 during the Summer of 2019. This will hopefully be a pilot that could be repeated as needed, and should be designed with potential future incision in mind. The right bank currently has developed a bar from failed material at the toe of the bank. Additional measures to stabilize these features will provide continued protection for the outer bank. Knowledge of the potential incision will allow for appropriate monitoring to occur, potentially identifying the issue and allowing for proactive management including bank setbacks, and anticipating the need to move non-essential structures away from the top of bank.

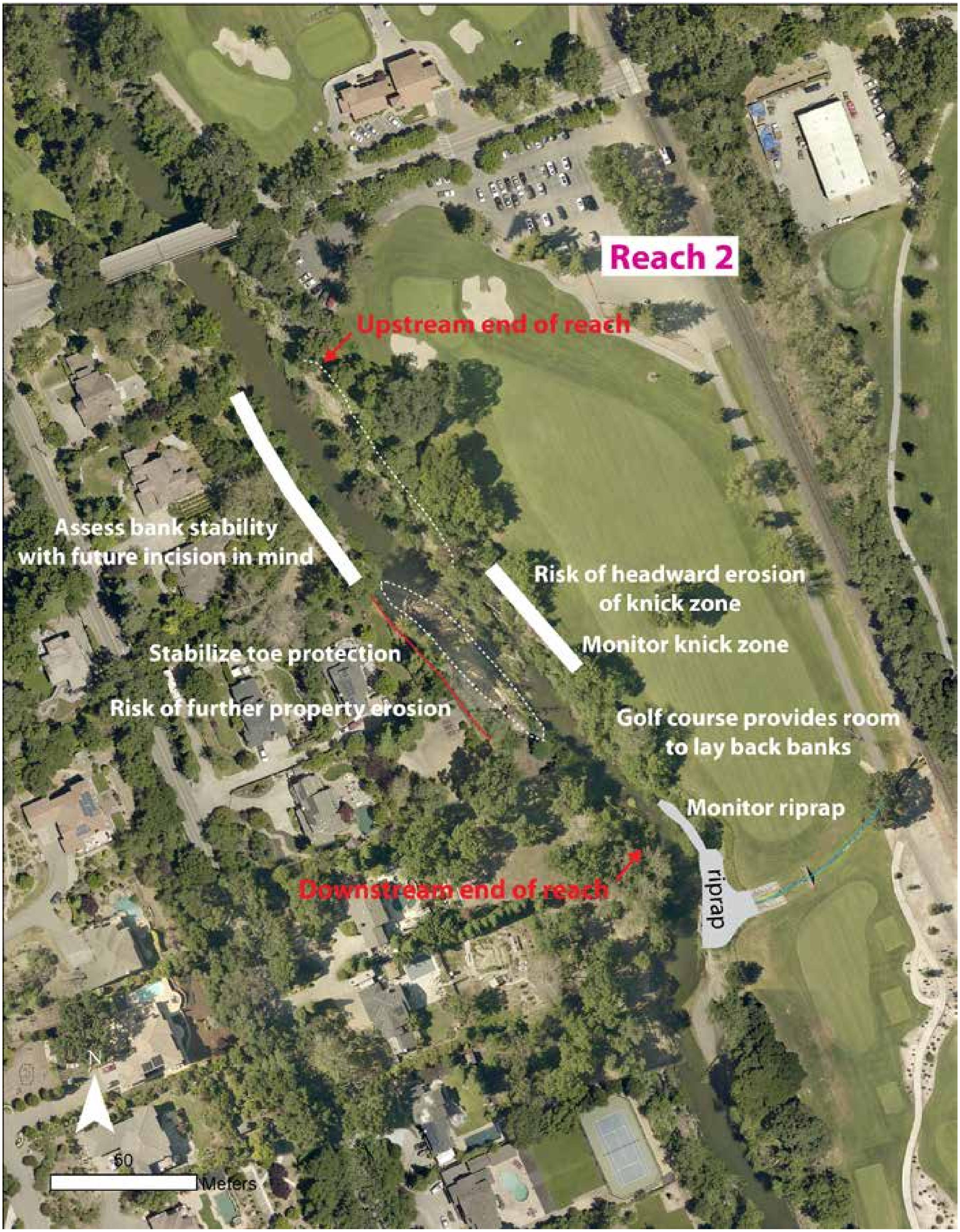


Figure 26. Risks and opportunities within Reach 2.

REACH 3- ARTIFICIAL RELATIVE STABILITY

Description

Reach 3 extends from just downstream of Castlewood Drive, upstream through a portion of the Castlewood Country Club golf course (Figure 27). This reach has been artificially relatively stable for a few decades because it is "locked in" by the riprap that is placed from the top of the bank to the toe. The riprap was placed in the late 1990s, as the Country Club was concerned about chronic bank erosion in this reach, likely due to previous incision. This hardening has significantly simplified the channel cross section, so that it is essentially a U-shaped trench that has almost no channel complexity. The channel is a long single pool with a low-flow water depth greater than 2 m. Overall this reach has low habitat value for aquatic or riparian wildlife species. Presently, none of the upper banks (e.g. those above the bankfull contour) were observed to be failing, which is different than most of the overall study area length. Because the reach was not wadeable, good observations of the toe of the riprap were not able to be made. However we believe that there may be some (<1m) recent incision at the toe, which may lead to future destabilization of the hardened banks.

Current land use along the banks in this reach includes Country Club property on both banks upstream of Castlewood Drive, and Country Club property along the left bank and residential properties along the right bank downstream of Castlewood Drive (Figure 28). We note that the terrace surface along the right bank is lower in elevation than the left bank in the reach upstream of Castlewood Drive.

Current Evolution Stage

This reach is currently in CEM Stage I (Stability), however this is artificial due to the extensive riprap placed in the late 1990s. And while this reach is not currently exhibiting the signs of bank erosion observed in other reaches, the artificial "stability" created by the fully riprapped banks is not necessarily a desirable characteristic. Flows in this reach likely have higher velocity due to the homogenous and simple channel morphology, which does not promote deposition of sediment, or support aquatic species that require refuge during high flows. The higher velocities may be detrimental to Reach 2, promoting increase incision or bank erosion. And artificial stability of this reach may be essentially causing an artificial grade control for Reach 4. And finally, the homogenous riprap banks harbors invasive plant species, and does not provide high quality habitat for riparian wildlife species. See summary Figure 55 for additional context.

Likely Future Evolution Stage

In the future we expect this reach to remain in CEM Stage I (Stability), due to the continued maintenance of the riprap by the Country Club. However, the downstream end of this reach should be closely monitored to detect any potential incision related to the knick zone downstream in Reach 2. In other words, if the knick zone were to migrate upstream into this reach, it would likely undermine the toe of the riprap, causing failure of the riprap and likely rapid and large-scale bank erosion. If incision were to occur, the reach may quickly evolve through CEM Stage II (Disturbance) to CEM Stage III (Incision).

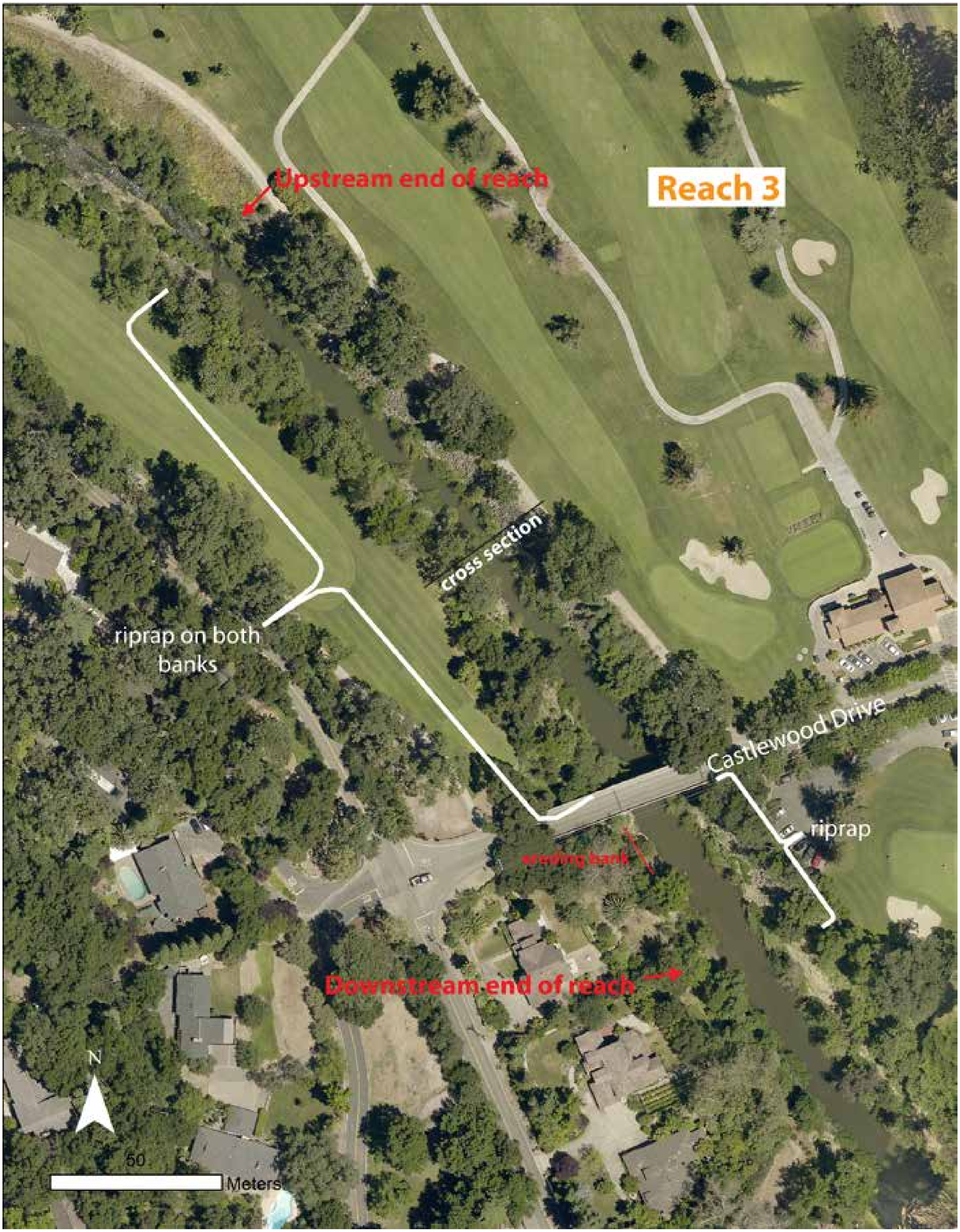


Figure 27. Channel map of Reach 3.

