Midpeninsula Regional Open Space District

R-20-76
Meeting 20-19
August 26, 2020

AGENDA ITEM 10

AGENDA ITEM

Sediment Monitoring Results from the Watershed Protection Program at El Corte De Madera Creek Open Space Preserve

GENERAL MANAGER'S RECOMMENDATION

Receive an informational presentation on the sediment monitoring results from the Watershed Protection Program at El Corte de Madera Creek Open Space Preserve. No Board action required.

SUMMARY

In July 2017, the Midpeninsula Regional Open Space District (District) contracted with Balance Hydrologics, Inc., (R-17-93) to repeat a sediment study first conducted between 2004 and 2009 at the beginning of the Watershed Protection Program (WPP) in El Corte de Madera Creek Open Space Preserve (Preserve). The recently completed study quantifies the sediment reduction in creeks as a result of road and trail improvements implemented from 2004 to 2019 as part of the Watershed Protection Plan. Results indicate reductions in stream sediment from multiple independent lines of evidence. The study correlates a reduction in downstream sedimentation with road and trail best management practices. The reduction of downstream sedimentation is providing a measurable positive impact on stream habitats particularly for salmonids.

DISCUSSION

In 2001, District staff met with the Regional Water Quality Control Board, California Department of Fish and Wildlife, and other regulatory agencies in response to a citizen complaint about the roads and trails within the Preserve contributing excess sediment to El Corte de Madera Creek and ultimately to San Gregorio Creek, which supports steelhead and coho salmonids. The regulatory agencies outlined four requirements to address the issues:

1. Identify sources of sedimentation in the preserve that originate from roads and trails;
2. Evaluate recreation, maintenance, or management activities that may be responsible for sedimentation;
3. Develop a plan to implement the necessary repairs or corrective actions at high-priority sites throughout the preserve; and
4. Establish a monitoring program to track the success of corrective actions.

In 2002, the Board of Directors (Board) approved contracting with an engineering geologist (Tim Best) to address requirements 1 through 3 by analyzing potential and active sediment sources in the roads and trails at the Preserve, and developing road and trail improvements to reduce sediment transport to nearby streams and watercourses (R-02-26). The Board approved a contract with Balance Hydrologics (Balance) to develop a monitoring program and fulfill the 4th requirement set out by the regulatory agencies, by measuring sediment as it moves through the streams in the Preserve (R-04-72). This work consisted of an inventory of large landslides near streams, installation of a stream and rain gage to measure flows and storm events, water quality monitoring, and direct measurement of sediment in pool features within the stream. The study was used as an effectiveness monitoring tool during the WPP work from 2004 to 2009. The data gathered from 2004 to 2009 characterizes the “before” or “baseline” conditions of the WPP.

District staff and contractors constructed the road and trail improvements in the WPP over 15 years. This work is estimated to have cost $1.25 million, not including the cost of thousands of hours of staff time. In total, the WPP upgraded 24 miles of road and trail, which included replacing culverts, installing bridges, reducing many miles of road to trail width, and decommissioning some roads altogether (see Attachment 2).

To characterize the “after” condition of the WPP, the sediment study began in the winter of 2017 and included field data gathered through the winter of 2019-20. Balance staff led the winter stream gaging and sediment sampling. District staff provided the labor for the summer V-Star pool monitoring (which measures sediment by probing a measurement rod into a pool). The District’s Water Resources Specialist oversaw the work of a Water Resources Intern in the summers of 2018 and 2019 to provide the bulk of the labor, with assistance from Land & Facilities staff and the Conservation Biology Intern. Balance provided quality assurance and control of all data products.

The V-Star data indicate that sedimentation in measured pools dropped 15% from 2004-07 to 2018-19. The stream gage and sediment sampling show that when comparing storms of equal magnitude, approximately 62% less fine sediment is leaving the Preserve than before. Streambed texture data (which counts the size of streambed materials: sands, gravels, cobbles, and boulders) also show a 24% decrease in surface sedimentation and a 3% increase in exposed gravels, which directly benefits salmonids. All of the evidence (winter gaging, V-Star pool measurement, and the streambed texture) points in a positive direction. The significance of each line of evidence is evaluated in the context of the natural variation in sedimentation that is caused by drier and wetter winters. The attached report provides a broad, public-friendly executive summary and a technical report that explores the contextual analysis of the data and provides a deeper interpretation for hydrologists and practitioners.

These efforts have confirmed that the District’s best management practices for road and trails make a measurable difference in the environment. Preliminary results from the study have been used to inform other V-Star related assessments from the Regional Water Quality Control Board in the Pescadero and San Gregorio Watersheds.

The next phase of the project includes sharing the results with scientists and other land managers. A presentation, workshop, and field tour with Balance and District staff was scheduled as part of the 38th Annual Salmonid Restoration Conference, which was postponed due to COVID-19. District staff is evaluating further outreach amongst technical and land management communities. Public Affairs staff are developing materials and information for broader public consumption to showcase this work and the positive net results to the natural environment and to local fisheries.

FISCAL IMPACT

This informational item has no immediate fiscal impact.

BOARD COMMITTEE REVIEW

This item was not previously reviewed by a Board committee.

PUBLIC NOTICE

Public notice was provided as required by the Brown Act.

CEQA COMPLIANCE

This item is not a project subject to the California Environmental Quality Act. The WPP was evaluated through an Initial Study and Mitigated Negative Declaration adopted by the Board in 2004.

NEXT STEPS

District staff will continue outreach and sharing the results of the WPP and the sediment monitoring study with partners, stakeholders, and the public.

Attachments

1. Sediment Monitoring Report, Balance Hydrologics 2020.
2. Watershed Protection Program Map

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Executive Summary
El Corte De Madera Creek Open Space Preserve
Watershed Protection Program Effectiveness Monitoring

July, 2020

Summary:

In 2004, the Midpeninsula Regional Open Space District (Midpen) adopted the El Corte de Madera Creek Open Space Preserve Watershed Protection Program (WPP). The goal of the WPP was to reduce the amount of sediment entering El Corte de Madera Creek and to improve spawning habitat for salmonids (steelhead trout and coho salmon) over 12 years of sustained construction to re-route trails, decommission roads, improve roads, install bridges, and more. Midpen construction staff performed most of the work and Midpen invested roughly $1.25M in the project through equipment, materials, and contractors. To monitor the effectiveness of the WPP, Midpen contracted with Balance Hydrologics, Inc. (Balance) in 2004. Initial monitoring focused on measuring sediment in the creeks and the data indicated more study and ways of measuring sediment were necessary. Ultimately, Balance's monitoring work from 2004-08 formed a 'baseline' condition as the WPP implementation proceeded from 2009-2016, and which continues in part today through ongoing maintenance. Upon completion of the majority of WPP work, Midpen returned to Balance with the idea of capturing the 'after' condition in the stream systems of ECDM. The enclosed report summarizes the recent monitoring efforts from 2018-2020, draws conclusions about the effectiveness of the WPP in reducing sedimentation instream and offers insights into the monitoring methods employed for the benefit of the scientific and resource management community. All of the evidence gathered in this study points in a positive direction. The significance of each line of evidence is evaluated in the context of the natural variation in sedimentation that is caused by drier and wetter winters. The clear outcome of the monitoring is that less sediment is entering the San Gregorio watershed than before the WPP was implemented.

Background 2004-2007:

In 2001, in response to citizen complaint, Midpen worked to develop a plan to reduce sedimentation with state environmental agencies including the California Department of Fish and Wildlife and the San Francisco Water Quality Control Board). The San Gregorio watershed was listed as impaired for sediment in 1998 and remains so today. Additionally, steelhead trout and coho salmon had seen declines in populations over the proceeding decades, in part due to sediment harming salmonid eggs in the creek. Out of this grew a process to change the roads and trails in the preserve to improve the water quality and the native fish habitat, while continuing to provide an enjoyable experience for visitors. The WPP tried to balance the experience preserve visitors, particularly mountain bicyclists, would have with the environmental goals of the project and the challenges facing salmonids.

The WPP used best management practices developed throughout California to identify and prioritize construction activities that would reduce sedimentation. Particular attention was paid to steep slopes, roads as they approached creeks and places where preserve visitors were likely to cause erosion. Achieving the WPP goals of reducing sedimentation also entailed changing the preserve visitor experience and the trail system as a whole. New or retrofitted trails allowed for trail designs that were less likely to have ruts, were muddy for a shorter period of the year, and, by installing drainage structures in a rolling pattern, created a varied riding experience for mountain bikers. Some mountain bikers miss the steeper trail system that was legacy of logging and motorcycle riding in the 1980s. Nonetheless, ECDM is more popular than ever and offers some of the best mountain biking in the Bay Area.

