Dry Creek Watershed Sediment Source Reconnaissance Technical Memorandum

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Introduction

Problem statement

Since construction of the flood control channel on lower Alameda Creek in the 1970s, net sediment deposition has required periodic dredging to maintain flood capacity in the channel as it passes through Union City and Fremont. Because dredging is costly, and because the permitting process for channel maintenance is becoming more challenging, the problem of controlling deposition within the flood control channel now includes identifying upstream sediment sources within the watershed and investigating which sources are potentially controllable. Since coarse sediment (sand and gravel) is the primary grain size deposited in the flood control channel, the watersheds that are small, steep, and proximal to the channel that supply dominantly coarse sediment may have a disproportional influence on depositional processes within the flood control channel.

Previous reconnaissance-level studies have identified some locations of potentially substantial sources of sediment within the watershed. For example, Collins (2005) identified reaches of the Arroyo De La Laguna tributary and the upper Alameda Creek tributary as possible large sources based upon current channel morphology. A recent sediment budget for these reaches estimated that approximately 6% of the sediment passing through the Niles gage (from 1994 – 2006) was derived from net channel erosion within this study area, despite the reaches only comprising roughly 0.25% of the entire watershed stream network length (Bigelow et al. 2008).

Although large sources of fine sediment are derived from the upper watershed (e.g. roughly 62% of the total sediment load at Niles was derived upstream of Verona gage, Bigelow et al. 2008), sources of coarse sediment that are directly connected to the flood control channel merit consideration as well. One such source is the Dry Creek tributary watershed, the largest tributary watershed entering the flood control channel downstream of the Niles gage. However in addition to Dry Creek, a couple of other small unnamed tributaries exist downstream of the Niles gage (Masonic Home, Landmark Letters, and Niles Reservoir watersheds, named by SFEI), as well as the larger watersheds of Stoneybrook Creek, Sinbad Creek, and Vallecitos Creek between Niles gage and the town of Sunol. These watersheds also have the potential to deliver large volumes of coarse sediment, however no information on these watersheds currently exists.

Sediment sources proximal to the flood control channel, such as Dry Creek, are typically coarser due to lower particle attrition from shorter transport distances and limited opportunities for storage on floodplains or in-channel bars. In addition, since the response time of Dry Creek is shorter than that of the larger Alameda Creek watershed, water and sediment provided by Dry Creek reaches the flood control channel earlier than the flood peak from Alameda Creek reaches the same location. Thus, Dry Creek sediment entering the flood control channel has a high likelihood of being deposited at the confluence due to lack of transport capability of Alameda Creek due primarily to a wide oversized channel cross section and low water depth during common floods (<1:2 year return interval).

Initial observations of the flood control channel show the presence of a large, coarse tributary fan immediately downstream of the confluence (McKee, 2009 page 11). Additionally, previous data collection and study by Collins (2005) shows that the highest rates of sedimentation within the flood control channel occur adjacent to the Dry Creek confluence. This leads us to the question, “Is the Dry Creek tributary a potential large source of coarse sediment to the Alameda Creek flood control channel?”

Initial questions

SFEI was retained by the Alameda County Flood Control and Water Conservation District (the District) to conduct a reconnaissance study of the Dry Creek tributary watershed to assess the relative contribution of sediment to the flood control channel. This study was designed as an initial effort to broadly look at the sources, storage, and transport of sediment in the watershed at a qualitative reconnaissance level (i.e. it is not a quantitative sediment budget).

To help determine if Dry Creek is a potential large source of coarse sediment to the flood control channel, we considered a number of related questions, including:

- What are the primary sources of sediment in the watershed?
- Where are the primary areas of sediment storage?
- How efficiently is sediment routed through the Dry Creek flood control channel?
- What are the indications of high sediment supply from Dry Creek?
- Can we estimate a sediment yield from the Dry Creek watershed, and compare it to measured yields in Alameda Creek?

Setting

Watershed location and character

The Dry Creek watershed drains an area of approximately 25.4 km^2 (9.8 mi^2), consisting primarily of steep terrain in the East Bay Hills (Figure 1). The Dry Creek watershed comprises approximately 1.5% of the total Alameda Creek watershed area and 2.8% of the Alameda Creek watershed area below reservoirs (Calaveras, San Antonio, and Del Valle Reservoirs). The watershed terrain is characterized by substantial change in elevation from the headwaters down to the East Bay Plain, with channel gradients ranging from 0.70 to 0.001 (Appendix Figure 1). Land use within the North Fork of the watershed includes a new ridgetop housing development and a golf course (Stonebrae Country Club) in the headwaters, and Garin and Dry Creek Regional Parks (East Bay Regional Park District) in the lower portions. Additionally, the North Fork has an on-channel pond, Jordan Pond, constructed in the 1950s for recreation. One-third (7.9 km^2 (3.1 mi^2)) of the watershed is upstream of Jordan Pond, which likely traps most of the sediment load from this portion of the watershed (Figure 2). Land use in the South Fork of the watershed includes Dry Creek Regional Park (East Bay Regional Park District) and smaller private parcels used for ranching and grazing.

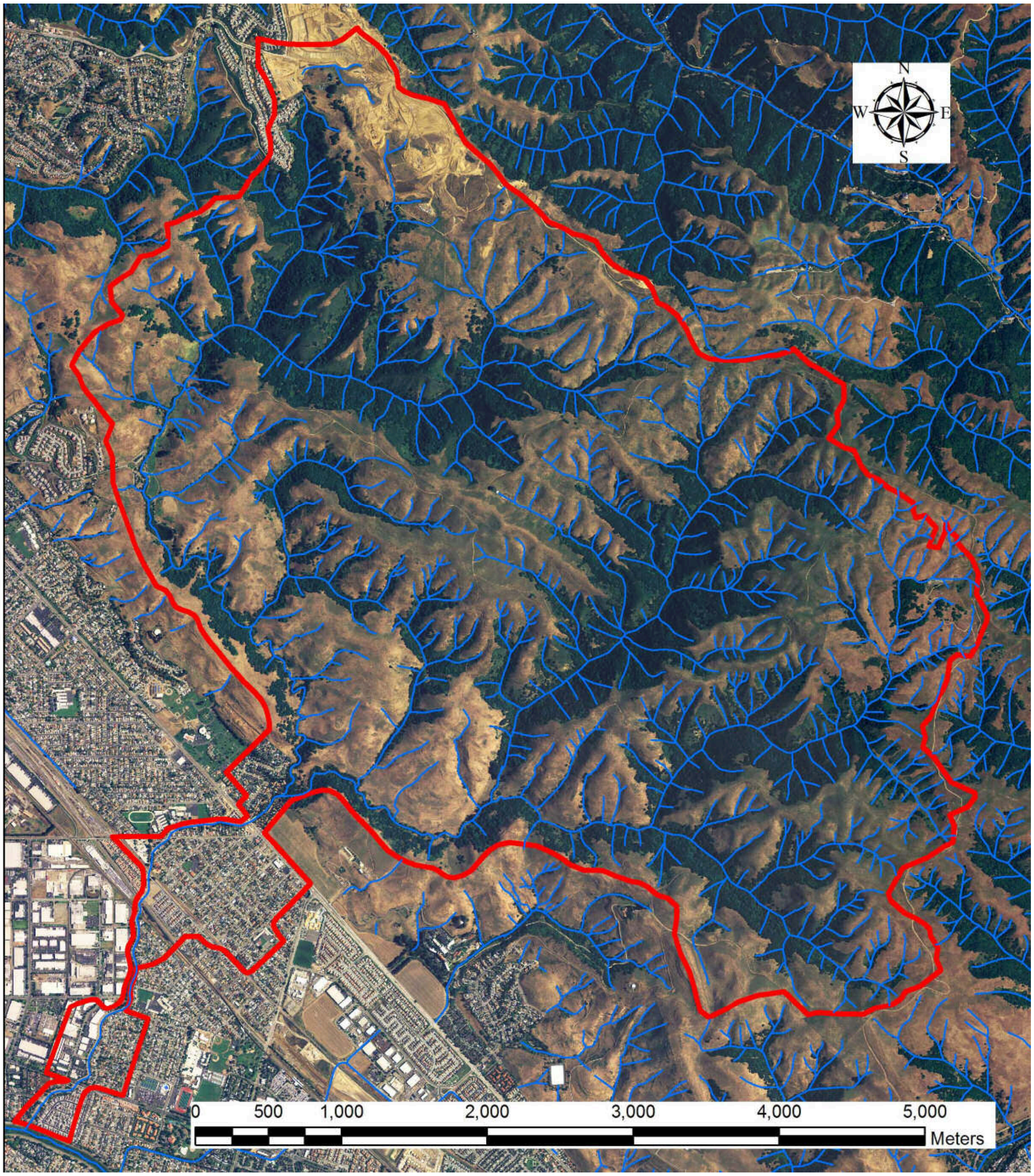

Figure 1. The Dry Creek watershed. Watershed boundary is shown in red, and channels are shown in blue, on top of 2005 NAIP aerial imagery. The confluence with the Alameda Creek flood control channel is in the lower left corner of the figure.