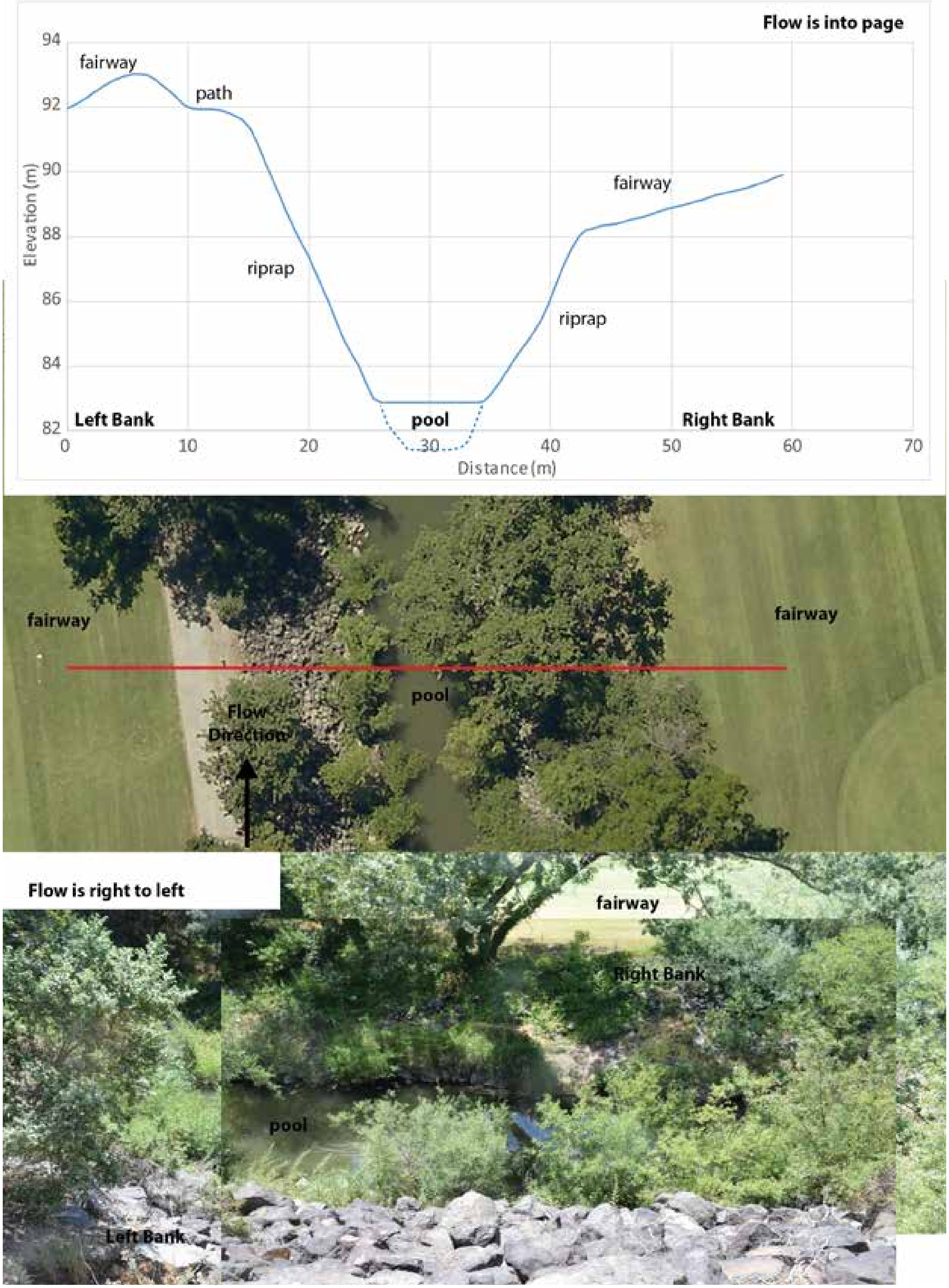


Figure 28. Representative Reach 3 channel cross section. Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation.

Additional data/studies to do

Further fieldwork to inspect the toe of the riprap slope upstream of Castlewood would confirm or refute the observations of a minor amount of incision, potentially caused by velocity-related channel adjustment since the placement of the riprap. Using the appropriate field gear, such as a small boat to re-survey the reach upstream of Castlewood, a field team should specifically make observations of the toe of slope. This could also be done by setting up monumented cross sections to monitor for potential incision of the reach.

While this reach appears relatively stable, it is advisable that the Country Club and Zone 7 make an advance plan to anticipate changes in management should the riprap fail, which could take place if precipitation patterns continue to change, and larger storms become more normal. This type of anticipatory management is necessary so that all landowners and agencies can efficiently enact fixes that are in line with an overall vision for this portion of ADLL, and advance the goals for both the reach and the functioning of the entire stream. This plan could help to avoid emergency bank repairs that may be costly and unsustainable in the long term, by creating pre-designed and permitted solutions to anticipated problem locations.

Risks and Management

While the riprap has prevented recent bank erosion, causing the reach to appear relatively stable today, there is risk of incision of the reach due to future headward migration of the knick zone, which could undermine the toe of the banks, leading to rapid failure of the riprap, and increased instability of the channel banks (Figure 29).

However, opportunities for proactive management exist because both banks are currently Country Club property. The reach is currently overgrown with non-native and highly invasive English Ivy (Hedera helix); vegetation management efforts could remove this invasive and increase habitat value by replacing with a palette of more structurally complex native plant species. And, if there was support to conduct a large-scale channel and bank restoration project in this reach, the project would occur with a single landowner, and in an area without any permanent structures, removing two common hurdles experienced by many other projects.

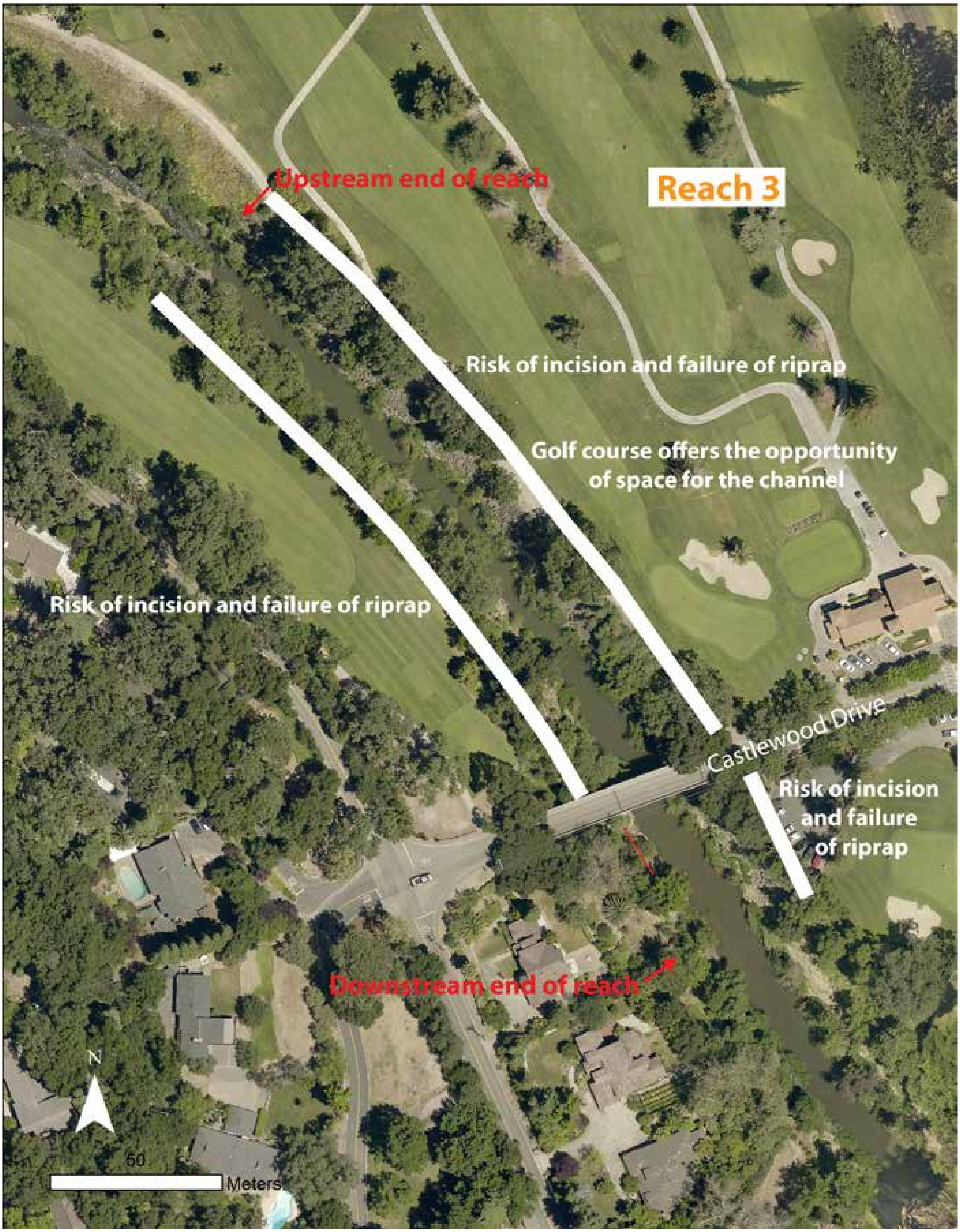


Figure 29. Risks and opportunities for Reach 3.

REACH 4- OLD WEIR

Description

This reach extends from the upstream extent of the riprap in Reach 3 upstream to the confluence with Line B.2.1 (Figure 30). This reach is defined by a previous concrete weir that was located on the channel bed approximately 5 m upstream of the pedestrian bridge in the Castlewood Country Club golf course. The weir fully spanned the channel bed and caused an approximately 1m step in the channel bed gradient (Figure 31). Castlewood Country Club staff report that the slab was protecting a number of pipes that were crossing the channel, including one that brought water uphill to the “hill course” and the homes built there (John Vest, personal communication) (Figure 32). Those homes were built in the late 1950s and early 1960s, and thus our best estimate is that the slab was installed after the 1950s floods. But given that it was at approximately the same elevation as the exposed hardpan in the reach, it could have been installed at a later date, after the channel has incised to the hardpan elevation. Field photographs from 2007 shows the slab still largely functioning and intact, however golf course staff report that the slab was unstable in 2003 and likely before (John Vest, personal communication). The slab was completely undermined and collapsed during the December 2012 high flows, and was then removed in early 2013. The current channel only has scattered riprap remaining in the previous weir location (Figure 33).

This reach also has the downstream-most exposure of hardpan in the channel. Hardpan essentially acts like a layer of impermeable concrete on the channel bed that slows incision. Likely because of the hardpan and/or the previous weir, the upstream channel gradient is more shallow than the downstream reach (Figure 34).

Overall the reach is fairly straight in planform, with a well-defined pool/riffle sequence that is evident in the surveyed longitudinal profile (Figure 34). In many locations current fluvial sediment is being deposited as a bar on top of the hardpan surface. The reach also has some larger boulders scattered across the bed; these are likely a mix of blocks of failed outer bank material and failed riprap from this reach (Foothill Road protection) and from previous development and repairs that have occurred further upstream (1988 Golden Eagle development and 1996 Zone 7 storm damage repairs). The outer banks are steep, but not quite vertical, with evidence of dry-ravel style failure (visible in the field) and slump block failure (visible in the LiDAR). There is one significant fresh bank slump location (Figure 35) that contributed a mix of sediment grain sizes directly to the channel. The reach has LWD in the channel due to outer bank failures recruiting riparian trees into the channel. Currently many other trees are located on top of the bank and are in danger of falling in with future bank failures. Terrace surfaces at different elevations on the right and left banks are clearly observed.