The WPP reduced chronic erosion (i.e. erosion that occurs in typical year of average rainfall) and episodic erosion (i.e. erosion during rare and large storm events). Reshaping roads, rocking roads, and eliminating ruts and gullies helped reduced chronic erosion. Making larger stream crossings with bridges and bigger culverts helped reduce episodic erosion by allowing big storm flows to pass through the roads. The condition of these sites after improvement is monitored visually and qualitatively for loss of soil or erosion near the creek. These efforts are estimated to have prevented thousands of cubic yards of sediment from entering the creek over the study period of 2004-2020 (a typical dump truck carries 10 cubic yards). The Santa Cruz Mountains have naturally high rates of sedimentation compared to other regions, due to steep slopes, erosive soils, and the underlying geology. The central challenge of this study was to develop a monitoring method that is sensitive enough to measure the relatively smaller sedimentation caused by roads and trails.

The monitoring efforts have been a collaboration between Midpen and Balance, spanning over 16 years. Both organizations have many of the same people working on the past and present projects. In response to Midpen in 2004, Balance recommended an approach to monitor sediment in the creek called the "V-Star" method (V*). V* monitors change in creek sediments by probing the streambed with a metal rod marked like a ruler. Typically, one person takes the measurement and another records the data point in an unbiased grid across the stream. V* sites are all 'pools', which are natural depressions in the creek (visualize a small swimming hole). Anywhere from 50-200 data points at each pool may be gathered depending on the size of the pool. The average depth of the sediment and the depth of water is used to estimate how full of sediment the pool is. The V* value is a percentage of how much sediment is in the pool (0 = free of sediment and 100 = full). The V* method monitors the change in V* values year over year by remeasuring these pools. The majority of these pools are located in the very bottom of the watershed, towards the southern boundary of ECDM near the Virginia Mill Trail bridge. By locating the measurement sites lower in the watershed, Balance and Midpen aimed to better measure the effects of the WPP, which occurred upstream throughout the entire preserve. Balance trained Midpen staff to collect this data in 2004 and then Midpen collected the data in 2005 and 2006. To set up a point of comparison, Balance recommended Midpen also monitor six pool locations in nearby La Honda Creek Open Space Preserve, in the same watershed with the same geology at a similar elevation with similar rainfall, to act as a control group.

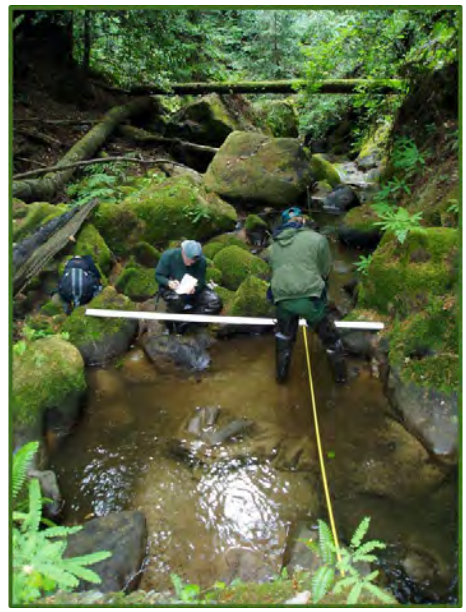


Figure 1 Midpen staff gathering V data, 2005*

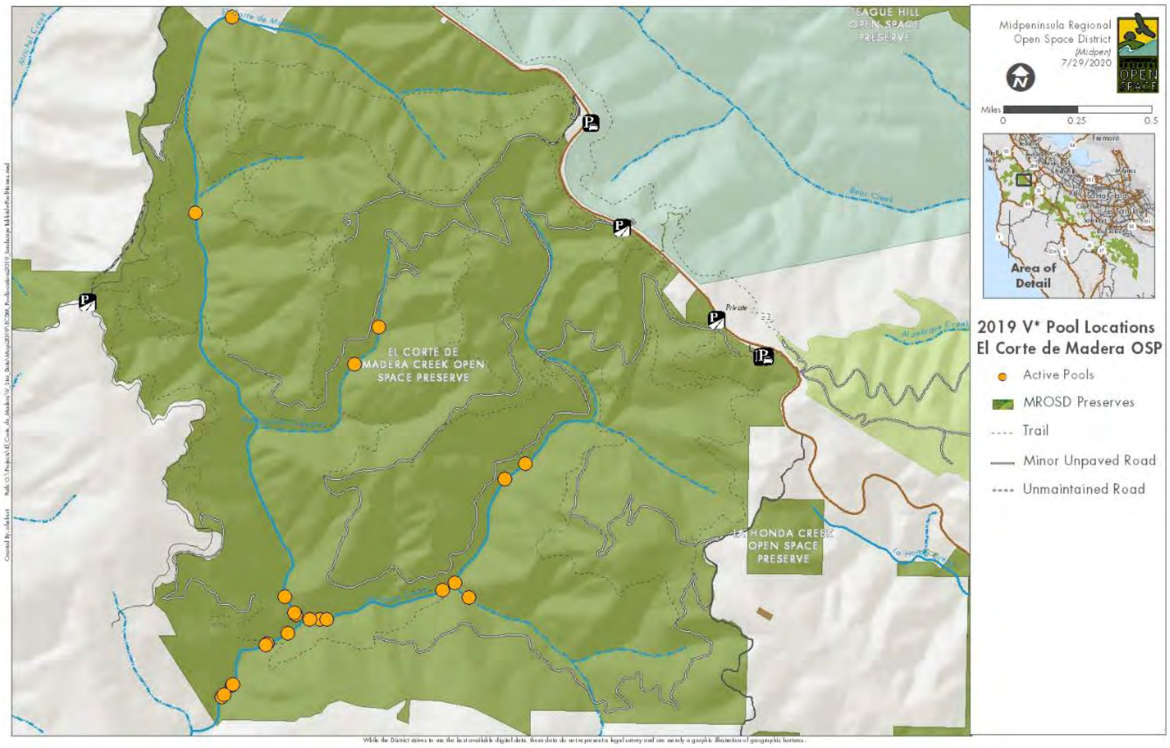


Figure 2 V Pool Locations in ECDM*

It was important to separate background rates of sedimentation from that created from human activity and to “normalize” V* measurements in order to provide context for the results. To do this, Balance staff surveyed large landslides that had entered the creeks throughout most of the ECDM and estimated the volume of those landslides. Most of these landslides appear to have originated or been remobilized by the 1998 El Nino event. Additionally, Balance estimated a potential range of sediment that could be coming from roads and trails. Together, these data suggested in the 2004-07 period that 80% of sediment is attributable to large landslides and 20% may have come from roads and trails.

By 2006, the long-term nature of the WPP was apparent. Balance recommended an additional independent line of evidence, separate from V*, that would be necessary to effectively measure change over time. Midpen contracted with Balance to conduct a stream gaging and sediment sampling program to compliment the V* data. Balance established a stream gage at the bottom of ECDM that measures the height of stream (“stage”). Using an electronic sensor, these data were recorded every 15 minutes. The gage data are also used to measure the volume of water that is leaving ECDM. By measuring the depth of water along the stream across from the gage, Balance could relate the stream height on the gage and the depth to create an area of water. With a velocity meter (visualize a little propeller), Balance gathered stream velocity. Multiplied by the area, velocity provides the volume of water leaving ECDM ("discharge") in cubic feet per second. Monitoring discharge allowed Balance to describe how and when water and sediment moved through the creek system.

Figure 3 At left, El Corte De Madera Creek Gage at High Flow Conditions 2019. At right, Midpen staff at Stream Gage 2006.

When large storms come into the Santa Cruz Mountains, rain quickly mobilizes fine sediment particles into the creek, causing a muddy appearance. This is a natural process, but the degree to which the water is cloudy or muddy ("turbid") reflects how much sediment is in the creek, naturally or because of human activity. During large storms, Balance collected water samples from the creek and then sent them to a laboratory to precisely weigh and describe the sediments in the creek from that exact moment it was collected. This turbidity data could then be connected to the discharge data, relating the magnitude of the storm (e.g. a 1-2 year storm event at ~200cfs, which is a storm that is likely to occur every year to every other year) to the quantity of sediment leaving ECDM. This relationship between storm events and sedimentation (bigger storms move more sediment and the inverse) established another 'baseline' and speaks to how sedimentation in ECDM might affect downstream salmonid habitat.

Figure 4 Balance staff collecting sediment during a storm. Sample at right.

During the V* data gathering, Balance staff recommended at each data point Midpen record what size of rock is found on the pool surface (e.g. sediment, gravels, cobbles, boulders), called streambed texture. The V* values speak to the volume of sediment reduced by the WPP but does not describe directly how that might affect fish habitat on the surface of the streambed. Coho and steelhead spawn in gravels and without gravels, they cannot reproduce as well. Their eggs also get smothered in sediments, reducing oxygen at a critical time. ECDM is too high up in the watershed for salmonids, past natural waterfalls that prevent migration, but the sediments, gravels and wood that leave the preserve directly affect downstream habitats. The streambed texture data gathered alongside the V* data measures how pools in the preserve have changed in response to reduced sedimentation and suggests how downstream pools might have also changed.