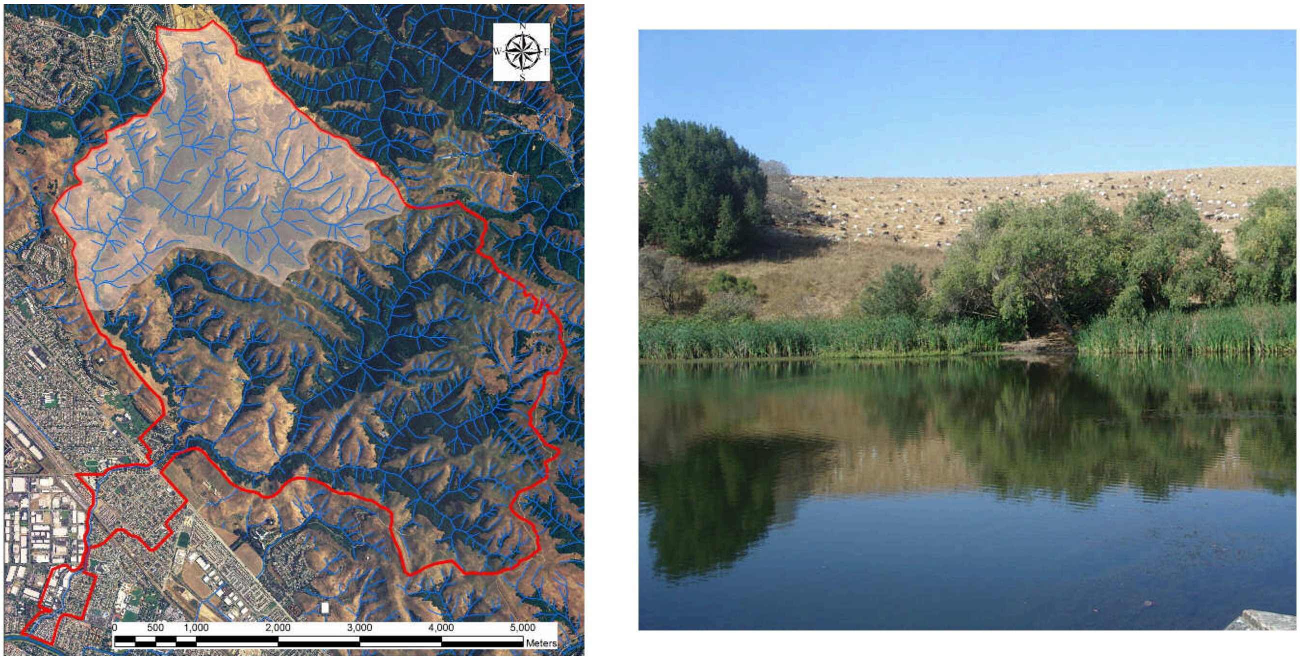

Figure 2. Left: The Dry Creek watershed with area upstream of Jordan Pond highlighted in pink. Right: Photograph of Jordan Pond, looking west.

Bedrock geology

The bedrock geology underlying the watershed is important for determining the topography of the hillslopes, the soil type that is produced, the erosion potential, and the style and size of sediment that is delivered to the channel network. The Dry Creek watershed is largely underlain by Cretaceous sandstone units, with smaller areas of Miocene sandstone, and Jurassic Coast Range Ophiolite (Appendix Figure 2).

Stream channel

The North and South Forks are natural channels in the uplands, with only minor influence from pedestrian bridges, culverts, and re-routing adjacent to ponds. The forks come together just west of the base of the hills, upstream of Mission Boulevard. At Mission Blvd the creek becomes channelized, first entering a large concrete channel to route the flows under Mission Blvd, then flowing in a trapezoidal channel armored with gabions (on both its bed and banks) until it reaches Alvarado-Niles Road. Between Alvarado-Niles Road and the confluence with the Alameda Creek flood control channel the channel is still a trapezoidal flood control channel, however we did not find any evidence of gabions in this reach.

A longitudinal profile of the South Fork of Dry Creek (Appendix Figure 3) illustrates the steep headwater reaches that are largely affected by the physical properties of the underlying bedrock, the more gentle but graded profile of the South Fork mainstem, and the low gradient in the flood control reach with numerous grade controls (bridge footers). The steep low-order channel reaches are predominantly sediment sources, supplying sediment from the adjacent hillslope processes (landslides and soil creep), and from scouring debris flows in the channel. These reaches transition into higher-order sediment storage reaches in the mainstem of the South Fork. This reach historically stored sediment on its floodplain, and likely still does during periods of high sediment supply (e.g. El Niño events, 1950s floods).

However, despite the potential for sediment storage, the channel is generally incised and mostly disconnected from its floodplain and currently functions primarily as a transport reach. Finally, the flood control channel is also a transport reach as designed, due to its trapezoidal shape, low roughness, and maintenance regime.

The USGS has operated a streamflow gage on Dry Creek (11180500 Dry C at Union City CA) just downstream of Mission Blvd for the years 1917-1919, and 1959-present (Appendix Figure 4). For the period of record, the peak streamflow occurred on January 9, 1995 with a measurement of 1,680 cfs and a gage height of 5.32 ft. No sediment data has ever been collected at this gage location.

Sources of sediment within the watershed

For this reconnaissance study, we aimed to observe examples of the various potential sources of sediment in locations across the watershed, from small steep low-order headwater channels to larger low gradient high-order channels. Based on our reconnaissance-level qualitative observations, the primary erosional processes appear to be channel debris flows in low order channels and streamside slides and channel incision in mid to higher order channels, while hillslope erosion, roads, trails, and urban sources comprise smaller sources. Below we discuss each sediment source in more detail.

Channel erosion

Many types of channel erosion processes are occurring, on many different scales, and in many different locations within the channel network. For example, some processes such as incision are occurring throughout the watershed, whereas others, such as streamside sediment slides, typically only occur in certain stream orders. Here we summarize our observations as they relate to sediment sources.

1st and 2nd order channels: These channels are characterized by very steep gradients with small drainage areas. Sediment sourced from these channels is primarily from hillslope landslides/debris flows that are directly connected to the channel, soil creep from the adjacent very steep hillslopes, and stream scour from episodic channel debris flow events.

3rd and 4th order channels: These larger channels are characterized by larger drainage areas and lower gradients, and include the larger tributaries and the North and South Forks. In addition to any sediment input from directly connected hillslope landslides and soil creep, the older valley alluvium from the channel bed and banks are also sources of sediment. Channel incision is the dominant process occurring in these reaches upstream of Mission Blvd. Incision is observed on both forks, however, incision appears slightly more severe on the North Fork (Appendix Figures 5 and 6) below Jordan Pond, a typical channel response below dams. Incision is evident from exposed tree roots, abandoned historic floodplains, hanging tributaries, and undercutting of pedestrian bridge footers. In some locations the channel has incised down to bedrock; the less erosive bedrock will limit further incision, potentially causing lateral erosion through bank erosion in the future. The channel has incised through older valley alluvium (valley fill), which consists of coarse rounded gravel, cobble, and boulders. This alluvium is one likely source of coarse sediment sourced from the watershed. Based on our limited observations, the causes of incision appear to be due to several forcing factors, including continued tectonic uplift of the East Bay Hills (1.5 mm/yr; Kelson and Simpson, 1995), degradation following periods of high sediment supply (e.g. El Niño events, Coe and Godt 2002) typical of North Coast Range channels (e.g. Appendix Figure 29), adjustments due to decreased sediment supply below Jordan Pond, and potentially adjustments to downstream channel straightening or simplification.