This upstream end of the reach is defined by the location where a tributary enters from the northeast, and the valley widens significantly, also to the northeast (Figure 36). Additionally, mapping of landslide deposits shows an ancient Pleasanton Ridge landslide deposit in this location (Majmundar, 1995). Although it would require significant additional study to test, we hypothesize that the interaction of the landslide (from the west), ADLL (flowing north to south), and the tributary (from the east) caused the valley widening, and may have contributed to the

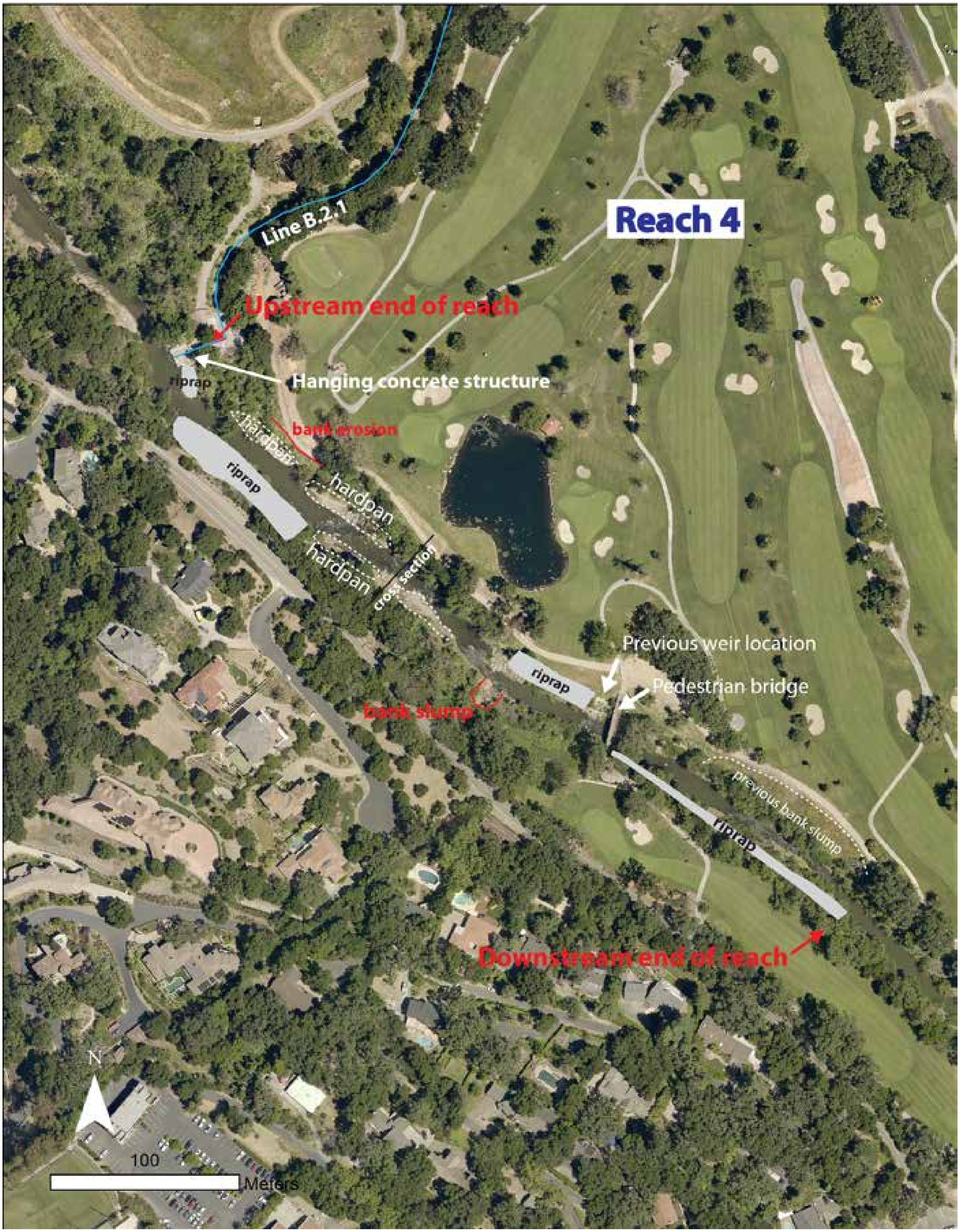


Figure 30. Channel map of Reach 4.

Figure 31. Two 2007 photos showing the previous condition of the concrete weir before it was undermined and collapsed (courtesy of Zone 7, and Mahacek, 2007).

persistence of the Pleasanton Marsh Complex and the late Pleistocene creation of the hardpan stratigraphic unit (which was observed in Reach 4 and upstream, but not downstream). For example, if the ancient landslide impinged upon the course of the stream channel, it could have been "pushed" to the northeast, combining with the tributary to create a wider valley in this location. Also, the landslide (or series of landslides mapped along Pleasanton Ridge) could have created enough topography (a convexity in the channel profile) to prevent full drainage of the valley, thus acting as a bottleneck, enhancing the persistence of the Pleasanton Marsh Complex, and allowing the conditions for the development of the hardpan unit upstream of the landslide deposit, but not downstream. This hypothesis, if sufficiently tested, could potentially provide some context to interpret the current stratigraphy visible in the channel, and help predict future evolution of the channel by better understanding the landscape context. For instance, perhaps the S-curve morphology and evolution that are observed in Reach 1 would not occur in Reach 4 or 5 due to the presence of the hardpan.

This reach shows evidence of previous incision. The channel has managed to incise through the relatively resistant hardpan, likely due to greater volumes of runoff from upstream development, leaving the hardpan exposed approximately 0.5 to 1 m above the current channel bed. In addition, we know that the concrete structure at Line B.2.1 was constructed in 1963; it currently is approximately 3-4 m above the low-flow water surface providing a fixed structure to measure the incision that has occurred since the 1960s. Additional fieldwork could provide an accurate measure of the distance between the channel bed and the concrete structure.

Although the terrace elevation is somewhat rounded in the representative cross section for this reach, other places in this reach have more prominent terraces that were readily visible in the field (Figure 37). A terrace surface about 5-6 m above the current bed exists on the right bank, and a terrace surface about 7-8 m above the current bed exists on the left bank. Hardpan is exposed in this reach, with the highest elevation approximately 1.5 m above the current bed.

Figure 32. Field photograph of the left bank and an historical pipe that was underneath the concrete weir before it failed and was removed. Pipe is now approximately 1 m above the current bed elevation.

Figure 33. Current view of weir location, looking upstream from the pedestrian bridge.

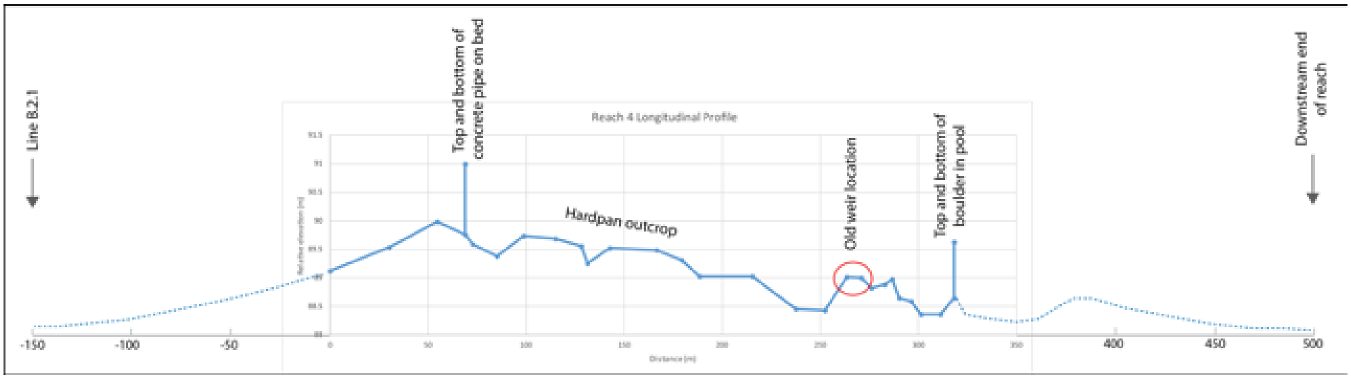


Figure 34. Field surveyed longitudinal profile for Reach 4 (solid line). Units in meters. Each end of the profile is estimated (dashed line). The previous weir location is circled in red. A very large and deep pool exists at the confluence of Line B.2.1; a longer profile would provide more context for this short reach, including showing the gradient change of this segment in context with the larger reach.

Figure 35. Bank slump location in Reach 4 that is contributing a mix of grain sizes to the channel.

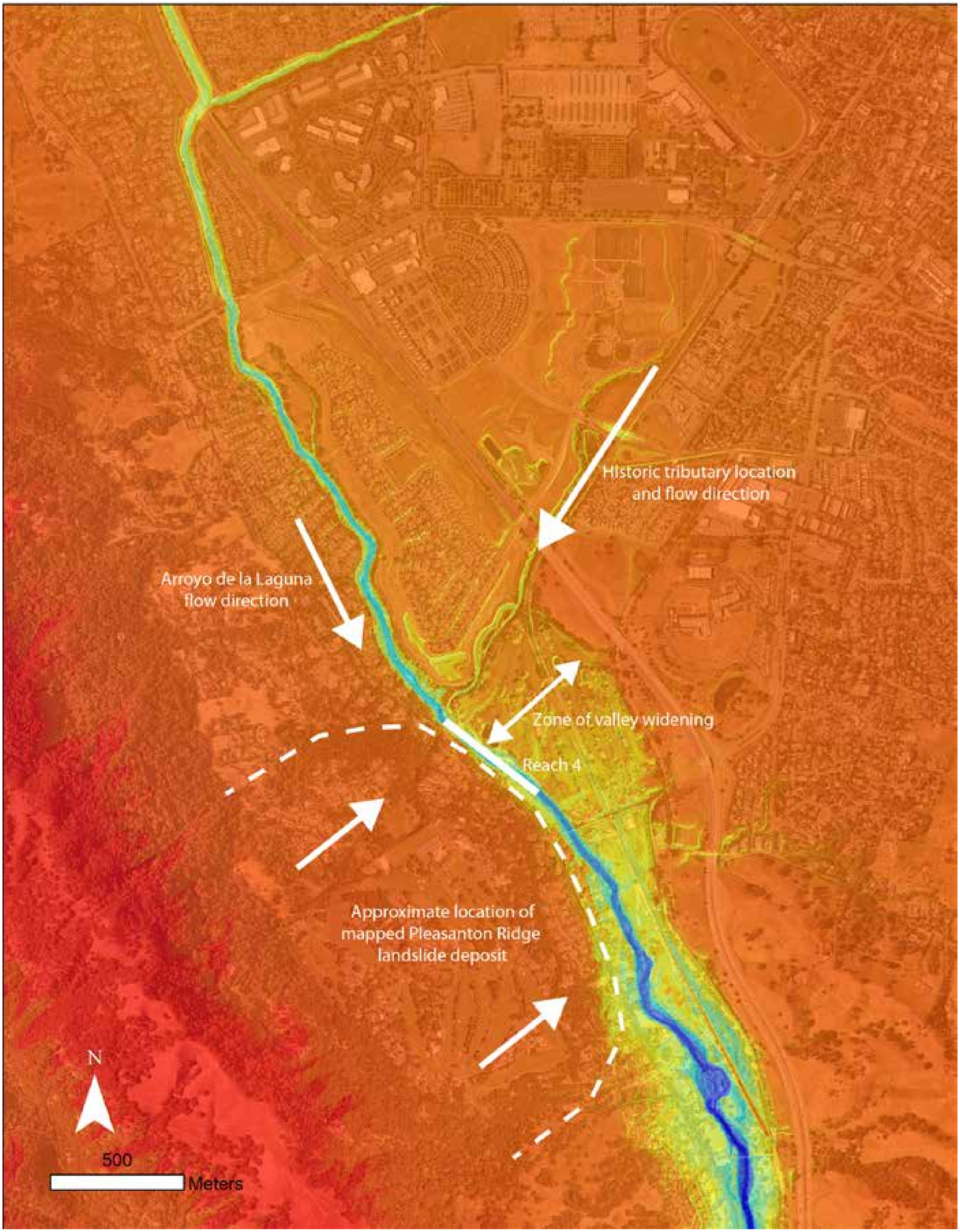


Figure 36. Annotated DEM illustrating the location of a Pleasanton Ridge landslide deposit and the zone of valley widening. Warm colors are higher elevations, and cool colors are lower elevations.