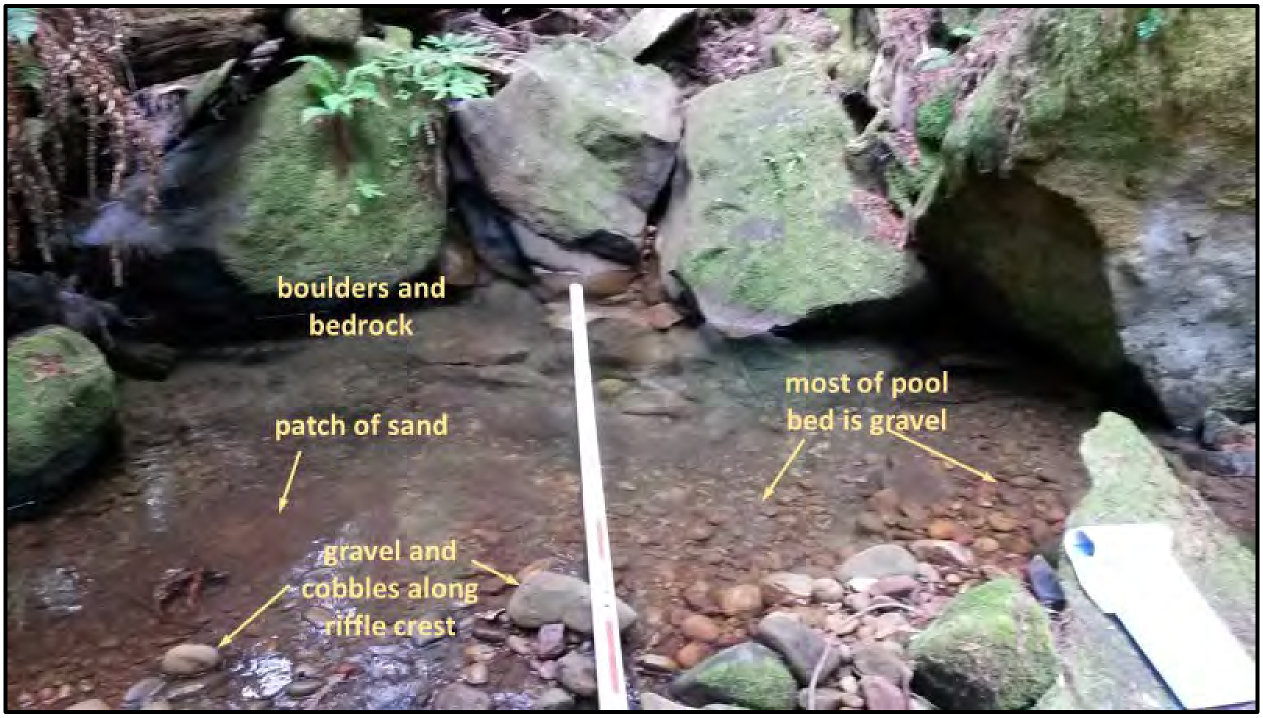


Figure 5 Diagram Highlighting Stream Texture at a V pool*

These three lines of evidence (V*, discharge/turbidity, and streambed texture) collectively measure the changes over time in sedimentation.

2018-2020 Study

The first phase of the Balance's efforts was to make sure the streamgage installed in 2006 was in working order to continue and repeat the discharge and turbidity data gathering. The remoteness of the site (an hour fifteen minutes from the urban San Francisco Peninsula) makes very frequent monitoring or sampling cost prohibitive. New and cheaper technology allowed for a turbidity probe to be installed to gather a measurement of the visual clarity of the water (muddiness) every 15 minutes, allowing a year-round record without frequent fieldwork. This continuous data would then be calibrated with the same sediment sampling sent to the lab to ensure accurate recording. Having continuous streamflow data and turbidity data provided a record that could be compared against the San Gregorio gage at the bottom of the watershed, operated by USGS (and partly funded by Midpen).

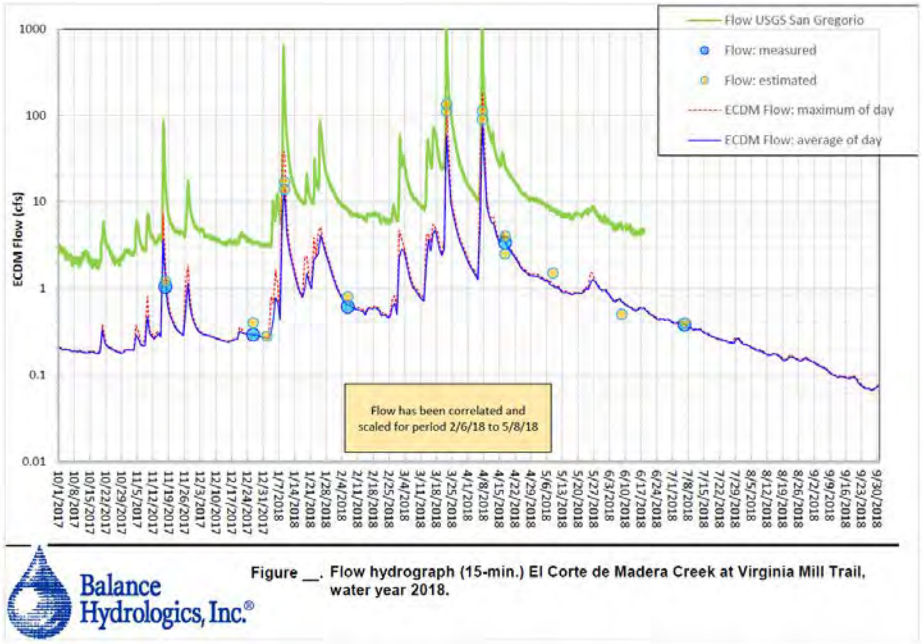


Figure 6 Stream Flow at ECDM and San Gregorio in 2018, log scale

Additionally, Balance and Midpen walked the majority of the creek system to reevaluate how large landslides might be affecting sedimentation. How the very wet winter of 2017 may have changed the stream was an important question (many highways had closed for part of the winter due to landslides). The surprising conclusion was that relatively few new landslides had occurred. This may reflect that the historic rainfall was spread out over the winter and not highly concentrated in fewer, larger storms.

In the fall of 2018, Balance and Midpen staff re-learned the complexities and technicalities of the V* method and began resurveying the same pools as studied before. Balance and Midpen staff compared past photos, sketches and GPS data to reassess the pools. 4 of the La Honda Preserve V* sites were substantially different, due to streambank/road failures and Sudden Oak Death causing tan oak die off into the pools, altering how sediment was stored. Alternatively, only 2 of the ECDM pools were significantly changed, reflecting the stability of the boulders that define most of pools. Midpen hired a Water Resources intern to carry out the bulk of the labor for the V*. The dedicated labor allowed for additional data gathering. Balance and Midpen added 7 new pools to ECDM and selected 2 new replacement pools to La Honda Preserve. An average water year followed the fall of 2018 and another year of V* data gathering continued with another Water Resources intern in fall 2019. Midpen and Balance kept the stream gage in operation through winter 2019-20 in the event large storms would add to the data set (no such large storms occurred).

Results and Interpretation:

All of the data gathered show a decline in sedimentation. The strongest evidence comes from the turbidity-discharge data, comparing 2006-08 to 2018-20. For example, when a 1-2 year storm moves through ECDM, less sediment leaves the system today than before and this is true of every type of storm event. Finer sediments have decreased by 2.4x and coarser sediments of 4.3x from 2006-08 to 2018-19.