In addition, bank erosion is occurring in the high-order channels where the channel is adjusting its form by eroding laterally into the steep banks of the older valley alluvium (Appendix Figure 7). This process typically occurs on the order of 1 to 100s of m in length, 1 to 2 m in height, and 10 to 100s of cm in lateral retreat. Where the high-order streams impinge on steep colluvial hillslopes or terraces, streamside slides are common (Appendix Figure 8). These slides are typically on the order of 10-50 m in length, 2 to 20 m in height, and laterally remove up to 2 or 3 m of material. For example, a single average size slide can supply about 800 m^3 of sediment over a period of time ranging from a single flood event to a season or several years.

Landslides/Debris flows

The East Bay Hills contain numerous landslides due to their steep topography, bedrock geologic properties, and periodic high intensity or duration precipitation events. Landslides as referred to here include slow-moving earth flows and rotational and translational slides. Large landslides in Alameda County (>8,000 individual slides) have been mapped (Roberts et al, 1999), and include a number of slides within the Dry Creek watershed (Appendix Figure 9). This publication reproduces work completed by Nilsen (1975), based upon aerial photograph interpretation, and only includes slides that occurred prior to 1966. These features are primarily old and ancient slow-moving slides and earthflows with a thickness greater than 3 m. More recent mapping has been completed by Majmundar (1996), but at this time we have not been able to review it due to it not being available on-line and the time and cost of purchase.

In addition to large, deep-seated landslides, the East Bay Hills are also prone to shallow, fast-moving hillslope debris flows (Appendix Figures 10 and 11). Debris flows are fast-moving flows of mud, gravel, and organic material that commonly mobilize from landslides. The Walpert Ridge area was mapped by the USGS after the 1998 El Nino rainstorm to show the locations of hillslope debris flows that occurred during the February 2-3, 1998 storm (Coe and Godt, 2002). Over 500 debris flows were mapped, with maximum concentrations of 30 per 0.25km^2. Most of these locations were debris flows that mobilized from shallow, freshly-activated soil slips on hillslopes. To be clear, the term debris flow can be used to describe hillslope soil slip features, or in-channel scouring erosional processes that typically occur in steep low-order channels and swales. Coe and Godt (2002) used aerial photographs to map hillslope debris flows, the soils slips that occurred on convex or concave slopes that are not part of the stream network (Figure 3). Consequently, all of the features mapped did not necessarily deliver material to the channel network. Of greatest concern for this study were mapped flows that were directly connected to the channel network. We targeted a few mapped locations to specifically observe the potential sediment contribution from this source. Appendix Figure 12 illustrates one example location where a long debris flow was directly connected to the North Fork, delivering sediment to the North Fork channel during the 1998 event. For this study, we did not directly calculate the potential volume of material delivered across the watershed during the 1998 event, but due to the high quality of the USGS data, such a calculation could be done in the future.

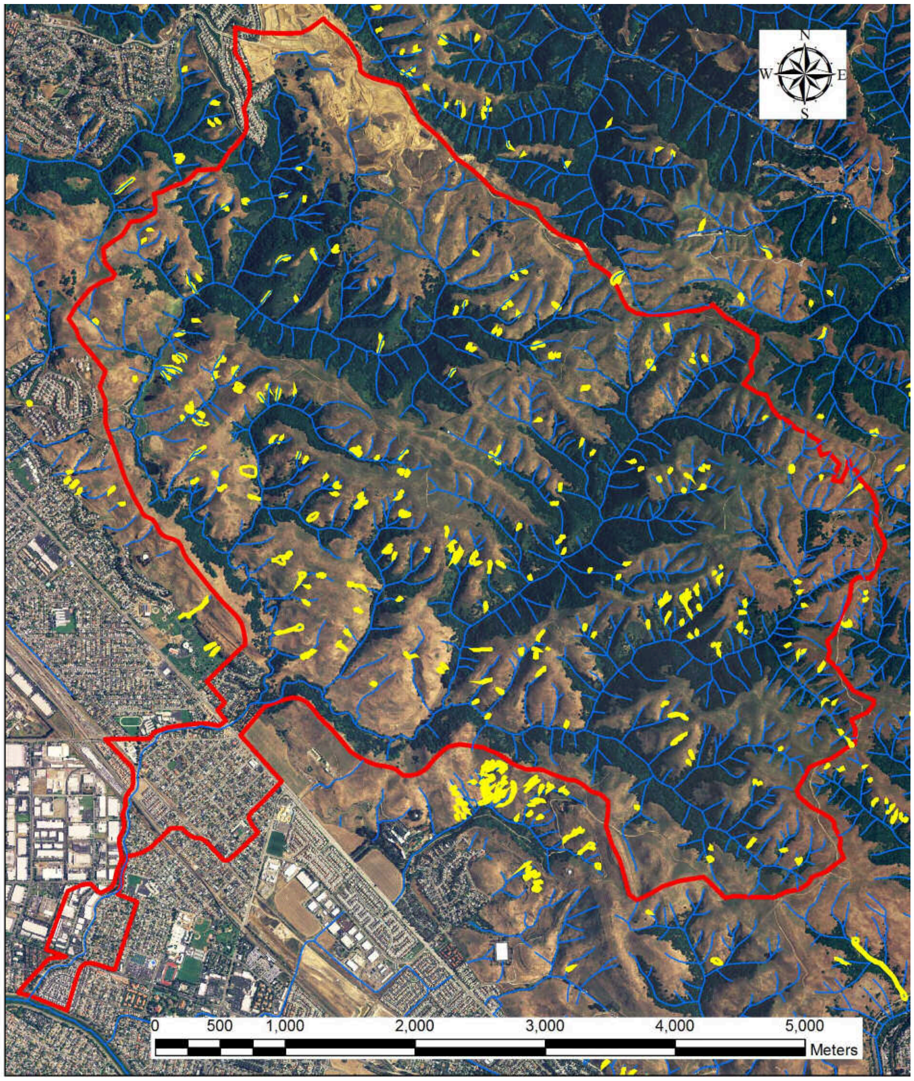

Figure 3. Hillslope debris flows mapped by Coe and Godt, 2002 in the Dry Creek watershed.

Hillslope erosion

Portions of the Dry Creek watershed have historically, and currently are grazed by cattle. Within Garin and Dry Creek regional parks, cattle are currently kept at a low density (approximately 200 head of feeder steer on 1,200 acres), and are removed during the summer months (R. Mueller, pers. comm.). Country Club lands in the upper watershed were grazed this year for the first time in four years. And practices on private parcels are unknown, although cattle densities are presumed to be greater.

Although detailed information on the intensity of grazing was not collected, the minor grazing pressure put on the hillslopes is visually evident by the formation of terracettes on the hillslopes, cattle trails, cattle stream crossings, and compacted soils. Although the grazing likely contributes to some fine sediment delivery and increased runoff from the hillslopes, based on our reconnaissance observations, these effects appear (1) minor in comparison to mass wasting and incision sources of sediment from the watershed, and (2) localized in nature. For example, Appendix Figure 13 shows a location of a watering trough with many cattle trails leading to it, and trails leading into the channel where cattle can escape the heat. Slight modification of watering areas and addition of fencing along channels would likely reduce most of the direct fine sediment supply impacts from grazing. However increased flow (hydromodification) is more difficult to address as it is a broader issue relating to soil compaction, changes to the vegetation regime (grasses and trees) and changes to the channel density and the role of roads and trails in channeling water.

Roads and trails

We considered the numerous fire roads and recreation trails as potential sources of fine sediment. In other Bay Area watersheds, poorly maintained roads can potentially contribute fine sediment (1-10% of the total sediment budget)(Pearce et al, 2005; Collins et al, 2009). Our limited reconnaissance in the EBRPD property suggested that the roads are generally well maintained, include appropriate erosion-control features, and are not a substantial source of sediment. From our limited observations, we were only able to find one example of road runoff contributing to a hillslope landslide (Appendix Figure 14). However, we did not observe road segments on private property, which may be less well maintained. We did not explore the impact of roads upon hydromodification, or increases in flow volume and peak flow to channels; because roads have greater soil compaction and are able to route runoff to swales, gullies, and creeks, watersheds with higher road densities may have greater water and sediment effects.

Urban sources

Two areas of the watershed are urbanized: the extreme northern tip of the watershed contains the Stonebrae Country Club residential and golf course areas (Appendix Figure 15), and the lower portion of the watershed from the confluence of the North and South Forks, downstream to the confluence with Alameda Creek contains residential and industrial uses in Union City. Although new construction, especially in areas of high topographic relief, can contribute sediment from surface erosion, the area in the northern watershed is entirely upstream of Jordan Pond which likely traps most of the sediment. East Bay Regional Park District staff have noted (anecdotal) increased runoff (hydromodification) in the North Fork following the Stonebrae development.