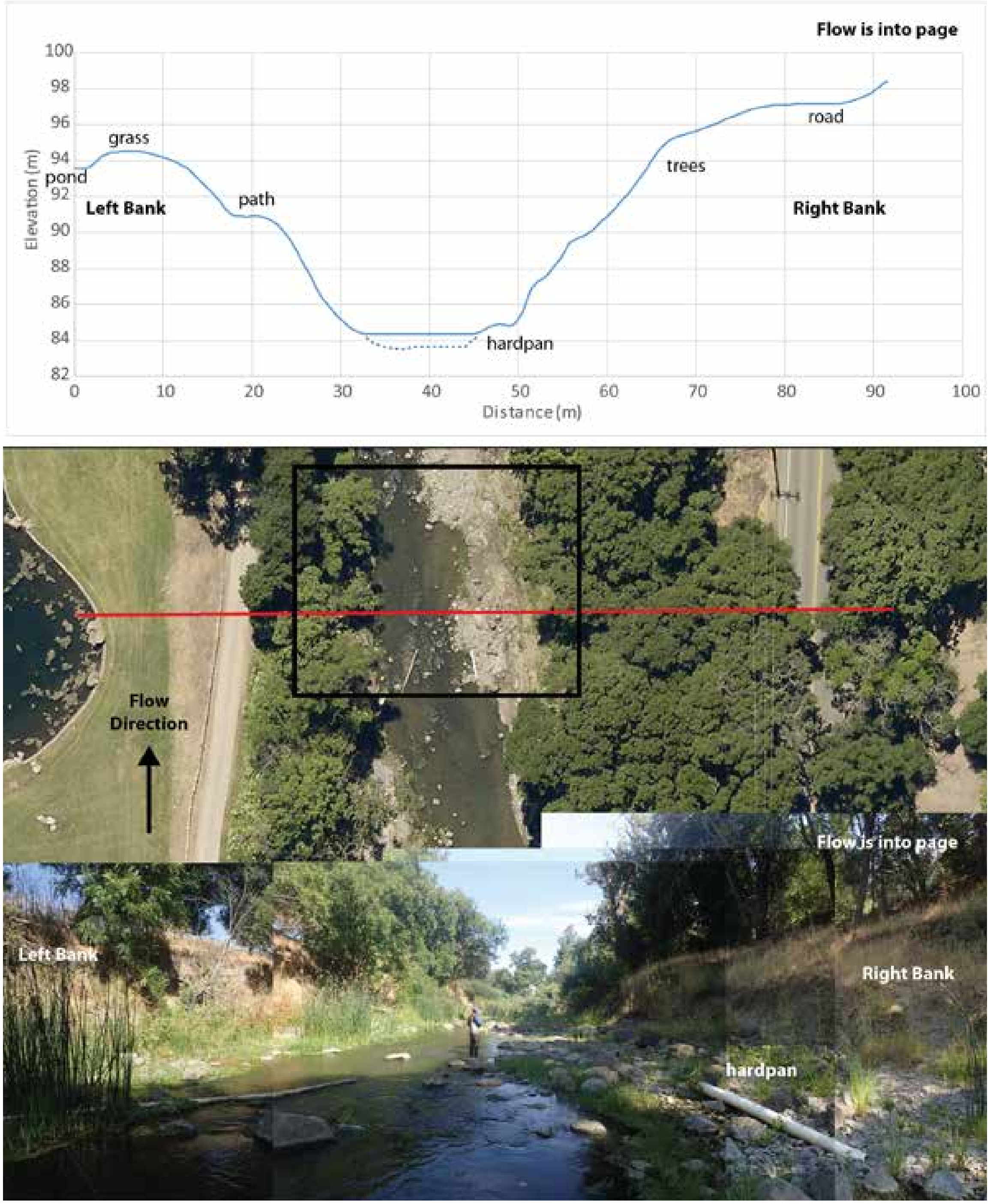


Figure 37. Representative cross section for Reach 4. Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation.

Current land use along the banks in this reach is entirely golf course along the left bank, and on the right bank, golf course along the lower third, and slope up to Foothill Road along the upper two thirds. The upstream-most 100 m of the right bank has riprap placed along the entire height of the bank to protect Foothill Road, likely due to the proximity to the creek, but also possibly to protect the bank from outfalls from the Line B.2.1 concrete structure. The only significant structures are the golf course pedestrian bridge, Foothill Road, and the concrete outfall structure for Line B.2.1.

Current Evolution Stage

This reach is currently in CEM Stage III (Incision). See summary Figure 55 for additional context.

Likely Future Evolution Stage

We hypothesize that a new wave of incision may begin due to the removal of the weir, representing CEM Stage II (Disturbance), and then CEM Stage III (Incision). However, counterbalancing any potential incision is the presence of the hardpan, and the coarser grain sizes on the bed, providing additional channel roughness and thus reducing stream power.

Additional data/studies to do

Monument cross sections to monitor for potential incision due to removal of the weir.

Finish the longitudinal profile that was surveyed during fieldwork for this study (July 2018); consider tying into a longer profile (tying into the Stantec profile that ended at Castlewood Drive, upstream to the Line B.2.1 confluence).Use this data as a baseline to detect change by comparing it to a re-survey every 5-10 years or after large flood events.

More closely inspect the banks, mapping locations of slump-block style failures of the banks using a combination of LiDAR and field observation to identify potential risks to structures at the top of the banks.

Risks and Management

While removal of constraints upon a channel, such as the historic weir, is a benefit and allows the channel to fully adjust any aspect of its geometry, in this instance the channel has evolved since the weir was installed, adjusting to the increased volume of water delivered as the upstream Valley developed (Figure 38). The 2013 removal of the weir may pose a set of risks to this reach, as a new wave of incision incited by the weir removal could undermine already failing banks. This could lead to increased outer bank failures due to incision, which would primarily be characterized as slump-block style failure. Foothill Road is at the top of the right bank along a portion of this reach which increases stress on the toe of the slope, and may lead to more failure, or more riprap, which could enter the channel. Although unlikely, there is potential for undercutting of the Line B.2.1 outfall structure.

Although the Country Club need not be fully responsible for restoring Arroyo de la Laguna, in this reach there are opportunities for laying back the banks on the left side, on Country Club property. This would limit the erosive force against Foothill Road. There are several areas with limited riparian vegetation in this reach, and planting an additional row of trees behind the current trees located at the top of bank would increase habitat, shade, bank stability, as well as other benefits. Stream managers should examine the functioning of the Line B.2.1 structure, and installing an energy dissipator at the bottom to reduce scour from inflows. In addition, managers should discourage any new riprap intended as bank stabilization in this reach, and create an anticipatory management plan with landowners (Beagle et al., 2016), especially the Country Club, to carefully plan out potential future responses if incision does begin to occur. This plan should also explore if any new opportunities exist because the weir is no longer present.

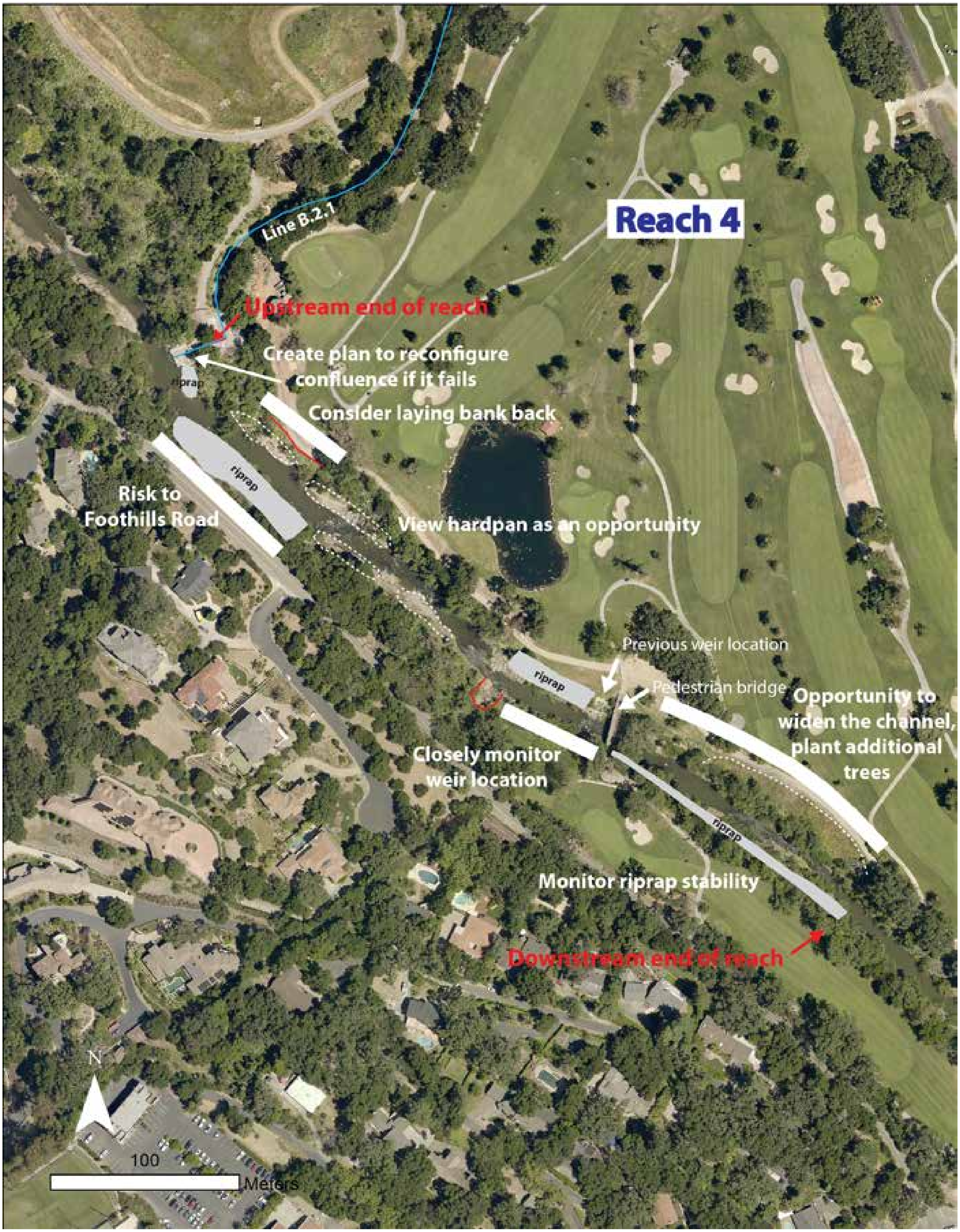


Figure 38. Risks and opportunities for Reach 4.