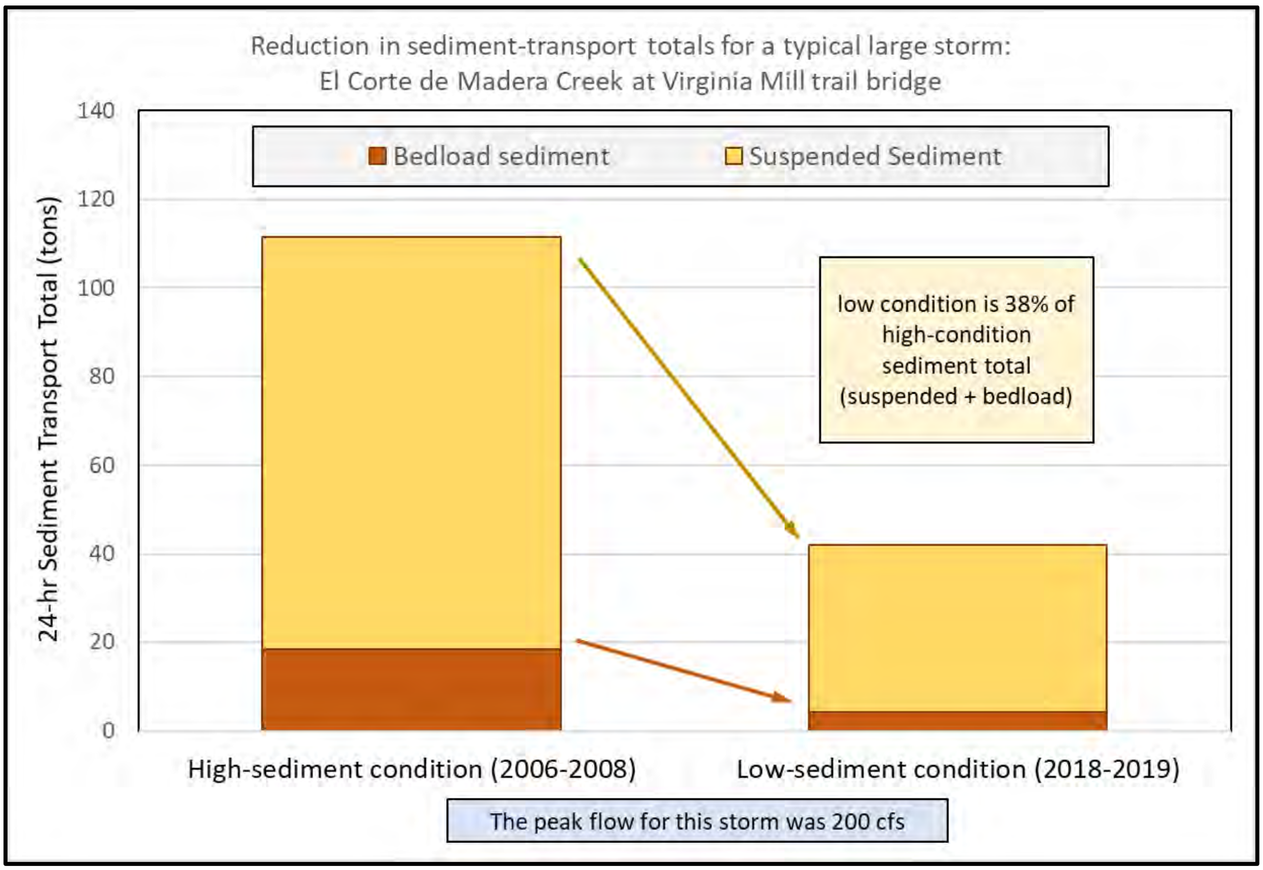
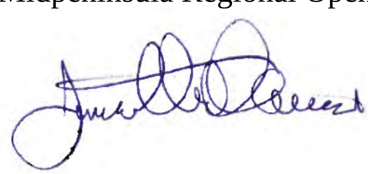


Figure 7 A 1.6-year storm event transporting sediment out of ECDM, comparing the before and after conditions.

Less sediment is affecting downstream fish habitat. The V* data show a 15% decline between the 'before' and 'after' data sets, but the relative volume of sediment stored in the pools compared against the volume of sediment moving within and leaving the preserves suggests this a relatively weaker line of evidence. The La Honda Preserve V* pools track in a similar way to the ECDM pools, though no restoration occurred upstream in La Honda. The streambed texture data shows a 24% decrease in sediment and an increase 3% and 8% in gravels and cobbles respectively. The pools are covered with less sediment. This is the type of change that would better support salmonids downstream.

Every year since El Nino 1998 would be expected to have less sediment as those landslides are flushed down the watershed. The drought of 2012-17 would also be expected to reduce sedimentation in the creek, because fewer storms occurred. The quantitative relationship between the WPP work on the roads and trails and what can be measured in the stream is complex. But the lack of erosion at the WPP sites combined with the three lines of evidence all pointing in the same direction (and no evidence to the contrary) suggests the work has been effective in reaching its goals. The enclosed report expands on this nuance and dives much deeper into the waters of ECDM.

-Aaron Hébert, Senior Resource Management Specialist,
Midpeninsula Regional Open Space District.



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Acknowledgments:

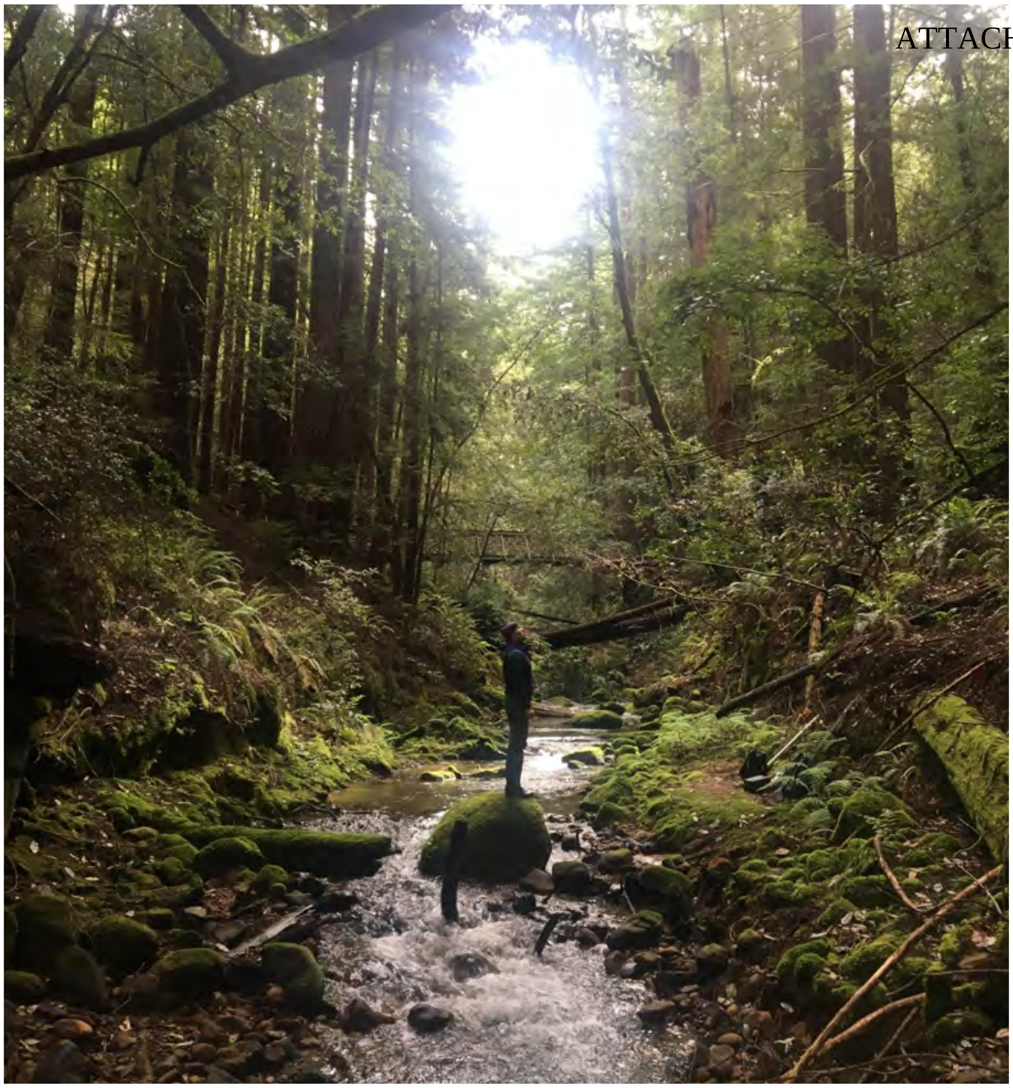
Special thanks to the Water Resources Interns, Julia Hathaway and Morgan Williams, for leading the V* fieldwork and inputting and double-checking all the V* data.

Special thanks to Senior Planner Meredith Manning for overseeing the V* work in 2005-06, retired Senior Resource Management Specialist Matt Baldzikowski for assisting with the stream gaging in 2006-2008 and Natural Resources Manager Kirk Lenington for initiating this study program and for whatever managers do!

To the many Midpen staff who gathered the V* data: patrol, land and facilities, Midpen volunteers, and the Conservation Biology Interns (Katarina Palermo and Elena Wolff), who were integral partners to the Water Resources Interns.

Many Balance staff performed field work (during both dry weather and in the rain) and/or data entry and analyses; the following people were consistent contributors with careful observations and off-trail fortitude: Chelsea Neill, Anna Nazarov, Dana Jepsen, Zan Rubin, Emma Goodwin, John Hardy, Barry Hecht, Scott Brown, John Gartner, Brian Hastings, Shawn Chartrand and Bonnie deBerry.