The lower urban area is approximately 1.5 km^2 in area (6% of the total Dry Creek watershed area), is fully serviced by storm drains, and is immediately adjacent to the Dry Creek flood control channel (Appendix Figure 16). Generally this area is relatively flat, completely built-out, and has limited new construction. For these reasons, we estimate this portion of the watershed is contributing very minor amounts of sediment, possibly on the order of 20-30 t/km^2yr, similar to the sediment yield on Zone 4 Line A, an analogous low relief urban watershed in Hayward (McKee et al., 2009).

Locations of sediment storage within the watershed

In addition to sources of sediment, the field team also aimed to observe examples of various potential locations of alluvial sediment storage within the watershed. The primary locations are ponds, floodplains, and in-channel storage. Note, we did not focus upon hillslope colluvial sediment storage (e.g. storage of landslide deposits on the hillslope, Appendix Figure 17) because this sediment is not delivered to the channel network on management timescales (<50 years).

Ponds

Jordan Pond, located on the North Fork of Dry Creek, is likely the largest location of sediment storage within the watershed. All of the coarse sediment and likely most of the suspended sediment is trapped in the pond, as the pond only overflows when the water level reaches the spillway elevation. Trapping efficiencies in small reservoirs range from 80-95% (Dendy 1974, 1982 as reported by Reid and Dunne 1996). The pond was built (it has an earthen dam on the south side) in the 1950s for recreation purposes, and was originally approximately 9 m (30 ft) deep. Due to rapid accumulation of sediment, the pond historically was dredged, with spoils dumped and graded on the adjacent area of valley flat. Dredging stopped in the mid 1980s because the pond is considered habitat for the Red-Legged frog, a threatened species. Currently the pond is approximately 4.3 m (14 ft) deep (R. Mueller, pers. comm.). A smaller, and further upstream pond (Newt Pond) was also constructed on the North Fork, but quickly filled in with sediment; the dam was removed and a new channel was cut in the 1970s, and the area no longer traps sediment (R. Mueller, pers. comm.).

In addition to these two mapped ponds, the watershed also contains a handful (<10) of smaller stock ponds (Appendix Figure 18). These ponds are in various states of connection to the channel, and various maintenance regimes, and would require greater study to determine which, if any, of these smaller ponds are trapping sediment from other portions of the watershed. Based on our reconnaissance observations, it appears these small ponds have very low trapping efficiency, and would only contain a small volume of sediment when filled during periods of high sediment supply (e.g. large storm and flood events). In general, while small stock ponds trap some portion of the sediment, they also typically induce downstream erosion due to release of “hungry water”, or water that is carrying very little sediment.

Floodplains

Historically, floodplains along the North and South Fork mainstems, as well as along the reach downstream of Mission Blvd were likely locations of significant sediment storage. However, because most of the channel network is now incised, the channel is generally disconnected from its floodplain, almost entirely eliminating this storage process. We observed a handful of remnant floodplain locations, including one immediately upstream of Mission Blvd (Appendix Figure 19). Also, in a third order tributary we observed a historic depositional package of sediment within the narrow valley area, with a lag of coarse cobbles and boulders on the surface. We hypothesize that during the 1950s flood events many debris flows and landslides occurred in the 1st and 2nd order tributaries, delivering sediment to the high-order low gradient channels where deposition occurred due to the high influx of sediment and wood. We now only see remnants of the packages, as the channel has incised through them, returning to grade, creating cut and fill terraces. On a smaller scale, EBRPD staff report observing similar filling of low gradient high-order channels from high sediment supply from steep low-order channels during the 1998 El Niño event, followed by incision through the fill material in subsequent years (see Appendix Figure 29). In addition, many pedestrian bridges and culverts were blown out by sediment influx during this event (R. Mueller, pers. comm.).

In-channel storage

Sediment that is supplied to the channel network is transported downstream when the channel has enough stream power to move it. Even during small flood events, the creek is able to transport fine suspended sediment (mud and silt) and fine bedload (sand). However, it takes a larger flood event to transport larger grain sizes such as gravel, cobble and even boulder. This coarse sediment is often temporarily stored in the channel bed and as bars. While the location of these bars may be similar over time, the individual clasts of coarse sediment moves from one bar to another during flood events. We observed in-channel bars to be very common in the high-order reaches upstream of Mission Blvd.

In the trapezoidal flood control channel, storage takes the form of a thin veneer of sediment on the active channel bed or in larger, more stable packages of sediment (Appendix Figure 20). We hypothesize that these packages of sediment are deposited during single large flood events (e.g. the 1998 El Niño event) based upon the lack of sorting observed in a handful of exposures (Appendix Figure 29). These packages may be more difficult for the channel to remobilize due to vegetation growth and elevation above the thalweg. Based upon cross sections in the channel as-builts (see following section) it appears that similar packages have been deposited in the past, and were subject to removal during past channel improvement projects.

Sediment transport in the Dry Creek Flood Control Channel

Here we look at the reach of Dry Creek that extends from Mission Blvd, downstream to the confluence with the Alameda Creek flood control channel in the context of efficiency of sediment transport (Figure 4).

Figure 4. Left: Aerial photograph showing the Dry Creek flood control channel extending from Mission Blvd (upper right), downstream to the confluence with the Alameda Creek flood control channel (lower left). Right: field photograph showing typical characteristics of the reach.

Channel construction and maintenance history

We searched the Alameda County Public Works Department Map and File Room archives for information relating to the channel construction, modification, maintenance, or dimensions to help us understand the past and present sediment contribution and transport in the channel. Although not all projects are listed below, the most relevant to this study are included.

None of the files contained information about why projects were constructed or maintenance was completed. However, we can hypothesize that the channel was experiencing instability, either bed incision or bank erosion, and that the instability was severe enough to warrant the County spending funds on these channel projects. Based upon the 1993 slope repair, and the 1996 backfilling and gabion installation, we suspect the channel was experiencing erosion, suggesting high shear stress on the bed and banks, and competence to efficiently transport suspended and bedload sediment through this reach.

In 1975, the concrete structure extending from Mission Boulevard, upstream 75 m was constructed. The plans include creating the concrete channel bed and retaining walls, as well as placing concreted stone onto the existing concrete weir and bed slope at the top of the reach.

In 1988, the channel from Railroad Avenue upstream to Mission Blvd was improved by constructing gabion channel bed and bank armor, contouring the channel banks to a 1:2 slope (Appendix Figure 21). These as-built plans appear to describe the gabions that we currently observe in the field.

In 1993, slopes were repaired from Alvarado Niles Road upstream to the BART tracks. A total of eight discrete locations were repaired, using 512 m^3 (670 yds^3) of backfill material and 510 tons of riprap.

In 1996, channel maintenance occurred from Alvarado Niles Road upstream to Whipple Road. Both excavation and backfilling of the channel occurred to re-contour the channel slopes to a 1:2 slope. Gabion mats and riprap were installed (Appendix Figure 22).

Current channel configuration

The Dry Creek flood control channel is currently a trapezoidal channel with both bed and banks armored by wire basket gabions from Alvarado-Niles Road upstream to Mission Blvd (Appendix Figure 23). The gabions currently exposed at the bed surface for approximately 50% of the reach length. It appears that the clasts filling the gabions are a mix of native rock and imported rock. For most of the channel length, the bank gabions are not visually apparent. Both vegetation and a veneer of sediment cover the gabions.

Efficient sediment transport

Based primarily on the limited amount of bars and sediment storage, the Dry Creek flood control channel appears very efficient at transporting any sediment, including coarse sediment, that is supplied to it. In addition, the trapezoidal shape, the exposed gabions, the lack of constrictions or debris, and low roughness all suggest that bedload is able to be passed downstream (Appendix Figure 24). Also, each of the concrete box culvert road crossings were all free of sediment deposition. Although not completed for this reconnaissance study, estimates of stream power (Shields stress, etc.) and mobile grain sizes classes (e.g. silt, sand, gravel) could be calculated or modeled for peak flows at the gage station location, using gage records, channel geometry, slope, and estimates of roughness.