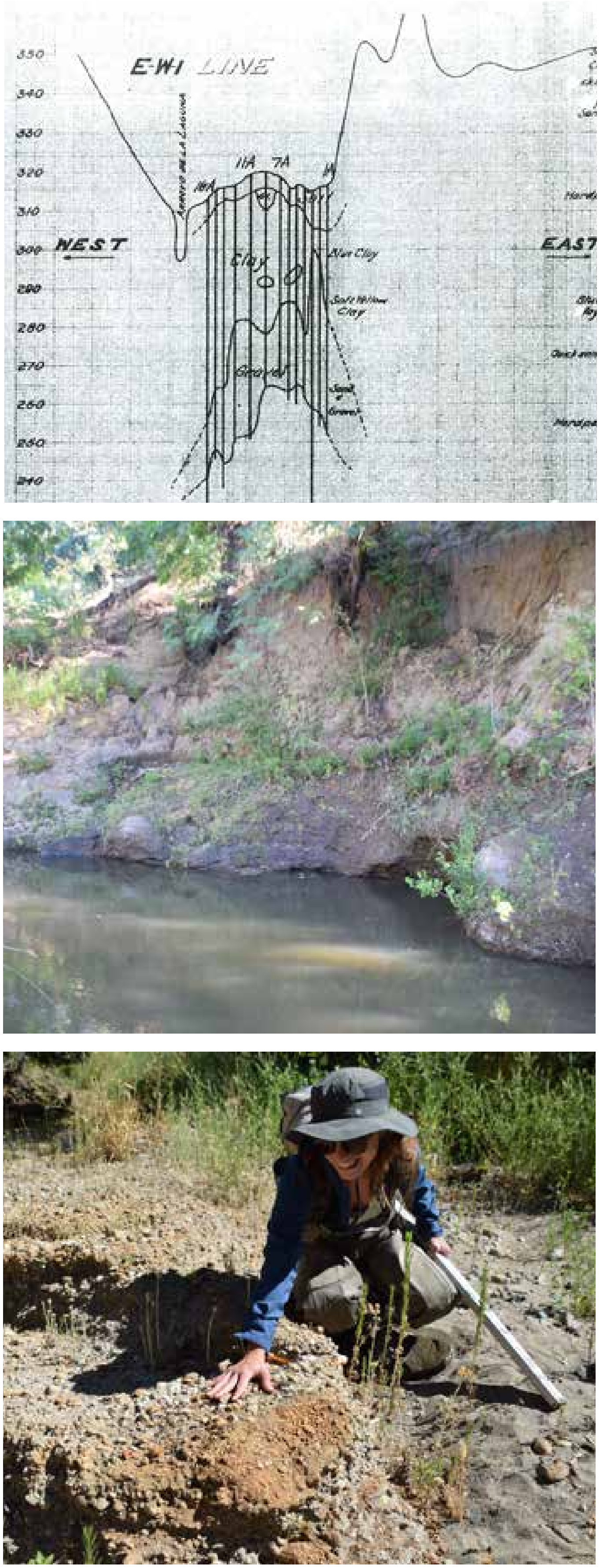
Figure 39. Channel map for Reach 5.

REACH 5- HARDPAN

Description

Reach 5 extends from the confluence with Line B.2.1 upstream to Bernal Avenue (Figure 39). This reach is marked by the presence of hardpan exposed in the channel, and currently forming a ledge approximately 1 m above the channel bed for most of the length. The channel is fairly narrow, with steep, nearly vertical outer banks. A terrace surface varying in height from 5-9 m is present throughout most of the reach (Figure 40). The banks show evidence of dry-ravel style failure, although many portions of the bank appear to not be actively eroding. Previous bank failures have recruited trees that are now in the channel as LWD, and a number of other trees are currently in danger of future recruitment. Some of the terrace slopes are seeping groundwater. Although a few riffles are present (7 over an 1,800 m distance) the majority of the reach length is characterized as a plane bed channel. There are some higher bar surfaces (about 2 m above the bed elevation) that appear to be activated during flows slightly higher than bankfull flows (i.e., approximately 1.5 to 2-year flows). The land use along the right bank is suburban residential, while the left bank is park land owned and maintained by the City of Pleasanton. The park contains an historical secondary channel of ADLL (at an elevation higher than the present mainstem channel bed), marked by the presence of remnant riparian vegetation.

Figure 40. Vertical outer bank and adjacent flat terrace surface (with riparian trees) in Reach 5.



This reach has more variable stratigraphy within the valley geologic deposits as compared to downstream reaches. Here is the first observed occurrence of a blueish clay deposit near the base of the exposed banks that was likely deposited in the historical Pleasanton Marsh Complex. We also observed a surface approximately 2-3m above the bed surface that was composed of consolidated gravels that have oxidized and turned a rusty red color, possibly an older stream channel. Using information from Bigelow et al. (2008), we see that Figure 41 shows an historical cross section near Castlewood Drive with stratigraphy that includes the blue clay, hardpan, and sands and gravels.

The channel has many elements indicating previous and ongoing incision. The channel incised to expose the hardpan, and has now cut through the hardpan, leaving it exposed above the bed (Figure 42). A culvert was observed to be hanging approximately 1.5 m above the current bed elevation. Near the middle of the reach, the field team observed an approximately 100 year old cottonwood tree rooted on the slope down to the historical channel bed, which is 2 m higher than the current bed elevation. We hypothesize that it rooted when the channel was at that location and receiving groundwater support. At several locations, riprap had been placed at the toe of the bank as protection from additional erosion. At the City of Pleasanton pump station, riprap was placed in 2000 on the pipe that traverses the bed when it became exposed due to incision (Figure 43). This riprap is likely currently serving as a small grade control. In general, the heights of the terrace above the current channel bed increase from the downstream (5-6 m) to the upstream (8-9 m) portion of the reach. This is counter-intuitive as systems that are incising generally have a greater distance between terrace surface and bed elevation further downstream, as the downstream reaches have had a longer duration of incision. However, we hypothesize

Figure 41. Historical cross section near Castlewood Drive (in Bigelow, 2008; original cross section from Williams, 1912); blue clay deposit at the base of the bank; oxidized gravel deposit.

Figure 42. Hardpan exposed above the channel bed.

Figure 43. Riprap placed on bed at pump station.

that the hardpan stratigraphy that is now exposed in this reach and in Reach 4 is holding the bed elevation more stable, keeping the current channel gradient fairly shallow; thus the difference in elevation between the previous channel bed elevation (the terrace surface) and current channel bed elevation would increase in the upstream direction. A longitudinal profile of the channel and the terrace/valley floor could help confirm this hypothesis.

Comparing current channel dimensions to historical dimensions can also help quantify incision that has occurred. In March 1902, Mr. B. Murphy, an employee of the Spring Valley Water Company, described ADLL as "Laguna Creek at the outlet of the "C" line of wells (downstream of Bernal Avenue) as 40 ft wide (12 m), 4 ft deep (1.2 m), with a velocity of 50 ft in 15 seconds [533 cfs]. Water raised 8 ft (2.4 m) during storm" (Williams 1912, taken from Bigelow et al. 2008). In comparison, the channel in this reach (from terrace edge to terrace edge) is generally 30 m wide and 8 m deep, however the bankfull channel is only approximately 10 m wide and 3 m deep. While we can't be certain exactly what part of the historical channel was described, it seems as if the channel today is at least deeper than historically.

The representative cross sections for this reach show that the channel is fairly narrow, with exposed hardpan sitting slightly elevated above the current channel bed (Figures 44 and 45). The outer bank slopes are steep, with a terrace running the entire length of the reach. The overall cross section shape is much more of a "V" rather than a "U" that is observed further downstream, indicating that the incision that is occurring in this reach is younger, and the channel has not yet widened.

The current land use along the banks is residential for the entire length of the right bank, and City of Pleasanton park land for the entire length of the left bank.

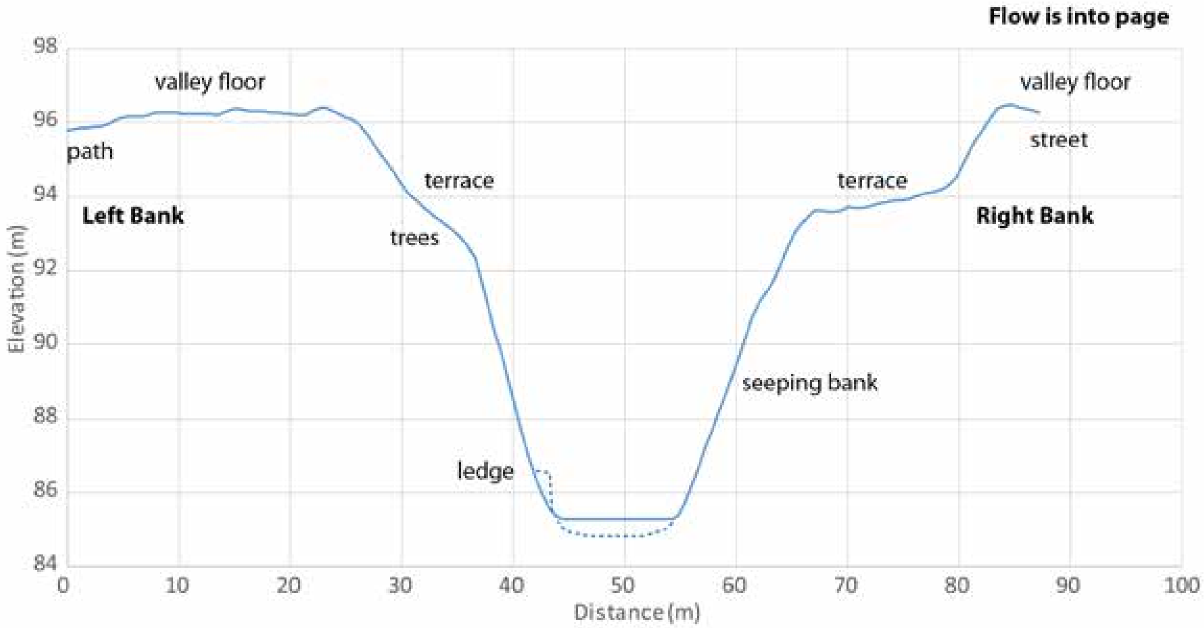
Current Evolution Stage

This reach is currently in CEM Stage IV (Incision and Widening). See summary Figure 55 for additional context.

Likely Future Evolution Stage

In the future we expect this reach to widen. Because of the presence of the hardpan in this reach and the downstream reach, we do not expect this reach to significantly incise further, unless a knickpoint works its way upstream (see more discussion on this in Reach 4). If this were to occur, incision would likely occur on the order of 2-3 decades. Instead, we anticipate erosion and failure of the outer banks, creating a wider channel cross section. Eventually the increased width will allow for deposition of bars and ultimately a floodplain.

Figure 44. Downstream representative cross section for Reach 5. Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation.


Flow is into page
valley floor
path
terrace
trees
Left Bank
ledge
seeping bank
terrace
valley floor
street
Right Bank
Elevation (m)
98
96
94
92
90
88
86
84
0
10
20
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40
50
60
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80
90
100
Distance (m)