ATTACHMENT 1



WATERSHED PROTECTION PROGRAM EFFECTIVENESS MONITORING: EL CORTE DE MADERA CREEK OPEN SPACE PRESERVE, SAN MATEO COUNTY, CALIFORNIA

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1 EXECUTIVE SUMMARY

This report presents 2 years of measurements and monitoring during 2018 and 2019, and compares new data to data collected during "baseline" studies that were conducted from 2004 through 2008.

1.1 Problem Statement

Following concerns of sediment washing from roads and trails into creeks, and potentially impacting fish habitat in the creeks, the Midpeninsula Regional Open Space District (MROSD) initiated programs to improve trails to reduce sediment contributions, and also to study sediment in the El Corte de Madera Creek Open Space Preserve (ECDM). ECDM is a preserve of approximately 2,906 acres with approximately 35.9 miles of roads and trails, located in San Mateo County, California, along the crest of the Santa Cruz Mountains. ECDM creeks and sediment drain into San Gregorio Creek, which is home to threatened species Steelhead trout (*Oncorhynchus mykiss*) and endangered species Coho salmon (*Oncorhynchus kisutch*); resident fish are present in the ECDM creek system. The terrain is steep with elevations ranging from 550 to 2,430 feet, with history of logging throughout the Preserve from the 1860s up through the 1980s. Roads and trails in ECDM were largely inherited logging roads that were later used for dirt bike riding and were not necessarily developed with sustainability or erosion in mind.

1.2 Watershed Protection Program

The MROSD began a Watershed Protection Program (WPP) with road and trail improvements in 2004 that was substantially completed in 2016 but continued in lesser degrees through 2019; this program improved drainage features, recontoured roads and trails, decommissioned some, and built or relocated other trails. During this period, this preserve has gained popularity among trail users, particularly among mountain bikers, and attracts outdoor enthusiasts from across the San Francisco Bay area.

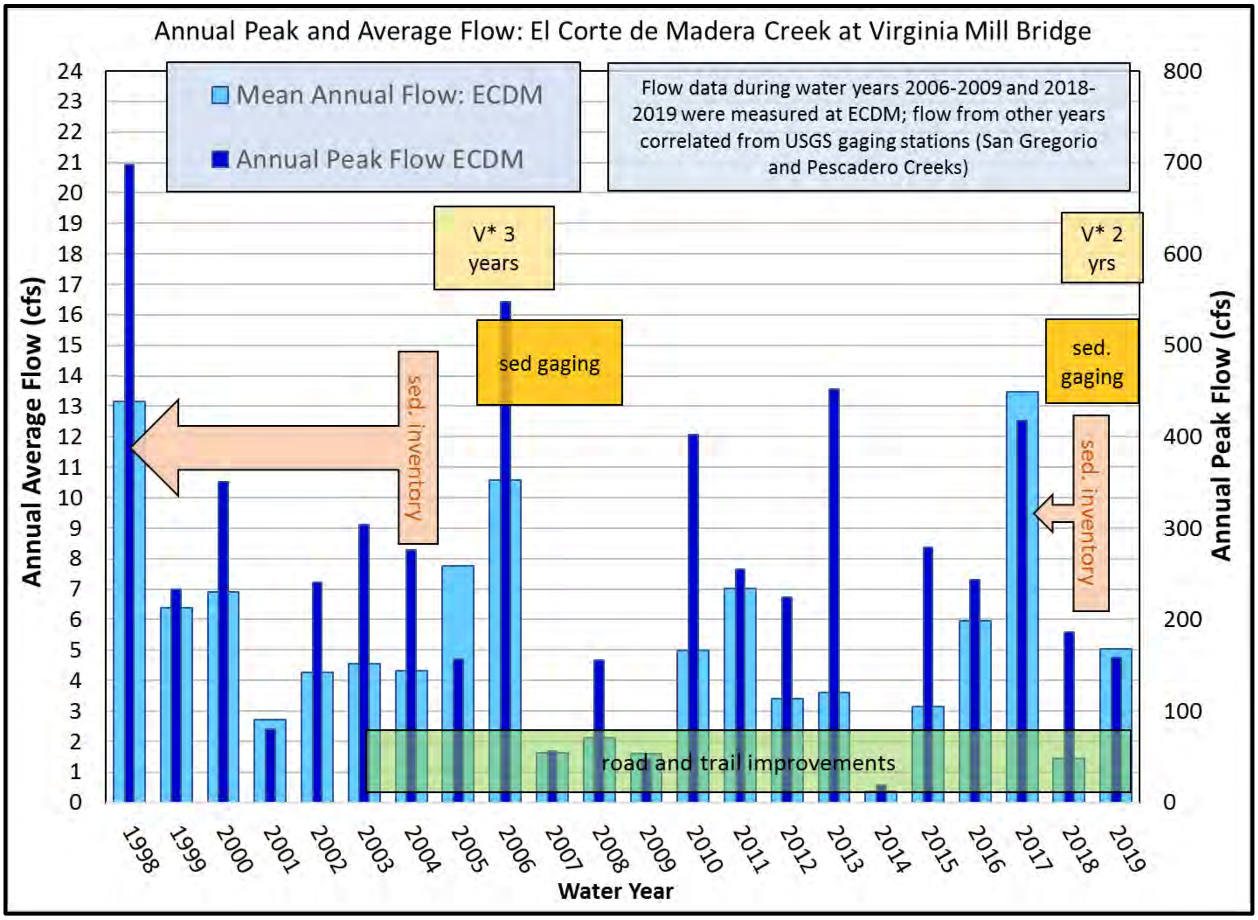
1.3 Study Plan Methods

Starting in 2004, Balance Hydrologics Inc. (Balance) worked with the MROSD to carry out a 3-pronged approach to study sediment in the creeks of ECDM. The main study elements were conducted during 2004 through 2008 and were then repeated during 2018 and 2019. The 3 study approaches are:

- Using the V* ["V-star"] technique to quantify the amount of sediment that fills pools; V* uses a grid system and a sediment probe to measure the depth of fine sediment that has accumulated in pools (2004 – 2006, and 2018-2019);
- Conducting a sediment-source inventory to map the locations and quantify the volume of sediment contributed to creeks by landslides and bank failures; locations and amounts of sediment stored behind wood jams were also mapped and measured (2004 and 2018);
- Operating a creek gaging station to measure creek flow, measure sediment transport during storms, and calculate annual sediment transport; fine sediment (suspended sediment) and coarse sediment (bedload) are tabulated separately (water years 2006-2008, and 2018-2019).[1]

The annual hydrologic conditions and the timing of the methods are shown graphically in this Figure.

[1] Flow gaging occurred on the tail end of first and second study periods (water years 2009 and 2020), in order to be ready to sample for sediment, in case a wet year occurred with large storms; however in both cases no additional sediment samples were collected because they were dry years with no large storms. Because no sediment was collected during those years, we generally do not refer to them in this report.