Historical sediment transport and deposition from the Dry Creek Tributary

While we have been focusing on present-day sediment transport through the engineered Dry Creek flood control channel on the East Bay Plain, it is important to loosely evaluate the historical sediment transport and deposition along this segment of Dry Creek. Based on the longitudinal profile of Dry Creek (Appendix Figure 3), it is possible that much of the sediment load from the Dry Creek tributary was historically deposited as an alluvial fan where Dry Creek exits the East Bay Hills. This location marks a major break in both slope (high to low gradient) and transition from narrow valleys to an unconfined plain, which are typical locations for sediment deposition in the form of fans and floodplains (e.g. the Niles Fan). Results from SFEI's current Alameda Creek Watershed Historical Ecology project could elucidate this possibility, and provide more context for Dry Creek's historic channel pattern, connection to Alameda Creek, and likely sediment transport and storage characteristics.

Sediment deposition in the Alameda Creek Flood Control Channel

Observation of a tributary fan

The existence and persistence of large tributary fans at the confluence where a high sediment load tributary enters a larger channel is well documented in the geomorphic literature (Benda and Dunne, 1997; Rice, 1998; Benda et al, 2004a; Benda et al, 2004b; Rice et al, 2006). These locations have a typical suite of responses including upstream flattening of the longitudinal profile, channel widening, and finer grain sizes, and downstream steepening of the profile, and coarser grain sizes (Figure 5). A large, persistent fan exists at the confluence of Dry Creek and the Alameda Creek flood control channel. This fan is visible on aerial photographs taken from 2007 back to 1993, however, because the low quality of many of the photographs, the variable season the photograph was flown, and the dense fan deposit and channel vegetation, a quantitative analysis of fan dimensions through time was not feasible.

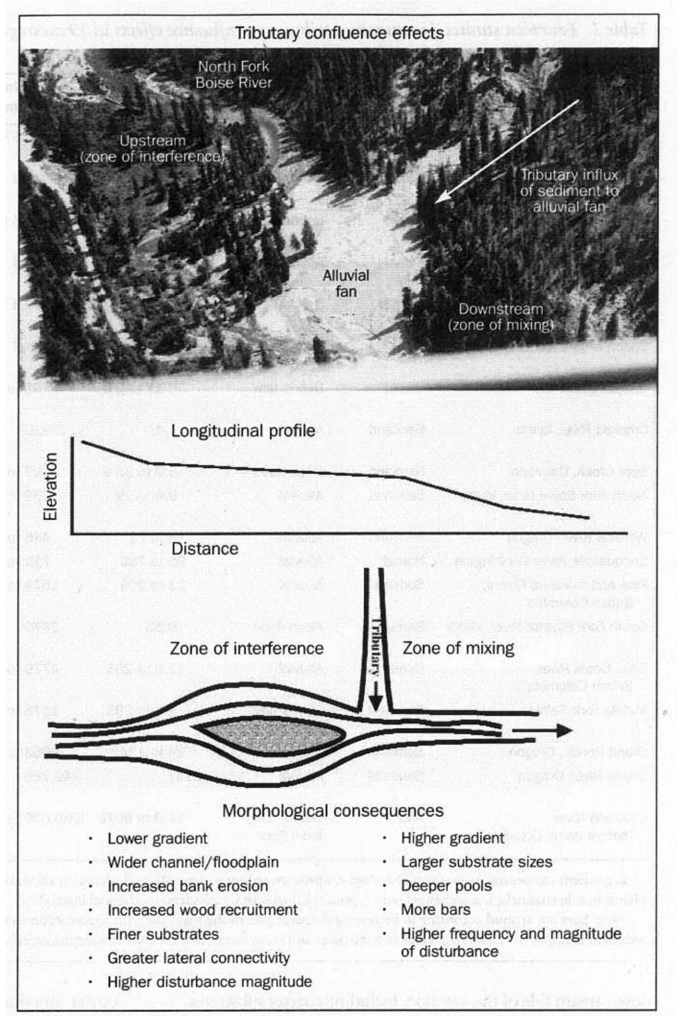

Figure 5. Description of a tributary fan (modified from Benda et al, 2004b).

Fan description

The current tributary fan deposited in the Alameda Creek flood control channel is located immediately downstream of the confluence with Dry Creek. The low flow channel of Alameda Creek is pushed towards the left bank as it is deflected by the presence of the fan (Figure 6). The fan is composed largely of loose sediment, primarily sand, gravel, and fine cobble (Appendix Figure 25). Many of the clasts on the fan surface were the same lithology as those observed in the Dry Creek channel (sandstone), however an extensive analysis of clast lithology within Dry Creek and of sediment deposited both up and downstream of the fan was not completed. In August and September 2009 the fan was densely vegetated with annual species including: Bulrush (*Scirpus acutus*) Cocklebur (*Xanthium spinosum*), cattail (*Typha latifolia*), curly dock (*Rumex crispus*), sweet clover (*Melilotus indica*), fireweed (*Epilobium brachycarpum*), atriplex (*Atriplex triangularis*), Horseweed (*Conyza Canadensis*), and smaller amounts of other species.

In early June 2009, SFEI staff conducted bulk sediment sampling on this fan; the vegetation was much shorter and less dense, allowing for greater observation of the fan surface. In addition, a cross section was surveyed in approximately the middle of the fan, illustrating general channel dimensions, the natural levee along the low flow channel, and the complex topography on the bar surface related to flow pathways (Appendix Figure 26).

Figure 6. Left: Aerial photograph showing the fan (outlined in yellow) formed within the Alameda Creek flood control channel by Dry Creek, as shown in 2007. Flow in Alameda Creek is from right to left. Right: 2009 aerial photograph showing the same location; Alameda Creek low flow channel is clearly deflected towards the left bank due to the Dry Creek fan.

Estimate of volume

We simplified the current geometry of the tributary fan immediately downstream of the confluence to allow for an estimate of its volume. We assumed that the fan is roughly a rectangle with average dimensions of 105 m in length, 31 m in width, and 1.1 m in thickness. However, to better capture the variability, we divided the fan into five pieces, measuring the length, width and thickness (elevational difference between the top of the fan surface and the adjacent thalweg) for each piece to estimate the total volume of material currently stored in the fan. Combining these measures provides an estimate of roughly 3,570 m^3 (4,670 yds^3) of sediment that is deposited at this location. Using a bulk density conversion of 1.6 metric tons/m^3, we calculate the fan to currently contain approximately 5,700 metric tons of material. This is a conservative estimate because we did not consider any of the material on the left bank side of the channel as part of the current fan. For comparison, previous dredging operations on the Alameda Creek flood control channel have removed between 20,600 and 145,000 m^3 (27,000 and 190,000 yds^3) of material (Collins, 2005).

Longitudinal profile

A thalweg longitudinal profile of Alameda Creek was surveyed using a laser range finder and a stadia rod for a selected reach upstream and downstream of the Dry Creek confluence. Because tributaries with high sediment supply often produce a “bulge” or knickpoint in the profile, representing sediment delivered by the tributary that has not yet been removed by the mainstem channel (Benda et al, 2004b), we wanted to test the hypothesis that Dry Creek would cause a bulge in Alameda Creek’s longitudinal profile. Tributaries that create such confluence effects typically are either of relatively large size (drainage area) compared to the receiving mainstem channel, or have uniquely high or coarse sediment yields (Rice 1998, Benda et al. 2004a). Although the Dry Creek watershed drainage area is relatively small in comparison to Alameda Creek, and would have a low probability of confluence effect according to Benda et al. (2004a), a tributary fan is apparent as shown by the bulge in the longitudinal profile, suggesting the sediment yield from Dry Creek is either high or coarse and persistent. In addition, a wedge of sediment is backed up behind (upstream of) the fan, representing backwater deposits caused by the constriction of the tributary fan on the mainstem channel (Figure 7). The volume of material in storage upstream of the confluence was not calculated, but is likely equivalent or exceeds the volume in storage in the fan, underscoring the noteworthy influence of the Dry Creek tributary in not only supplying sediment to the Alameda Creek flood control channel, but also causing sediment deposition in the flood control channel behind (upstream of) the fan.

Using the longitudinal profile data, we also were able to plot the channel gradient of Alameda Creek as it traverses the fan (Figure 7). Upstream of the fan in the backwater deposits, gradients are low (0.5 to 1%), but increases substantially (3 to 6%) as Alameda Creek crosses the fan. Additionally, we visually estimated the dominant bed grain size in Alameda Creek as we surveyed the longitudinal profile (Figure 7). Upstream of the fan in the backwater deposits, grain sizes were fine, ranging from silt to sand. However bed grain sizes increase as the channel crosses the tributary fan, ranging from sand up to cobble.