Flow Direction


Flow is into page

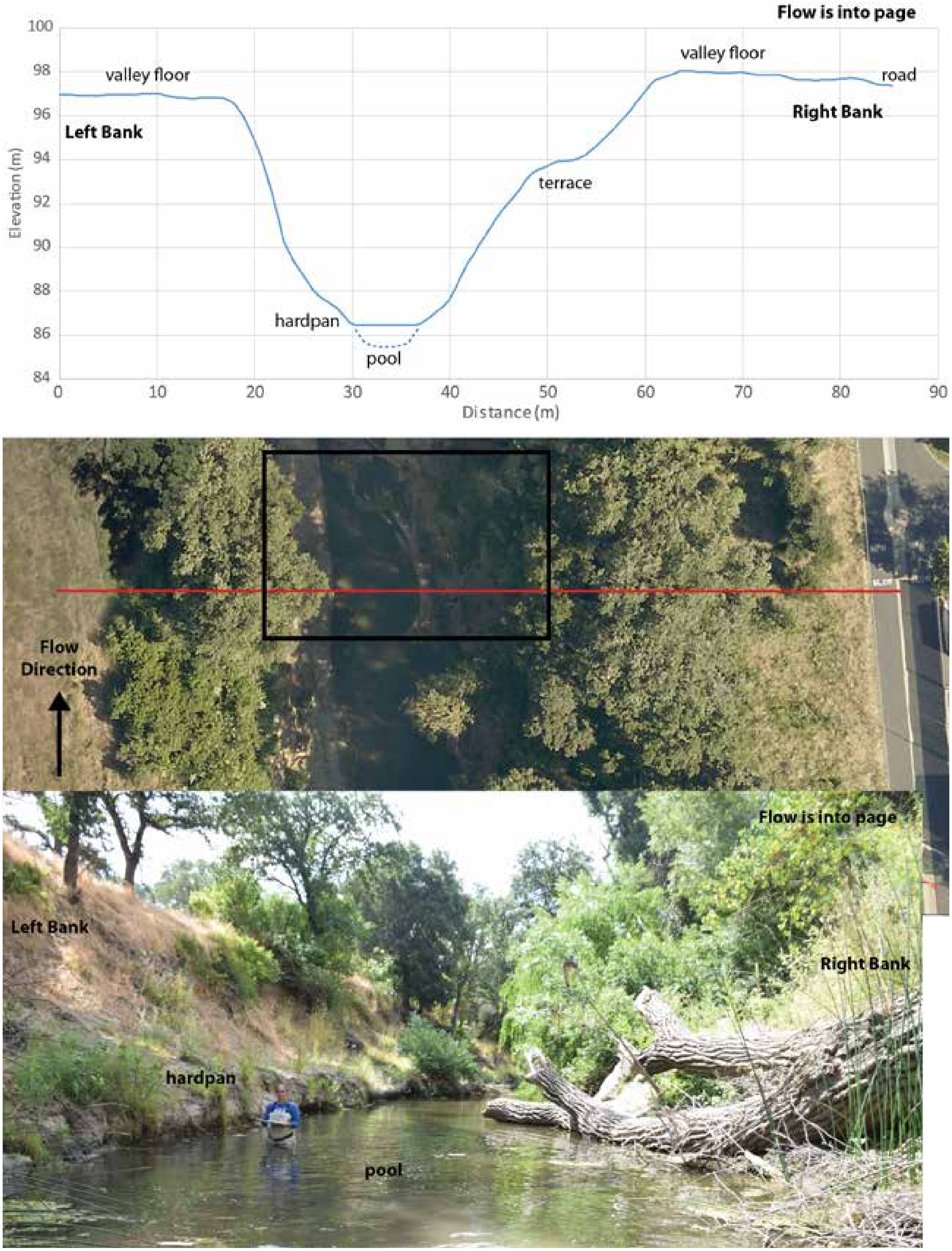

Figure 45. Upstream representative cross section for Reach 5. Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation.

Additional data/studies to do

Additional fieldwork could include a field-surveyed longitudinal profile that ties in with Reach 4; along with measures of terrace elevation (from Lidar) would confirm/refute the hypothesis of shallower current channel gradient.

Careful mapping of the exposure of hardpan, blue marsh muds, and consolidated gravels could help explain channel patterns that are observed and anticipate likely future evolution. Also, building a stratigraphic column, potentially using boring or well logs, would help identify the stratigraphic relationship between units observed in the banks.

While this report completed an initial estimate of structures/property on the right bank that are threatened by future widening, a more formal analysis should be completed, so that potential left bank widening projects could be most effectively planned.

Just downstream of the Bernal Avenue Bridge there is evidence of major bank erosion on both sides of the channel, suggesting that evaluation of the hydraulics and sizing of the bridge may be necessary.

Risks and Management

Like many of the other reaches, there is risk of further erosion of the outer banks due to channel widening that threatens to erode property on the right bank (Figure 46). This could be exacerbated if the headwardly eroding knick point moves through Reach 4, and begins to impact Reach 5. Erosion of the protective riprap placed on the pump station pipe that spans the channel bed may continue, leaving the pipe vulnerable to damage.

In terms of opportunities for proactive management, the left bank is entirely City of Pleasanton park area which could be laid back to limit/reduce erosion occurring on the opposite bank, without major changes to park function or alignment. An historical side channel still exists through the park, and, though its elevation is much higher than the current channel bed, and the frequency with which it activates is unknown, it could present an opportunity to engineer a solution to spread flows across a wider cross section in the reach and alleviate pressure on banks downstream. It could be evaluated for feasibility, and would increase channel complexity and habitat value of the stream. As with other reaches, an anticipatory management plan (Beagle et al., 2016) could be created to plan for failures that occur on the right bank, allowing fixes to occur that will work with the larger channel evolution in this reach, and will not deflect erosional problems onto adjacent properties.

Figure 46. Risks and opportunities for Reach 5.

REACH 6- HISTORICAL DITCH THROUGH THE MARSH

Description

Reach 6 extends from Bernal Avenue upstream to the Interstate 680 crossing (Figure 47). The reach overall is very homogenous, and maintains a simple shape likely due to its history as a ditched reach through the historical Pleasanton Marsh. The reach is fairly straight, except for the curve at the upstream end where it flows underneath the 680 bridge.

The right bank is a constructed constant slope that extends from the maintenance road at the top of bank down to the channel bed. This bank was laid back as part of a channel widening project in 1981 (Joe Seto, personal communication).On this bank, the upper two-thirds of the length has been cleared of woody vegetation, while the downstream third is dominated by eucalyptus trees at the top of bank. A number of drains that route runoff from the adjacent neighborhood are routed down the slope in concrete chutes. These chutes are all hanging above the current bed by approximately 0.5 m; additional investigation could resolve if this concrete was installed at the bed elevation or at the current elevation to determine if channel incision has occurred. Some have void space underneath the concrete, as erosion of the bank has removed soil material (Figure 48). Many portions of the reach have riprap placed at the toe of slope. The middle and upstream portion has a vertical slope at the toe, indicating recent channel incision of approximately 0.2- 0.5 m.

The left bank has woody riparian vegetation for the entire length, and has a terrace surface approximately 4-5m above the current bed elevation. There is evidence of small dry-ravel style failures of the terrace bank surface. Similarly to the right bank, the left bank also has a vertical slope at the toe indicating incision.

The channel pattern is mostly glide, with a riffle at the top (intentionally placed riprap that is forming a grade control), the middle as it flows over riprap (likely intentionally placed), and the bottom (intentionally placed riprap associated with the bridge footers) (Figure 49). Hardpan is exposed in the lower half of the channel reach, extending from Bernal Avenue upstream to the middle where a large low elevation bar has formed on the hardpan (Figure 50). There are no 1950s flood deposits or emerging floodplains in this reach.

At the downstream end of the reach, the Bernal Avenue bridge deck is high above the bed, but the bridge earthen footers impinge upon the channel cross section (Figure 51). The width between footers is fairly narrow, and likely causes a hydraulic constriction during high flows. As the channel passes through the footer, a steep riffle has formed, with a gradient much higher than the channel up or downstream of the bridge. The riffle gradient is approximately 2.7%. Likely because of the constriction, downstream of the bridge the banks have blown out due to eddying, with significant failures of both the right and left vertical banks. Because these banks are 10-12 m tall, failures contribute a significant volume of sediment to the channel. In addition, a very deep pool (too deep to wade) and an arcuate bar on the downstream side of the pool have formed due to the scour and resultant deposition from the constriction (Figure 52) that are technically in Reach 5.

The representative cross section shows the constant constructed slope of the right bank, and the terrace on the left bank (Figure 53). It also shows the slight break in slope on the right bank that

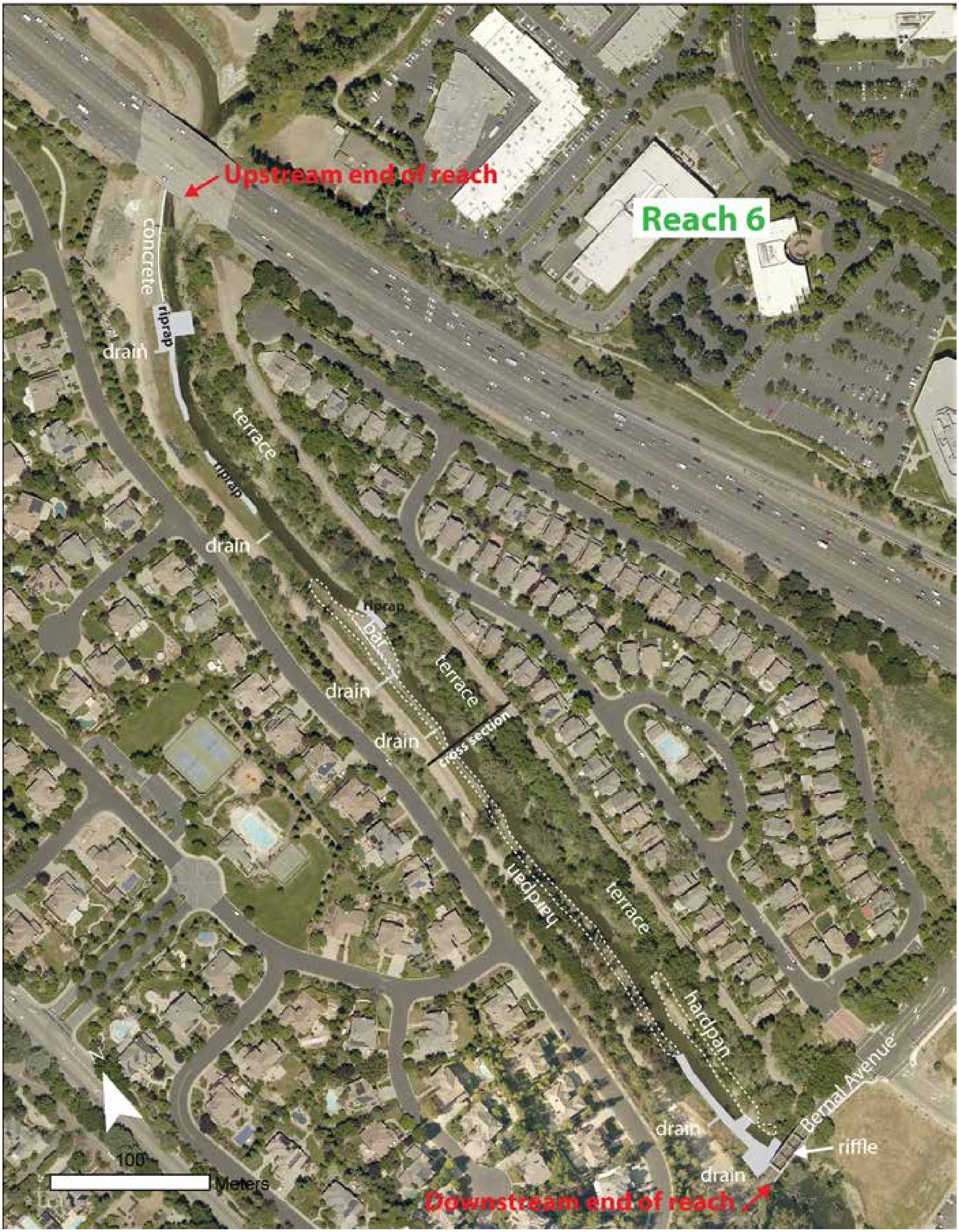

Figure 47. Reach 6 channel map.

Figure 48. Concrete drain with void space indicating erosion.

Figure 49. Riprap forming riffle at top of reach; riffle at bottom of reach under Bernal Avenue bridge.

Figure 50. Exposed hardpan on the right bank in the middle of Reach 6.

Figure 51. Bernal Avenue bridge footers.

Figure 52. Looking upstream at the pool developed on the downstream side of Bernal Avenue; looking downstream at the arcuate bar deposited at the downstream end of pool.