1.4 Results

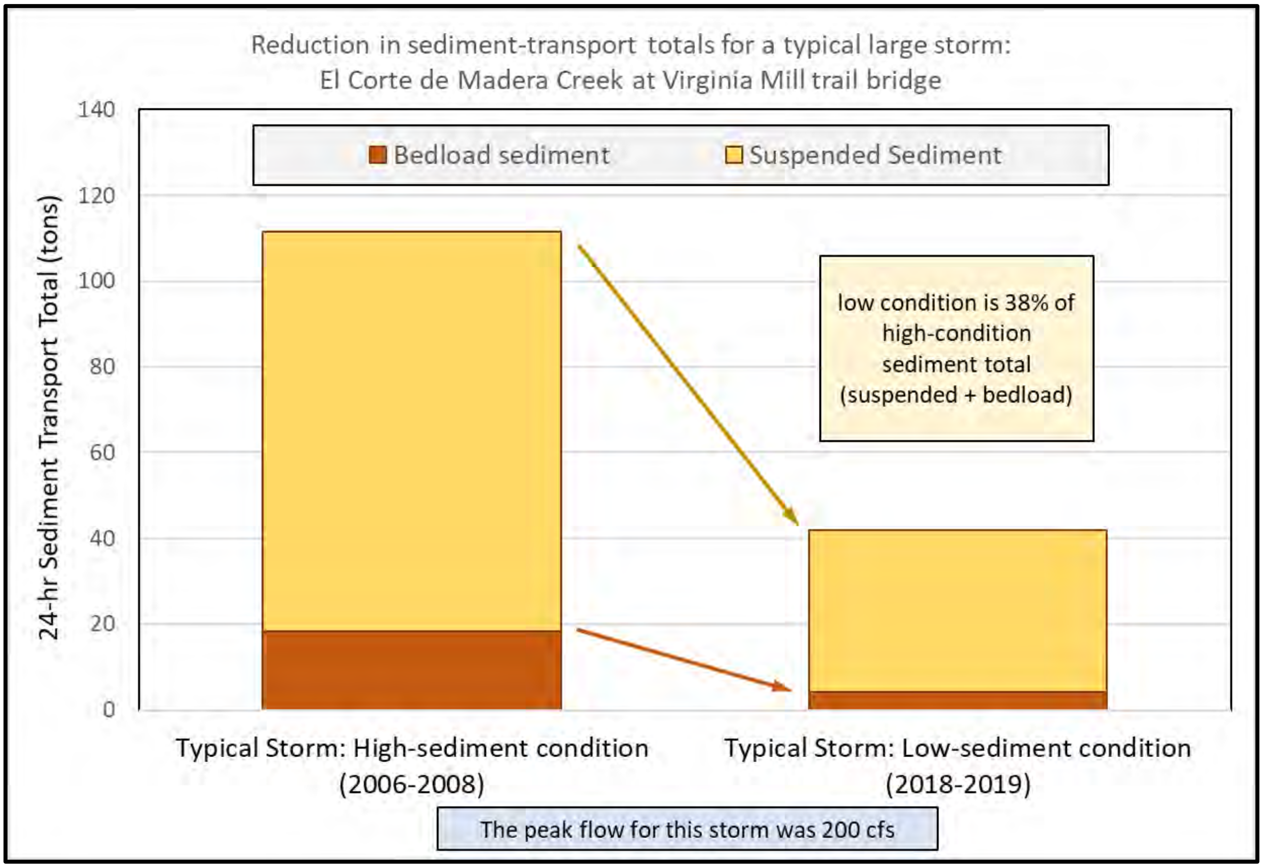
These study methods were then used to compare the magnitude of "natural" sediment sources to the magnitude possibly derived from roads and trails, and changes from the 2004-2006 period to 2018 and 2019 conditions. Keeping in mind that a confounding factor is that sediment production and transport varies greatly between wet years and dry years, results from the comparisons are:

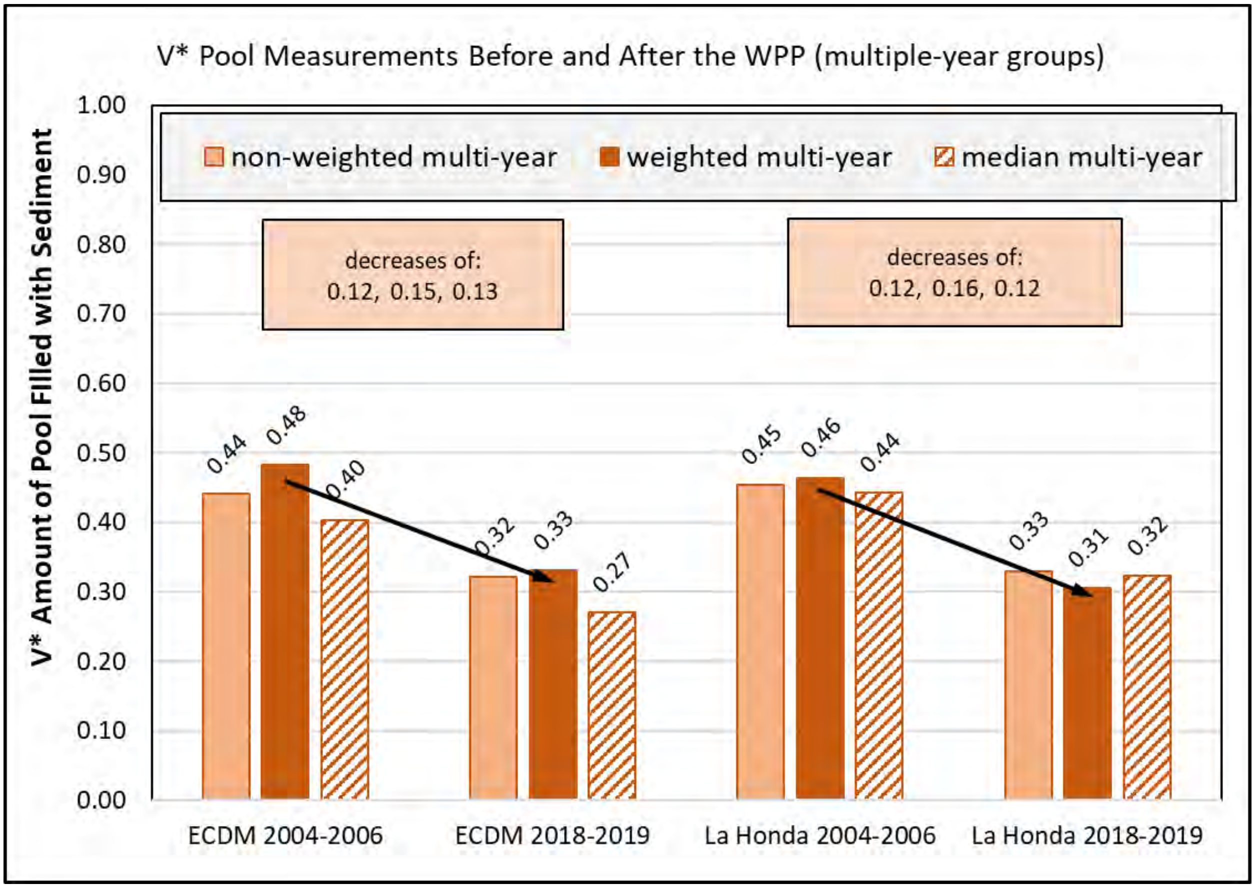
- Sediment rating curves for both suspended sediment and bedload sediment decreased substantially, which means that sediment transported downstream has decreased (by more than 50%) and is evidence that sediment production in the watershed and availability in creeks has decreased measurably in the watershed.
- Bed conditions in pools showed decreased sand (decreased 24%) and increased cobble and boulders sizes (each increased 8%); this is further evidence that sediment availability in creeks has decreased measurably in the watershed.

- V* values decreased from the 2004-2006 period (approximately 0.15; V* measurements in the La Honda Creek Preserve showed a year-to-year pattern similar to ECDM.

- Fewer landslides and bank failures occurred in the past several years (2017 and 2018), compared to the years preceding the first sets of measurements (1998 through 2004).

- In 2018, roughly the same amount of coarse sediment that was released from landslides was found to be trapped behind log jams, therefore limiting the amount of sediment being washed downstream; this is in contrast to 2004, when landslide volumes substantially exceeded sediment stored behind log jams.





1.5 Conclusions

1. Much less sediment is leaving the Preserve now than during our initial set of measurements. This could be due to the WPP, or fewer landslides, or a combination of both.

2. V* measurements show lower pool-sediment volumes in 2018 and 2019 than during the baseline period. This could be due to the WPP, or natural weather patterns, or a combination of both.

3. Sand on pool bottoms has been reduced (generally exposing more cobbles and boulders). This could be due to the WPP, or fewer landslides, or a combination of both.

4. Road and trail improvements of the WPP correspond to- and appear to have contributed to- decreased sediment transport rates in El Corte de Madera Creek. Because road and trail surfaces appear to be much less eroded now, than at the beginning of the study period, decreased sediment transport rates in El Corte de Madera Preserve can partly be attributed to road and trails-related

sedimentation reduction; additionally, the same trail improvements are useful to improve the trail experience for Preserve users.

5. Wood jams trap a substantial amount of sediment in the creek channel, and therefore contribute to modulating sediment transport, especially during wet years with large storms. If the wood jams were not there, much more sediment would likely have filled pools or washed downstream.

2 INTRODUCTION

El Corte de Madera Creek Regional Open Space Preserve (ECDM) is owned and managed by the Midpeninsula Regional Open Space District (MROSD). ECDM is a preserve of approximately 2,906 acres with more than 28 miles of roads and trails, located in San Mateo County, California, along the crest of the Santa Cruz Mountains (see Figure 2-1). The terrain is steep with elevations ranging from 550 to 2,430 feet, and has history of logging throughout the Preserve from the 1860's up through the 1980's. El Corte de Madera Creek drains into San Gregorio Creek, which is home to threatened species steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*).