Our observations of morphological effects from the Dry Creek tributary fan on the mainstem of Alameda Creek are consistent with the confluence effects summarized in the literature (Benda et al. 2004a, 2004b, Rice et al. 2008). Upstream of the fan we observe a wedge of sediment from backwater deposits, producing a wider, lower gradient, and finer grained channel. On the fan itself we observe a narrower, higher gradient, and coarser grained channel. And downstream of the fan, the channel returns to a lower gradient and finer grain size. These changes are also visually apparent in example photographs showing a riffle upstream of the fan and in the fan (Appendix Figure 27).

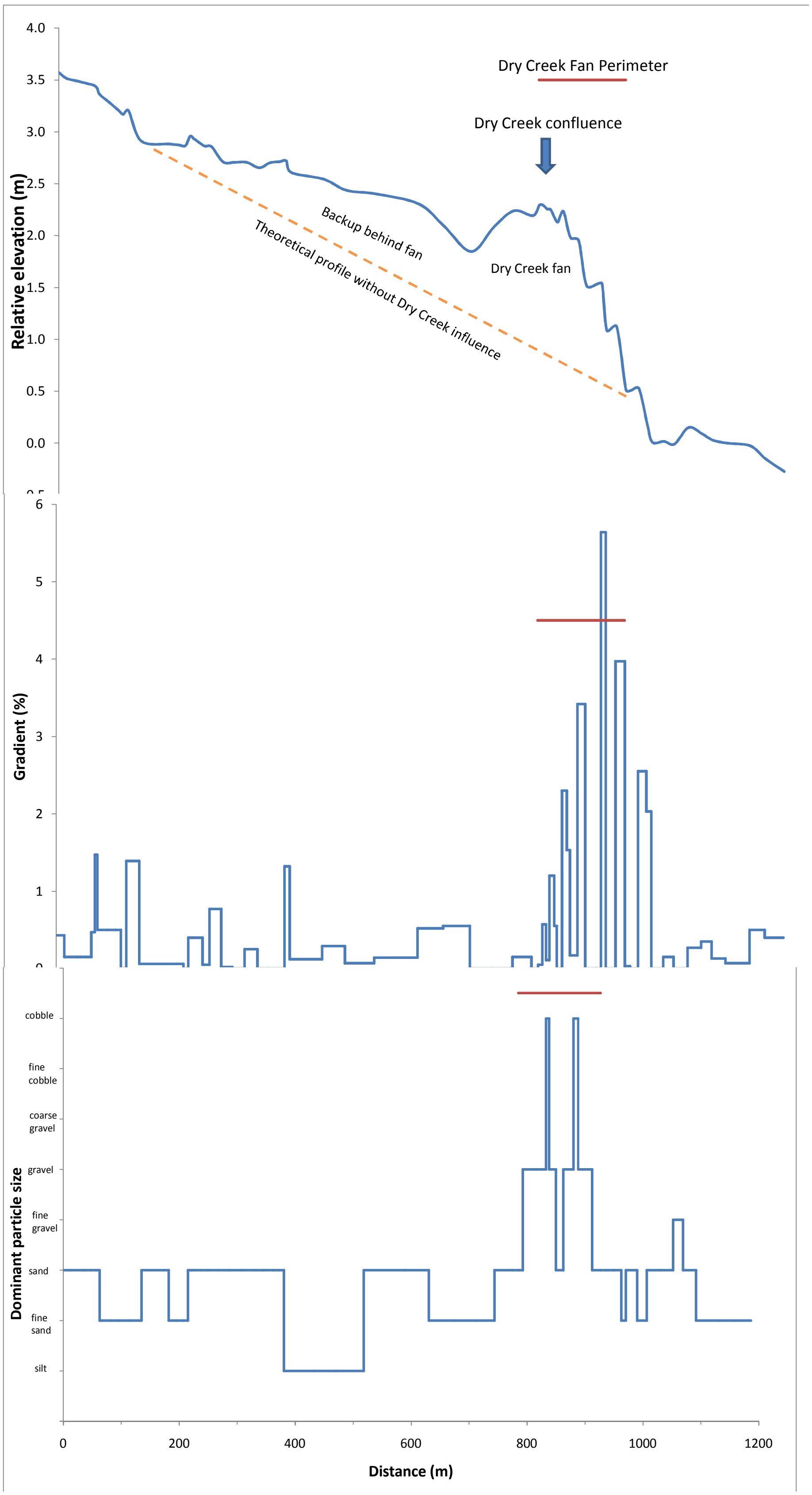
Relative elevation (m)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Dry Creek Fan Perimeter
Dry Creek confluence
Backup behind fan
Theoretical profile without Dry Creek influence
Dry Creek fan
Gradient (%)
6
5
4
3
2
1
Dominant particle size
cobble
fine cobble
coarse gravel
gravel
fine gravel
sand
fine sand
silt
0
200
400
600
800
1000
1200
Distance (m)

Figure 7. Upper: Thalweg longitudinal profile for the Alameda Creek flood control channel in the reach near the Dry Creek confluence. Distance (zero is upstream, 1400 is downstream) and elevation are relative. The blue arrow shows the location of the Dry Creek confluence, while the red bar shows the channel distance of the fan. The orange dashed line shows the approximate theoretical gradient of the channel if Dry Creek, under some future management regime, was to have no influence. The blue oval highlights the area of the Dry Creek fan, and the green oval highlights the area of “back up” behind the fan. Middle: Channel gradient (in percent) for the same reach. Lower: Dominant surface particle size for the same reach.

As the longitudinal profile data was being collected, we were able to observe the extent to which the Alameda Creek flood control channel is densely vegetated, including both in-channel aquatic species (Ludwigia sp.) and annual species (e.g. Melilotus sp., Scirpus sp., Typha sp.) on the low and high bar surfaces. This vegetation is trapping fine sediment by reducing flow velocities, especially on the frequent high-flow events (likely the flows that occur a couple times per year). During these events, the water levels are high enough to submerge the bar surfaces, but flow velocities are not high enough to actually remove the vegetation. We also observed a few young willow trees on bar surfaces within the flood control channel. The ages and locations of these trees will help us understand the current regime of sediment deposition, reworking, mobilization, and transport in the flood control channel, and feasibility of a modified channel (e.g. creation of a bankfull channel with riparian zone). This type of work will be part of the proposed future study as part of the “Geomorphic and sediment-related analyses for select creeks in Alameda County” program.

As a component of a different task within the larger project, SFEI conducted bulk sediment sampling in the active channel of the Alameda Creek flood control channel from Niles Canyon downstream to San Francisco Bay to support existing sediment transport modeling being conducted by DHI. When the longitudinal distribution of grain sizes is plotted, a typical downstream-fining pattern is revealed, with the exception of the active channel sample taken in the Dry Creek fan (highlighted in yellow) (Figure 8). The D50 of this sample is 8 mm, compared to the adjacent upstream sample D50 of 2.7 mm, and the next closest downstream sample D50 of 1.0 mm. The other data point representing coarse material in storage downstream at Alvarado (sampled in 2006) represents the pavement layer of a low bar sample caused by hydraulic effects of the bridge pier.