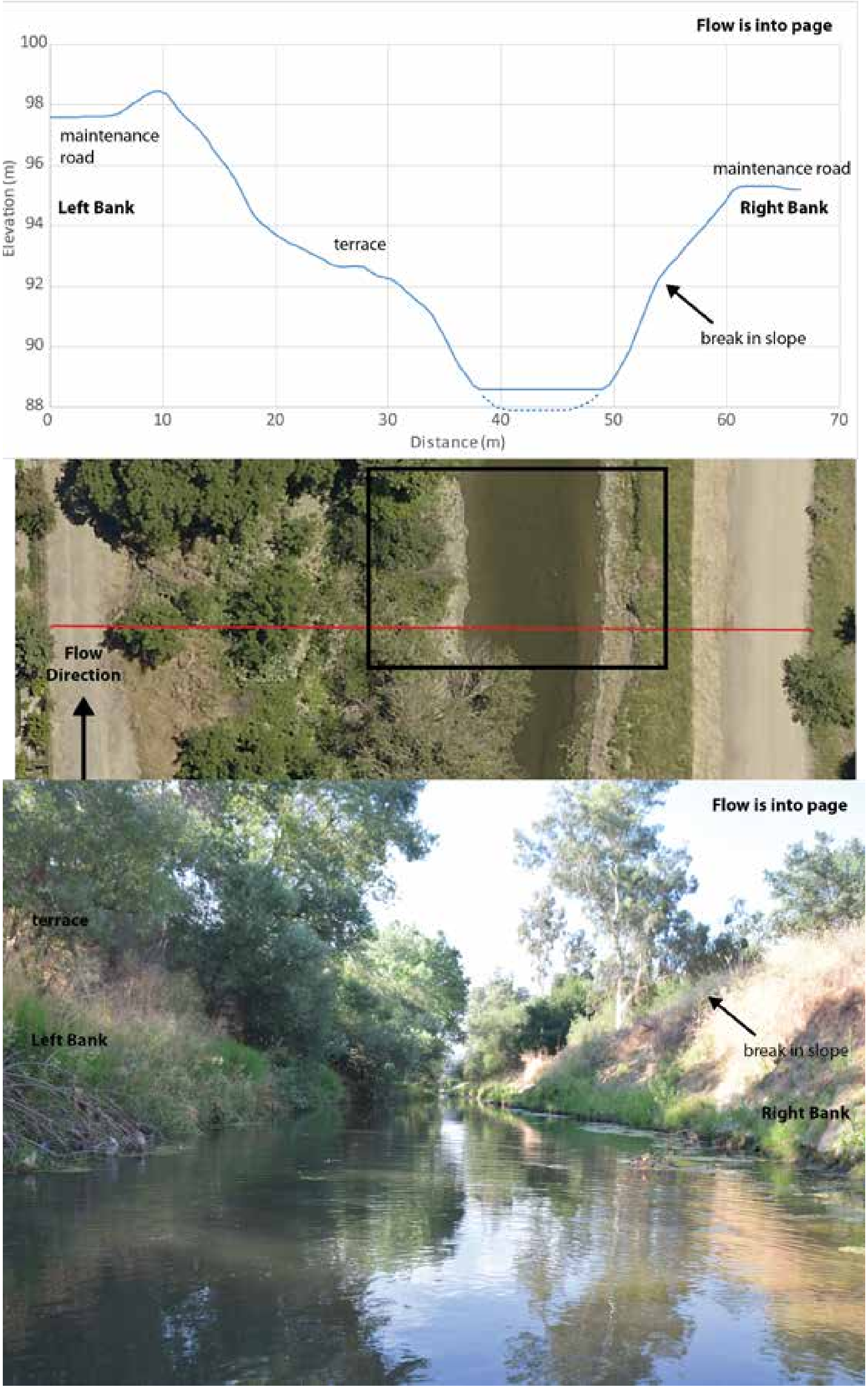

Figure 53. Representative cross section for Reach 6. Solid line shows elevations directly from LiDAR, while the dashed line shows approximate elevations from field observation.

corresponds with the terrace elevation. It also shows the "V" shape of the lower banks, and the vertical slope of the lowest portion of the bank.

The current land use on the right bank is a Zone 7 maintenance road, while the left bank has a terrace, maintenance road and then houses. This reach has no structures that are immediately in danger from bank erosion. However a large enough failure could damage the maintenance road or the Bernal Avenue bridge footers.

Current Evolution Stage

This reach is currently in CEM Stage I (Stability) although there is evidence of slight incision at the toe of slopes. See summary Figure 55 for additional context.

Likely Future Evolution Stage

We anticipate this reach to remain in CEM Stage I (Stability) especially given Zone 7's careful management of the reach. However instability could occur due to a downstream knickpoint that headwardly erodes up to this reach, or due to a major change in the footers of the Bernal Avenue bridge.

Additional data/studies to do

Hydraulic modeling of the Bernal Avenue bridge; the footers appear to be narrow, and causing a hydraulic constriction.

Monumenting and surveying the riffle underneath Bernal Avenue, monitor through time to detect any change.

Risks and Management

Risks in this reach are minimal, yet should be considered in a plan for the entire stream (Figure 54). It is possible, though unlikely that a knick point will move through this reach. More likely would include an undermining failure associated with the Bernal Avenue bridge footers, as well as rotational style failures of the right bank. If large enough, these failures could constrict part of the channel, which is fairly narrow in this reach. If one of the large trees (e.g. eucalyptus) were recruited or wind-blown and fell into the channel, it could block the narrow channel width at the Bernal Avenue bridge footer.

However, the right bank might provide opportunity to set the bank back or to create an inset floodplain, given that it has some available distance between the creek and the property boundary. The maintenance road could be narrowed, although it would need to remain wide enough to allow maintenance and construction vehicles, or it could be moved to the west so that it is immediately adjacent to the property boundary. The hardpan in the lower half of the reach should also be viewed as an opportunity because it will likely help hold the channel gradient.

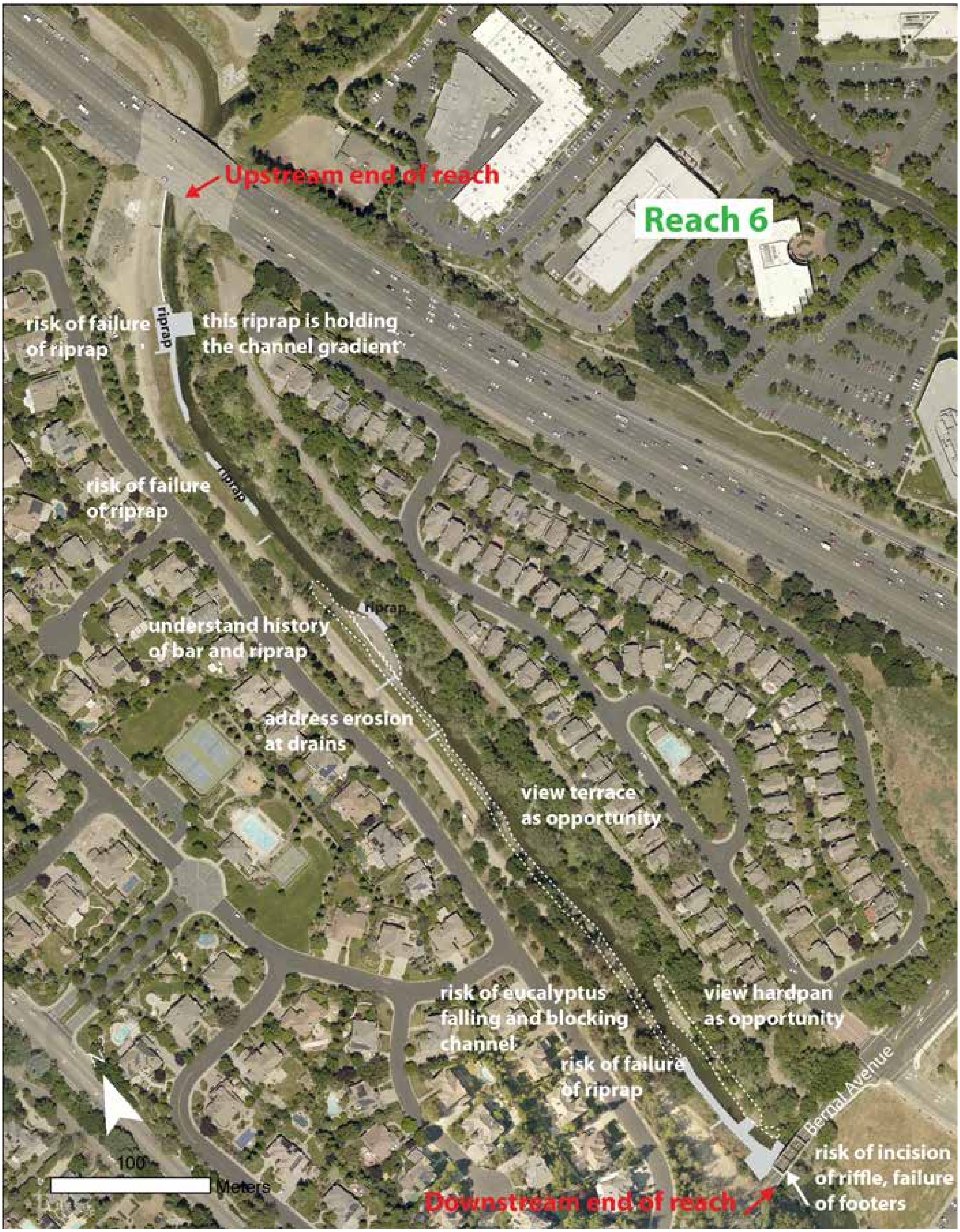

Figure 54. Reach 6 risks and opportunities.

NEXT STEPS

As we currently understand it, the ADLL Study Reach is a very dynamic reach due to its history of channel modifications, changes in upstream landuse and impervious cover, waves of incision that have caused resultant channel morphology adjustments, and it's overall position in the landscape as the drain of the entire valley. As a whole, the study reach is currently incising and widening, though the actual response is variable from reach to reach. Future evolution of the channel will depend on how climate change and further urban development will impact the region over the next several decades. For example, through analyzing the suitability of green stormwater infrastructure throughout the valley, we can quantify the reduction in peak flows at different return intervals. By analyzing these outputs using different hydrologic predictions, we managers may be able to evaluate the tradeoffs between using green infrastructure and widening with the creeks, against the impact along ADLL if no actions are taken in the future.

Although this report was based on a very limited field-based study of the reach, it was also supported by multiple previous studies within the watershed, as well as information from local landowners/managers, and the field team's and Zone 7 staff's personal experience in the channel network. This report is the culmination of observations and findings from each of these sources. Further testing and refinement of our collective understanding of the expected channel behavior and anticipated channel evolution will require monitoring, continued data gathering, and planning. However, this report can serve as a guiding document that allows Zone 7 staff to gather knowledge, check assumptions, and adjust their expectations about the channel at the reach scale.

In summary (downstream to upstream):

- Reach 1 is characterized by the erosional S-curves, and is morphologically most like the reaches downstream of Verona Road, likely because it has had a longer time period of adjustment, since the initial wave of incision and then the incision that progressed downstream to upstream after the 1950s floods. Locations in this reach where the flow changes directions (mimicking the direction of regional tectonic strain) appear to be nodes of increased erosion.
- Reach 2 appears to contain a smaller knick zone that could continue to migrate headward, and should be monitored.
- Reach 3 is currently controlled by the extensive riprap that was placed on the banks in the late 1990s and currently artificially relatively stable, yet this artificial stability is threatened by a downstream knick zone.
- Reaches 4 and 5 have outcrops of hardpan in the channel bed, which has influenced the evolution and current morphology. Incision in these reaches appears to be more recent than in Reach 1. The area impacted by the removal of the concrete weir in Reach 4 should be monitored.
- Reach 6 is controlled not only by hardpan, but also by its history as a constructed reach, placement of riprap, and the bridge footers underneath Bernal Avenue. Although this reach has evidence of incision, it has riffles at the top and bottom helping to control the overall gradient.