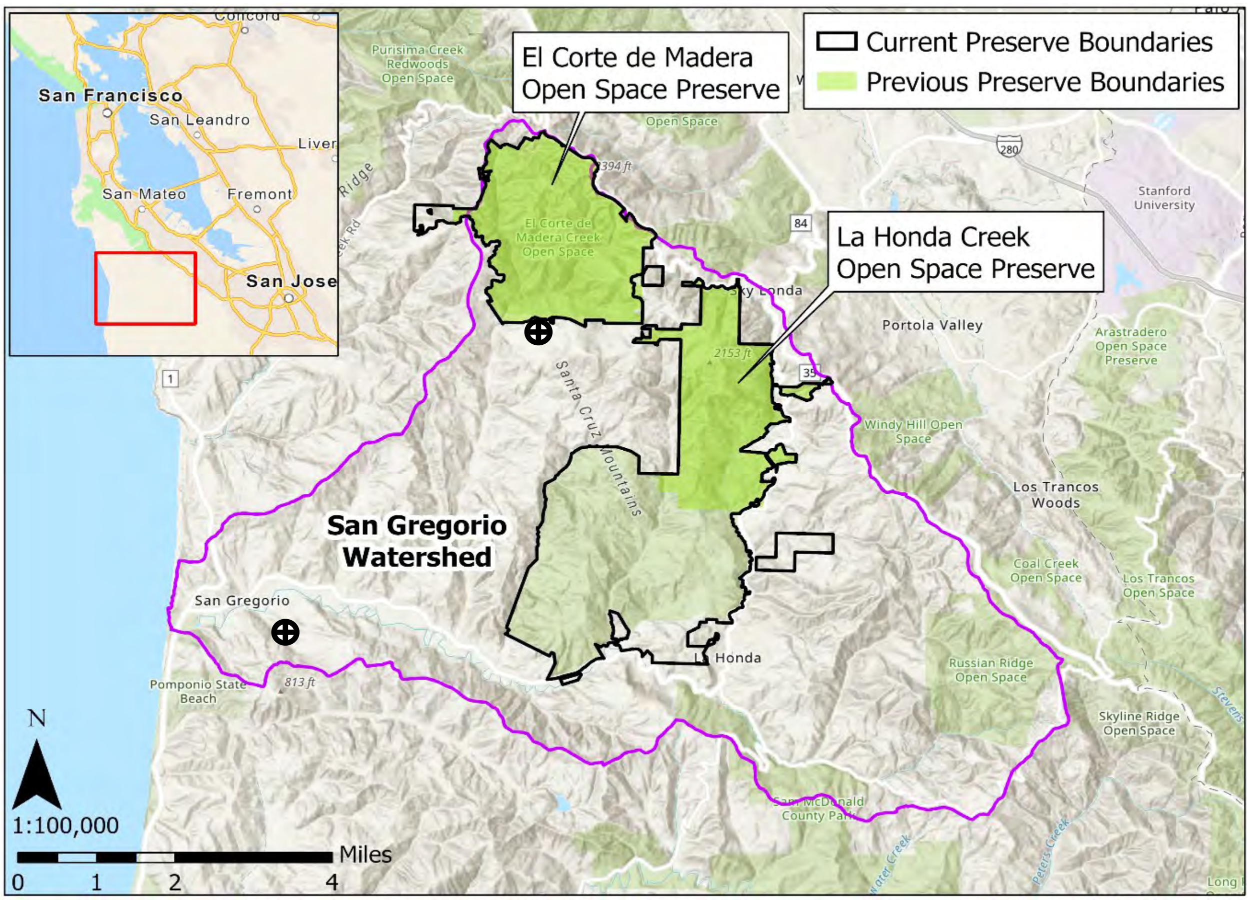


Figure 2-1 Regional and location map, with the larger San Gregorio Creek watershed delineated. The USGS and Balance Hydrologics creek gaging stations are shown. Skyline Boulevard (Route 35) runs along the northeast boundary of the Preserve. Highway 84 runs along the east side of the La Honda Creek Open Space Preserve.

There are reportedly natural fish barriers between San Gregorio Creek and the ECDM Preserve, sediment from ECDM eventually washes downstream and effects fish habitat in San Gregorio Creek. Resident rainbow trout are frequently observed in ECDM.

2.1 Starting Questions

At the beginning of the first phase of this project, the MROSD was starting a multi-year Watershed Protection Program (WPP) (adopted January 21st, 2004) to improve roads and trails to reduce sediment erosion, and to increase the sustainability of recreational use. Early work to describe locations and priorities for road and trail improvements was performed by Tim Best (2002).

Balance Hydrologics, Inc. (Balance) and MROSD collaborated to define a study approach to help the MROSD study the factors contributing to sediment in the creek system from 2004 through 2008. Initial questions that we sought to answer were:

- How full of sediment (sand) are pools?
- How much of the sediment is due to roads and trails vs. landslides and natural processes? Some landslides and bank failures may also be influenced by modern or older roads.
- Will the road and trail improvements in the WPP have an impact to the creek system that is measurable?
- Will the road and trail improvements create an initial disturbance that temporarily increases sediment getting to the creek system?
- How long does the logging legacy persist, and is the network of old logging roads and areas of channel fill still influencing the creeks?

We designed a study approach to address some of these questions, but some of the questions remain difficult to answer, particularly those concerning the historical impact of logging on sediment and creek conditions. The study approach is described in Section 2.

2.2 What This Study Project Was Not Trying to Measure

Frequently it can also be useful and clarifying to state what the project is not trying to measure or evaluate. These aspects can also make interesting follow-up projects to address related questions, but for this project we did not intend to- nor did we attempt to:

- Directly measure trail erosion. This could have been done by repeat fine-detail surveys of a large number and/or a representative sampling of different roads and trails of difference width, steepness, and usership.
- The amount of "active" erosion caused by road and trail use (detachment and erosion of soil particles) compared to "passive erosion" (rain splash erosion due to the presence of bare soil on roads and trails).
- How much road and trail erosion may be unavoidable, even with well-designed and maintained roads and trails.
- How direct measurements of trail erosion could also have been performed with "end-of-pipe" style of measurements where culverts or ditches collected runoff from road segments.
- Directly measure the effectiveness of individual or collective trail treatments; this could have been done with paired segments of roads and trails that received no treatment, and various levels of treatment.
- Upland sources of sediment that are far from creek channels. However, most of the steepest terrain that generates most of the sediment sources are locations close to creek channels.
- The effectiveness of road decommissioning in terms of both changes in amounts of erosion.

2.3 Historic Land Use – the Impact of Logging Practices

Historic land use in The ECDM Preserve could be the subject of an entire report, so we have included only a few pertinent aspects of the history as it pertains to hydrology, geomorphology and sediment conditions. The largest land-use impacts are due to multiple aspects of the logging history. Please refer to Balance's previous report for additional background details (Owens et. al., 2006).

MROSD provided the following historical timeline and map (Figure 2-2):

> In 1858, ECDM was part of Mexican land grant to Domingo Peralta and Máximo Martinez. 'El Corte de Madera' translates to 'wood-cuttings place', suggesting an

early history of logging. Clear-cutting of the forest followed. By the early 1940s, many second-growth redwoods in the region were large enough to be harvested again. This continued periodically in 5, 10, 15, and 20-year return intervals throughout the Preserve until the late 1980s. There are many recorded harvests in the Preserve after the 1972 Forest Practice Rules were adopted and record keeping of harvests began. Earlier aerial imagery shows logging in the decades before 1972. Logging-era refuse is found throughout the Preserve in the creeks: small railroad ties, stone walls for mills, and other implements and artifacts.