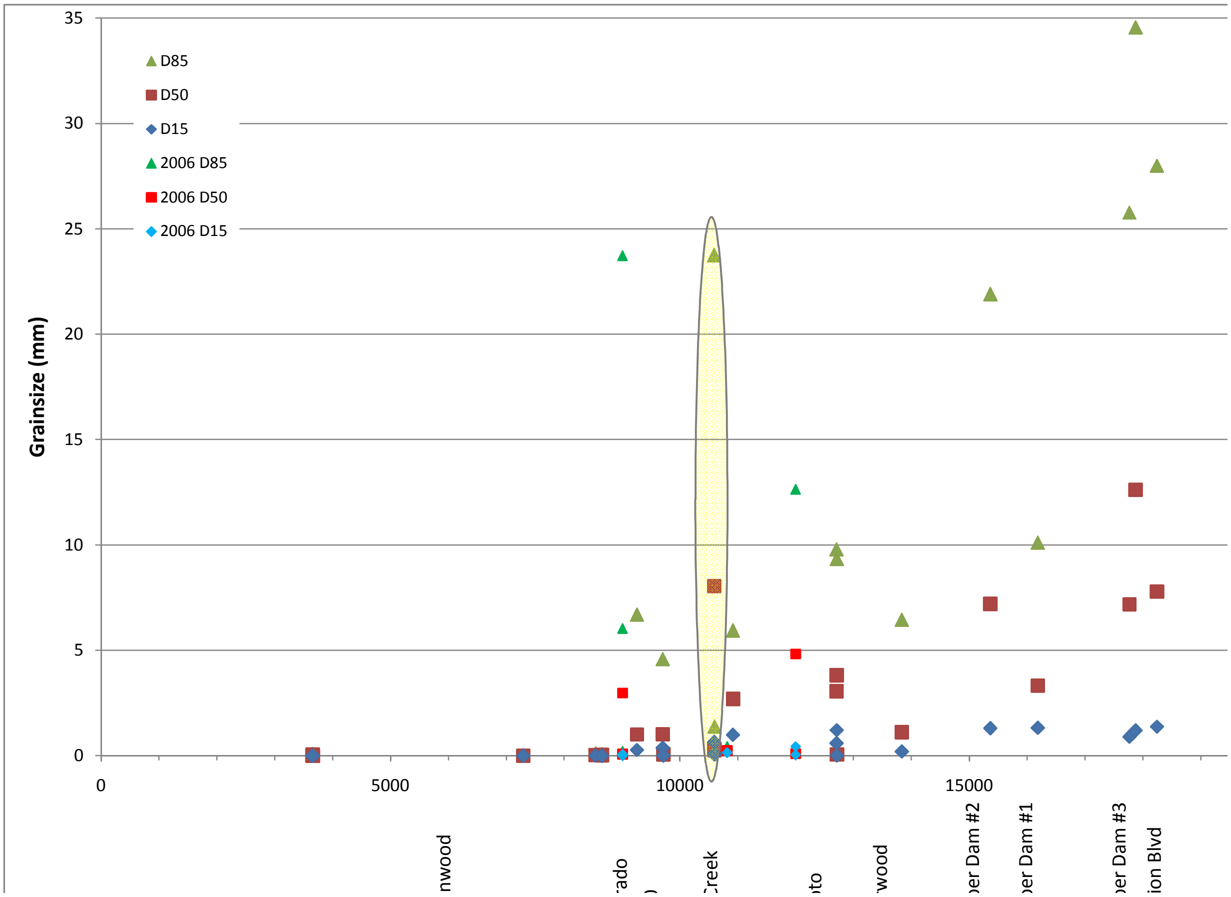

Figure 8. Longitudinal distribution of 2008 surface bulk sediment samples in Alameda Creek. Channel grain sizes D15, D50, and D85 are shown. Channel distance (in meters) is along the x axis; zero is the confluence with San Francisco Bay, and 19,000m is where Alameda Creek exits Niles Canyon. Note the downstream-fining pattern of grain sizes, with the exception of the sample taken immediately downstream of the Dry Creek confluence (highlighted in yellow). Also six samples taken in 2006 by SFEI following similar methodologies are shown. The reported grain size values for three upstream-most samples are qualified as minimum values; see Pearce and McKee 2009 for details.

The issue of sediment storage in the Alameda Creek flood control channel is larger than just the impact of the Dry Creek tributary. An analysis of the entire length from Niles Canyon to the Bay margin will be completed as part of the "Geomorphic and sediment-related analyses for select creeks in Alameda County" program. One of the objectives of that program will be to assess the effects of constrictions (bridges, weirs, fans, etc) and knickpoints that are controlling the location and volume of sediment deposition in the channel. This can only be accomplished with careful analysis of the detailed recent longitudinal profile of Alameda Creek. This analysis would provide context for the importance of sediment supply from Dry Creek versus other sources, or stored in other locations. Based upon the short longitudinal profile that we surveyed, and upon the bulk sediment sampling results, we hypothesize that both inputs of coarse sediment (from local, steep tributaries such as Dry Creek) and constrictions (such as bridges and weirs) influence sediment storage within the flood control channel causing maintenance costs for the District. However the magnitude, interactions between these features, and exact location of each is presently not known.

Origin of the Tributary Fan

Based upon field observations, we have documented the existence and dimensions of the tributary fan, but it was outside of the scope of this project to unequivocally determine the source of material stored in the fan. Material could be sourced from the Dry Creek watershed or the Alameda Creek watershed, or some combination of both. While we cannot be certain that the sediment deposited in the fan is wholly from Dry Creek, there is evidence to support that hypothesis. Visual observation of clast lithology (primarily light grey rounded sandstone) on the fan surface matches clasts observed along the entire length of the Dry Creek flood control channel and in the upland creek channels. Although data on bed surface grain size distributions for Dry Creek does not exist, visually the sands, gravels, and cobbles of the fan more closely match the clasts on the bed of Dry Creek compared to that on the bed of Alameda Creek in the reach immediately upstream. Also the coarse material in the bed of Alameda Creek at the fan is much coarser than material sampled in the reaches either immediately up or downstream (Figure 8). In addition, the location of the fan deposit suggests that it is composed of material originating from Dry Creek; the deposit begins immediately at the confluence and only extends downstream. We do not observe similar coarse material in the bars upstream of the confluence. However, it is possible that the fan could be the result of hydraulic conditions caused by the entrance of Dry Creek causing localized coarse sediment deposition in this reach. But given the evidence, we suggest that the material is dominantly supplied by Dry Creek, with only minor amounts supplied from Alameda Creek.

Comparison of sediment loads

Estimates of watershed sediment yield

One sub-objective for this study was to provide a better understanding of the magnitude of sediment discharged by the Dry Creek watershed. By comparing sediment supplied by Dry Creek to that supplied by the larger Alameda Creek watershed (as measured passing through the Niles gage) we can roughly estimate the significance of Dry Creek upon the sediment deposition regime in the Alameda Creek flood control channel. However, as mentioned in the opening section, Dry Creek sediment likely arrives out of phase with sediment pulses from the larger Alameda Creek watershed, a process leading to near 100% deposition, at least temporarily. It is only during larger flows in the mainstem that Dry Creek sediment stored in the fan could be re-suspended and transported downstream – although even that process is inefficient partly due to vegetation growing on the fan surface and because it takes more energy to re-suspend a particle than to keep it entrained.

First, we must estimate sediment discharge from Dry Creek since sediment data (suspended or bedload) has never been collected. We make this estimate by combining the sediment rating curves of Bay Area creeks with drainage basin areas similar to Dry Creek with the peak flow records for the Dry Creek USGS gage. Using sediment rating curves from Cull Creek (drainage area 15 km^2, 5 yrs data) and Crow Creek (drainage area 27.2 km^2, 4 yrs data) we can estimate suspended, bedload, and total load for Dry Creek. For the 25.4 km^2 Dry Creek basin for the years 1994-2006 we estimate an average wet season suspended load of 8,140 tons (U.S. tons), and an average bedload of 570 tons, which we can combine for an average total load of 8,710 tons. Here we highlight that for this watershed, approximately 6.5% of the total load is bedload, or grain sizes that are larger than 0.25mm.

We rely upon the data collected at the USGS gage station at Niles, which was compiled and analyzed by Bigelow et al (2008) to make our comparisons between Dry Creek and Alameda Creek. We can directly compare total loads (e.g. total load to total load, where Dry Creek is 5.5% of the load passing Niles), suspended loads (where Dry Creek is approximately 6% of the load passing Niles), and bedloads (where Dry Creek is approximately 3.3% of the load passing Niles) for the two systems. The proportion of bedload reported passing the Niles gage is high for such a large watershed. We suspect that the reported proportion may be affected by either contributions of coarse material from the walls and small tributaries of Niles Canyon which is mobile because of the channel confinement within the canyon, or because bedload is measured within a scour pool downstream of a concrete weir, which may be artificially increasing the amount of mobile sediment. Even if we downwardly adjust the bedload at Niles, the comparison between Dry Creek and Alameda Creek bedload only changes slightly. These estimates provide an order of magnitude estimate typical in geomorphic work considering all the uncertainties involved, including the lack of sediment data for the gage site, the unknown trapping efficiency of the ponds within the watershed, regional regressions, and extrapolating numerous sources of data. Given the numerous assumptions, estimates, and approximations involved, it is reasonable to consider the Dry Creek watershed, which is 2.8% of the total Alameda Creek watershed area (with areas upstream of large reservoirs not considered), to supply a volume of sediment to the flood control channel which is on the order of 3-6% of the load that is entering the flood control channel at the Niles gage.

While we estimate the proportion of sediment supply from the Dry Creek watershed to be equal to double its proportion of area, we suggest that because the supply is coarse, the supply is an issue to the District because Alameda Creek may not mobilize and transport the sediment supplied by Dry Creek as frequently as finer sediment supplied from upstream.