Given the history of evolution in the past, we expect each individual reach to continue to dynamically evolve into the future. The use of CEMs allows for an understanding of the channel history, the current geomorphic process, and the likely future condition. We note that many factors may affect future channel evolution, such as continued upstream development, water and sediment management actions, climate change, large earthquakes, regional flood detention or restoration projects, revetment, and large flood events. Although it is impossible to know exactly what the future holds, we can use the CEM, along with best professional judgement, to frame a range of possible future conditions at approximately mid-century (2050) and end of century (2100).

At mid-century, we expect the overall channel pattern to continue to be dominated by incision and widening.

- Reach 1 will likely continue to incise and widen, with significant widening and floodplain building occurring in the two S-curve locations.
- If the knick zone in Reach 2 does in fact migrate upstream, we would expect the channel banks to begin to widen.
- We do not expect any significant change to occur within Reach 3, assuming that the management remains the same. However, if the downstream knick zone progresses into this reach, we would expect undermining and likely failure of the riprap.
- Reaches 4 and 5 will likely continue to incise and widen, perhaps developing nodes of erosion similar to in Reach 1. Careful monitoring of the old weir location will determine if a wave of incision develops.
- Reach 6 may begin to widen, as the incision is controlled by the elevation of the riffle underneath Bernal Avenue. This may cause failures that threaten the stability of the maintenance road.

The future at the end of the century is much more difficult to predict, as longer term processes such as climate change and land use will play a pivotal role in water and sediment delivery to the reach. Despite the large uncertainty, and in expectation of continued urbanization in the watershed, and increased storm intensity with climate change, we expect:

- Reach 1 to evolve into CEM Stage V, with significant aggradation developing an inset floodplain within the widened reach, thus protecting the banks from further erosion. This likely will occur sooner in the S-curve locations.
- Reach 2 will also likely evolve to aggradation and development of an inset floodplain.
- The future of Reach 3 depends on any future waves of incision and the resulting management decisions made by the Country Club. It is unclear if management will dedicate resources to maintaining/replacing the riprap in an effort to keep the channel static, or if a future restoration effort will set the banks back and allow the reach to evolve. Maintaining the channel in its current configuration may be an impossible task.
- The future of Reaches 4 and 5 depend on the amount of continued incision. If a headcut does not migrate from the old weir location (within Reach 4), and the hardpan is able maintain the channel dimensions, we would expect the reaches to slowly widen and begin to approach aggradation.
- The evolution of Reach 6 is dependant upon the future of the Bernal Avenue bridge. If the footers and riffle remain stable, we expect only minor widening of Reach 6.

The summary graphic below (Figure 55) shows CEM stage by reach and by decade for the past, the present, and the future.

Summary table:

Reach	Current stage	Potential evolution	Risks	Opportunities
1	**IV / V** Widening/ Incision and Aggradation	**V** Aggradation	Continued migration of the S-curves, increased bank erosion, undermining the railroad trestle; residential property loss or threatening structures; possible recruitment of large riparian trees into the channel	The development of a large, functioning node(s) of floodplain in the S-curve locations, and the creation of complex habitat areas; Stabilizing the toe of slopes, to slow the bank erosion rate; Tree planting on the top of banks, create an "anticipatory management plan"
2	**III** Incision	**V** Aggradation	Continued or increasing bank failure actively threatens residential property	Bank setback opportunities in space on left bank between the top of bank and the fairway, including pilot project to be constructed Summer 2019; Managers should anticipate the need to move non-essential structures away from the top of the right bank.
3	**I** Stability	**?** Depends on management	Possible incision of due to headward migration of the knick zone, which will undermine the toe of the banks, leading to failure of riprap, and increase instability of the channel banks.	Both banks are Country Club property and could be part of a larger effort to lay back the banks or create an inset floodplain; invasive plant management focusing on English Ivy.
4	**IV** Widening/ Incision	**IV** Widening/ Incision	Possible new wave of incision due to weir removal; increased outer bank failures; risk to Foothill Road;. potential for undercutting of the Line B.2.1 outfall structure.	Laying back the left bank (golf course) would limit the erosive force against Foothill road; plant riparian trees at top of bank; Install energy dissipator at outfall of Line B.2.1 structure to reduce scour; create an anticipatory management plan with landowners, especially the Country Club.
5	**IV** Widening/ Incision	**IV** Widening/ Incision	Erosion of the outer banks due to channel widening; property at risk on the right bank.	Lay back the left bank to limit/reduce erosion occurring on the opposite bank; re-activate historical side channel; create an anticipatory management plan
6	**III** Incision	**?** Depends on management	Incision from downstream knickpoint or failure of Bernal Avenue bridge footers; right bank erosion; tree blocking the channel at Bernal Avenue bridge	Right bank has space available; exposed hardpan will help to hold channel gradient

	1800	1900	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Now	2050	2100
Reach 6	Broad, multi-thread channel, stable throughout	II	III	Incision throughout	incision and widening throughout	widening, some areas of relative stability	aggradation throughout	relative stability, minor reworking of 50s flood deposits	minor reworking of 50s flood deposits	Incision throughout	III	III	III	III	IV	?
Reach 5		stable through middle reaches	III								III	IV	IV	IV	IV	IV V
Reach 4			III								III	IV	IV	IV	IV	IV V
Reach 3			some aggradation?								I	I	I	I	III	?
Reach 2									III		III	III	III	III	IV	V
Reach 1		II	III						III		III	IV	IV	IV V	IV V	V
Overall	I	II	III	III	IV	IV	II	III	III	III	III	IV	IV	IV	IV	V
	stable	disturbance	incision	incision	incision and widening	widening	disturbance	incision	incision	incision	incision	incision and widening	incision and widening	incision and widening	incision and widening	widening and aggradation

Legend

I - Pre-disturbance: channel is stable and in dynamic equilibrium
II- Disturbance: time during and immediately after a disturbance
III- Incision: channel is downcutting
IV- Widening and Incision: channel banks actively failing and widening
V- Aggradation: deposition of sediment along channel banks and in-channel
VI- Dynamic Equilibrium: deposition of sediment, establishment of vegetation, meandering channel
VII- Floodplain Formation: dynamically stable channel, with proto-floodplain

Figure 55. Summary graphic illustrating channel evolution stage for each reach through time. Because of the relatively recent disturbance and continued adjustment of ADLL, stages VI and VII are not currently found in the study reach.

Beyond informing understanding about possible future channel response, a future Visioning process that involves all the stakeholders sitting down together to come to a consensus could help with management issues in a number of ways. This report has highlighted specific data that will be helpful, and specific opportunities that should be considered in the future. For instance:

> **Key missing data:** We encourage the collection of a few basic datasets to allow for greater understanding of discreet reach behavior and future monitoring of channel adjustment. This includes a field surveyed pool/riffle longitudinal profile that extends for the full study reach. In addition, a number of monumented channel cross sections in specific locations will allow for the identification of change, as well as quantifying the rate of change. Hydraulic modeling or specific monitoring of bank toe locations could assist in identifying potential restoration locations or the best methods of toe stabilization.
>
> **Civic engagement:** We also encourage local stakeholders to learn technical aspects about the channel response from current restoration efforts, such as the 3 Verona project, and the Castlewood Country Club pilot project. These smaller, sub-reach specific projects will provide valuable information about how projects and subsequent channel evolution interact and how the adjacent channel reaches respond to the project. Additionally, the stakeholders could choose to use this geomorphic evaluation as a springboard towards completing a full Visioning process for ADLL.
>
> **Landscape-scale planning:** Zone 7 and the larger group of stakeholders (e.g. the landowners, cities, and agencies) have the opportunity to think at a larger scale and approach the challenge presented by this reach with innovative restoration concepts that utilize multi-benefit solutions both at the parcel and the reach scale. The study reach has a significant number of opportunities, namely the adjacent Pleasanton City Park property and Castlewood Country Club property with room available for larger scale projects that will likely benefit all stakeholders of the reach, if work can be done proactively.

We emphasize that the erosion and instability of this reach of ADLL is a problem that goes beyond just a single land owner. At the largest scale, the stakeholders must consider the entire watershed area draining to ADLL, and think about the timing and volume of the delivery of water and sediment to the reach. The Valley has experienced tremendous growth since the 1960s and 1970s, significantly changing the drainage dynamics, and more development is slated to occur in the future. This reach is intimately linked with to the current and future land, water, and sediment management efforts occurring upstream. Appropriate land use planning in the watershed that focuses upon preventing increases in runoff, either by limiting development or by incorporating urban greening and low impact development, will be essential to the solution.

In addition, climate change is expected to alter the timing and intensity of storms, changing the discharge delivered to the channel yet again. Climate change, along with additional development and changing management of the watershed means that the hydrologic “goal posts” are moving; efforts to address the stability and evolution efforts in the study area must be aware of the moving goal posts, and think about various future scenarios.

At a smaller scale, stakeholders must think about each individual reach within the study area, its current stage of evolution, and how it relates to upstream and downstream reaches. At this scale, land use planning along the channel, and permitting structures and/or bank hardening features must consider the larger reach, and avoid exacerbating existing erosion, or impeding likely future evolution patterns. Knowing that the reach is currently incising and widening should guide decisions about the placement of future structures or infrastructure alongside the channel. And thus, at a minimum, projects should be planned and approached at the reach scale, with all landowners in the reach having a stake in the outcome of the project. Collaboration by landowners on both banks and throughout the reach length will be essential for the large-scale visionary projects to succeed.

For example, the length of Country Club property along the left bank in Reaches 1, 2, and 3 offer the ability for a very large-scale project, that works with channel evolution, and that has the benefit of occuring on land owned by a single owner. However, even if the project occurs solely on the left bank, the project should be a full collaboration with all of the landowners in the reach, both left and right banks. And despite the left bank currently providing undeveloped space for the channel, properties on the right bank should be subject to careful land use planning and permitting, so as not to exacerbate the current instability.

While the current Country Club pilot project is beneficial because it will lay the banks back along a short reach, there are many similar opportunities along the entire length of the study area, both on the right and the left banks. Some of these opportunities locations are short in channel length, while others have much longer lengths to take advantage of. All of these parcels should be considered when considering innovative and large-scale projects.

In Reach 3, the majority of the banks are currently fully rip-rapped and providing artificial stability for the banks. However, there is potential in the future that this riprap could be undermined. And thus, the benefit of this report is that it provides the stakeholders time to plan for the future, so that if the riprap does become undermined, a coherent reach-wide plan may already under development. And similarly in Reach 5, the City of Pleasanton park property offers a wealth of opportunity to plan for a long-term, large-scale, visionary project, perhaps laying the banks back or reactivating the historical secondary channel along the left bank. Knowing the evolutionary history of this reach, stakeholders should create a plan so that incision in this reach is ultimately arrested, and an inset floodplain is created. Because of the high property values of the houses along most of the length of the right bank, it might be economical to focus upon big idea projects that relieve erosional pressure by adjusting the left bank, as it may have minimal impact on the functioning and usage of the park. However, discussions with the stakeholder group (e.g. Zone 7, landowners, land managers, cities, agencies) should explore options for cost-sharing, given that the large projects would likely occur along the left bank, yet landowners along the right bank would receive the benefit of additional bank stability.

Upstream management of water, sediment and nutrients are critical for stemming continued impacts to ADLL, and Zone 7 is actively engaged in managing stormwater, slowing flows and storing sediment through floodplain widening projects, and other projects in collaboration with SFEI, the EPA, cities of Pleasanton, Dublin and Livermore, and other partners. These ongoing efforts are as important as active and anticipatory management of this dynamic ADLL reach and should be considered jointly.

This document provides a resource to both Zone 7 and other Arroyo de la Laguna stakeholders for short and long-term management and restoration concepts regarding the evolving stream channel. With the multiple goals of conveying flood flows, protecting habitat for wildlife, and allowing for stream evolution, the management of ADLL requires a clear understanding of its past and present condition, as well as an approach of anticipation that will allow stakeholders to plan ahead, together.

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