We hypothesize that material delivered annually by Dry Creek is not fully flushed out of the Alameda Creek flood control channel, leaving some available for deposition in the tributary fan. Additionally, when a large flood event on Alameda Creek is able to rework and mobilize material from the fan, that only portions of the fan are actually removed. Thus, material currently in storage represents an accumulation of many years of delivery from Dry Creek. Although the average residence time of material in the tributary fan is not known, we hypothesize that the fan is at least partially reworked and material mobilized approximately every 5 to 10 years. Understanding residence time of material both in the tributary fan, and in other bar storage locations in Alameda Creek should be a focus of future study.

Conclusions and Unanswered Questions

Based upon the results of this reconnaissance-level study, we conclude that yes, the Dry Creek watershed is in fact a source of coarse sediment to the Alameda Creek flood control channel. However, many questions of relevance to sediment management in the Alameda Creek flood control channel remain unanswered, including:

- What is the actual sediment yield from the Dry Creek watershed?
- What is the grain size distribution of sediment supplied by Dry Creek?
- What processes and where are the primary sources of sediment supply?
- Are sediment sources within the watershed potentially manageable?
- Are there other small watersheds that are supplying a disproportionately large volume of coarse (>0.25 mm) sediment to the Alameda Creek flood control channel

- Are there manageable sources of sediment upstream from Niles that if reduced could in concert with reach-based solutions in the flood control channel, reduce maintenance costs?
- What features of the flood control channel such as grade controls and channel constrictions are contributing to sediment deposition?
- Could a bankfull channel within the flood control channel help to more efficiently transport coarse sediment under annual flood conditions? These last two questions will be addressed as a part of the pending SFEI contract with the District.

Recommendations

Sediment deposited in the Alameda Creek flood control channel poses a significant problem for the District because it is costly to obtain permits and to physically remove sediment from the channel. In the context of assisting the District to reduce annual expenditures, the following recommendations are made. These focused studies could be covered as part of the "Geomorphic and sediment-related analyses for select creeks in Alameda County" program:

Dry Creek

- **Quantification of total sediment load via collection of suspended and bedload data:** Improved sediment data at the USGS gage station #11180500 would allow the creation of a sediment rating curve, and a more reliable estimation of sediment yield from the Dry Creek watershed. The data would also provide an understanding of the grain size distribution transported into Alameda Creek, and would enhance the existing DHI sediment transport model by potentially addressing the missing mass within the model calibrations. This recommendation is consistent with findings in McKee (2009) "The lack of measurements of suspended loads and particularly bedload sediments (these have proportionally greater impact on the flood control channel stability than the suspended load) in Dry Creek may be a data gap worth considering in relation to modeling and managing the Flood Channel and wetlands on the Bay margin.".
- **Quantification of sediment sources and storage:** Completion of a full quantitative sediment budget for the Dry Creek watershed would provide data on the magnitudes and locations of sediment supply from various geomorphic processes. This data could be used for source control, that is, identifying specific locations of manageable sediment supply for future erosion control projects, or identifying locations of sediment storage within the watershed. A focus upon the mainstem North and South Fork reaches of Dry Creek may reveal that these reaches have the greatest potential for significant sediment storage by reconnecting the channels with the floodplains. This storage option may be a viable solution because the lands are publically owned, and currently do not have development that would be damaged by a dynamic channel system.

Other small tributary watersheds

- **Assessment of adjacent tributary watersheds:** The District could also assess the adjacent small, steep tributary watersheds, such as the Masonic Home, Landmark Letters, and Niles Reservoir watersheds (Appendix Figure 28) for potentially contributing large volumes of coarse sediment. For example, the Masonic Home watershed, although very small, was mapped by the USGS as having the highest density of debris flows during the 1998 El Nino event in the entire Bay Area. Its upland area is connected to the Alameda Creek flood control channel via a trapezoidal flood control channel that is likely as efficient in transporting sediment as the Dry Creek channel. The assessment might also include the larger tributaries of Stoneybrook, Sinbad, and Vallecitos Creeks, as they have coarse loads from steep terrains with mass wasting, and likely have high overall sediment yields.

Greater Alameda Creek watershed

- **Identify manageable sediment sources in the greater Alameda Creek watershed:** Sediment deposition within the flood control channel is an entire watershed-scale problem that requires a broad understanding of sources, transport processes, and channel function across the entire watershed. We do not yet have a fundamental understanding of sediment supply and transport throughout the Alameda Creek watershed; a basic watershed wide analysis is greatly needed prior to or in conjunction with smaller focused sediment source investigations and development of reach specific solutions within the flood control channel itself. Such an analysis would identify basic processes and locations of sediment supply and storage throughout the entire watershed below dams with the objective of identifying manageable sources of sediment (both coarse and fine), prioritizing those sources, and developing conceptual plans for sediment management for each prioritized source.

Improved Flood Control Channel Function

- **Assess causes of siltation and impacts of flood control channel operations:** Many aspects of the current flood control channel morphology, habitat value and geomorphic processes are currently not known. As the first step in addressing District needs, an evaluation of the current physical and biological functioning of the channel must be completed. This evaluation will include collection of new field data, collation of existing data, synthesis of a variety of data sets, and improved model accuracy, all working toward the single goal of answering the questions that are essential to improving channel functioning . Answering specific geomorphic and sediment-related questions formulated by District staff will drive the focused field data collection, which will likely include datasets such as: a detailed longitudinal profile, detailed re-survey of select cross sections, focused quantification of surface grain size distribution in select locations, assessment of sediment delivery from local inputs, survey of bridge and weir locations, quantification of current low flow channel dimensions, detailed inspection of sediment removal and maintenance records, assessment of ACWD rubber dam operations, assessment of USGS sediment and discharge records, field observation during high flow events, assessment of in channel vegetation, assessment of the Old Alameda Creek confluence, determination of tidal influence, and assessment of habitat quality and use for birds, fish, and other species. Products to communicate findings may include a conceptual model illustrating geomorphic processes occurring within the reach, or a reach-scale sediment budget. These actions will help prioritize future studies and will directly inform the decision-making process for immediate channel maintenance activities.

- **Develop proactive maintenance practices that reduce dredging and improve habitat:** Utilizing the newly developed findings and datasets, a series of proactive maintenance practices will be developed to enhance transport of coarse sediment through the channel and improve in-channel habitat for a number of species. These practices are intended to be cost-effective short-term solutions (on the order of 5 years) that can immediately be implemented to address the requirements of the channel as set by the permitting agencies. Practice development should integrate the experience of other regional flood control channels (e.g. San Lorenzo River, Wildcat Creek). In addition each recommended practice must align with current USACE guidance, support the District's goals, and maintain or improve habitat value. The effectiveness of these practices and the locational optimization will be tested using the existing 1D/2D sediment transport model. This additional modeling is a cost-effective tool for testing hypotheses and generating potential outcomes for proposed channel configurations and management options, and will directly inform the final recommended suite of practices.

- **Evaluate the feasibility of options for channel modifications:** Building upon the data, findings, and the short-term maintenance practices adopted, a number of options for channel modification will be developed. These channel modifications are intended to be long-term more holistic solutions (on the order of 50-100 years) to address the District's (purpose/mission/function) as well as channel configuration, flood routing, beneficial sediment use, and biological requirements. With management questions in mind, the feasibility of each option will be extensively studied and modeled. Each option must meet both flood capacity and biologic requirements, while also being cost-effective to implement, adaptive to climate change, rising sea level, and continued urbanization, and compatible with IRWM and watershed goals. For example, the feasibility of constructing a bankfull channel that effectively transports sediment, maintains a healthy riparian zone, and provides appropriate habitat and passage for fish and other aquatic species while requiring very little to no maintenance will be a primary focus.

- **Complete a new sediment management plan that includes a revised dredging schedule and streamlined permitting process:** This integrated sediment management plan would be a consensus document, with (buy-in) from all of the regulatory agencies and stakeholder groups. The document would clearly outline the long-term (perhaps 100 year) vision for the Alameda Creek flood control channel, and the interim (10 year) steps necessary for operations and maintenance to align with and reach that vision. A new dredging schedule will be developed for the plan, that is based upon modeled long-term sediment deposition (including adjusted maintenance practices)and features new "triggers" for dredging that have been vetted and approved by the appropriate scientific and regulatory personnel. Also, a streamlined permitting process will be developed based upon consensus of earlier outcomes and long-term vision of the flood control channel.

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