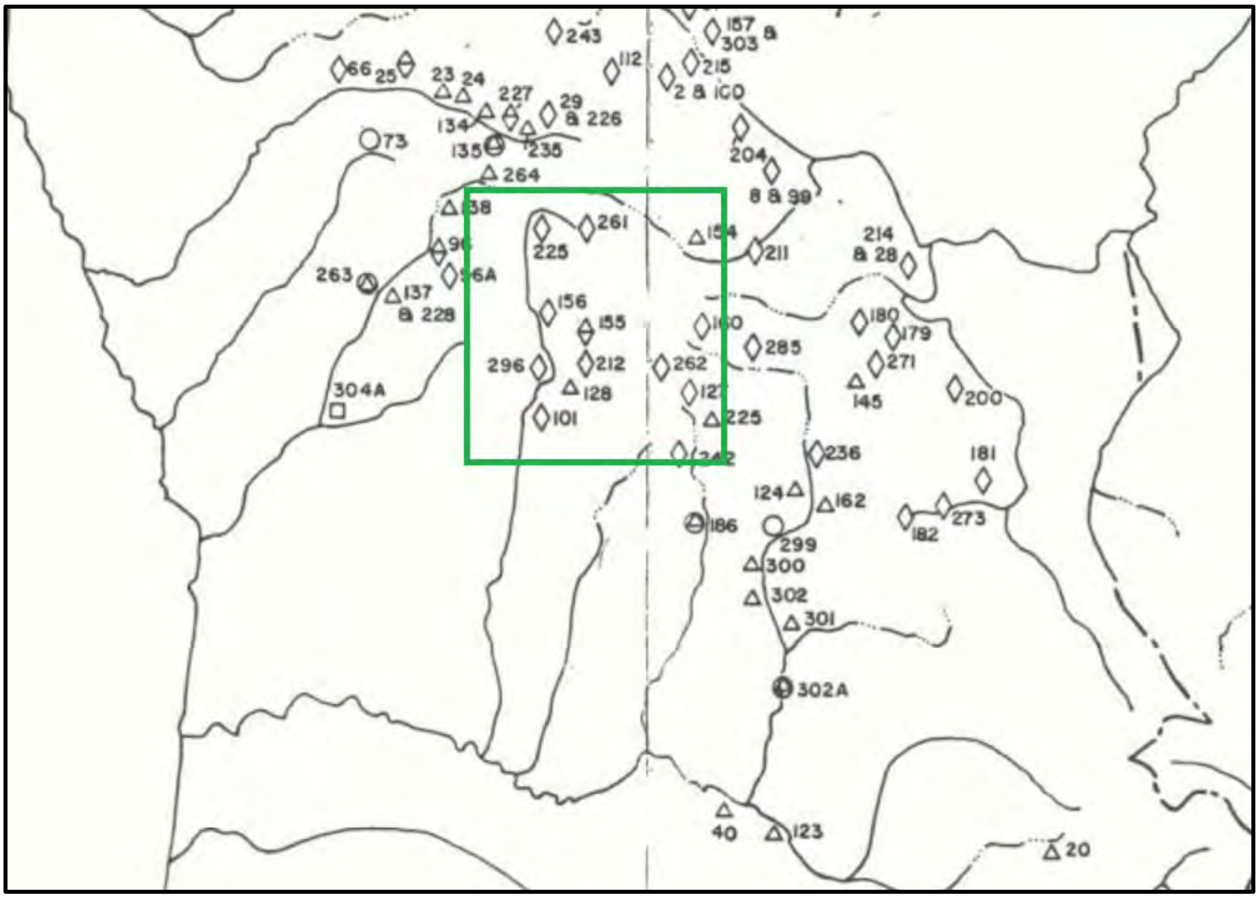


Figure 2-2 Historic sawmills in El Corte de Madera Creek Preserve. (Modified from Rood, 1975). Based on this map, there appear to have been 8 or 9 mills within the current boundary of ECDM.

The ECDM Preserve has a history of timber harvest dating from the 1860's (Stanger, 1967) until as recently as the 1980's. During our investigations, we observed numerous legacies of the timber-harvest era that serve to increase or accelerate sediment delivery to the creeks. Most significant were ubiquitous former skid trails, most of which have now become revegetated. The skid trails frequently track alongside the creek channels, sometimes on both sides, and angle across nearly every hillslope throughout the preserve. It is well documented that such roads can foster mass failures and destabilize former landslides (Wieczorek and others, 1988). Skid roads constructed adjacent to streams can destabilize the banks, promoting bank failures. It should be noted that even though many of the former skid trails have been colonized by vegetation, they may still alter or accelerate the flow path of water down slope (sometimes diverting flow from one catchment to another), and the portions of these roads that were constructed on fill will continue to be at increased risk of slope failures.

Logging era features that we observe in ECDM, which seem to have an influence on erosion and slope- and creek-bank- stability include:

- Roads with large cuts and half-bench construction
- Fall-line skid roads/cable yarding gullies
- Humboldt crossings
- Filled creeks in some areas
- Roads along edges of channels
- Mills in the creek channel
- Dam foundations, dams used to store water to run logs downstream
- Fire-scarred trees, perhaps from increased fire risk from post-logging slash

2.4 Steep Terrain and Bedrock Geology

2.4.1 Steep Terrain

The landscape at ECDM is visibly steep, with most roads and trails cut deeply into the hillslope. We performed a GIS analysis of slope steepness based on the topographic digital elevation model (DEM). As shown in Figure 2-3, almost all the terrain is greater than a 15-percent slope, and much is greater than 30 percent. The area-averaged slope over the whole ECDM Preserve is 57% (30 degrees). Please note that much of the steepest terrain is along the creek channels (“inner gorge”), which is also where landslides are more prone to occur, and thus many of the landslides we encountered often terminated in the creek channel. Frequently, the inner gorge slopes exceed 100% (45 degrees).

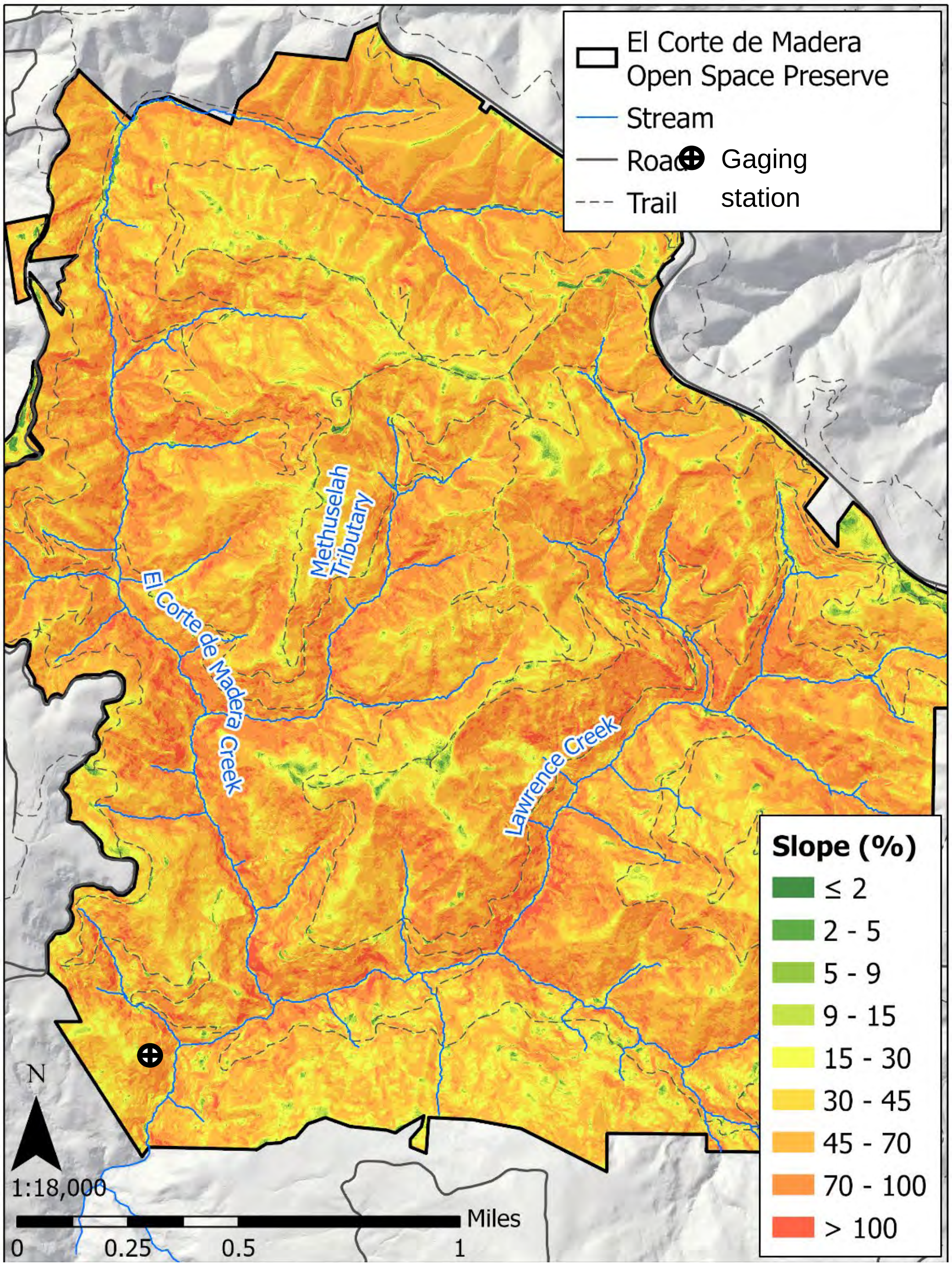


Figure 2-3 Slope steepness map analysis for El Corte de Madera Creek Open Space Preserve. Almost all the ECDM preserve consists of hillslopes of 15% or steeper, with most of the area having greater than 30% slopes; the steepest slopes are generally near the creek valleys. The area-averaged slope is 57% (30 degrees). (100% slope = 45 degrees)

The slopes of the creek channels and valleys are also relatively steep, as shown in Figure 2-4. Please note that the slope values were developed from a GIS database, and thus the longitudinal distance is at map scale and therefore does not capture all the meanders, twists, and turns that a creek takes on the ground.

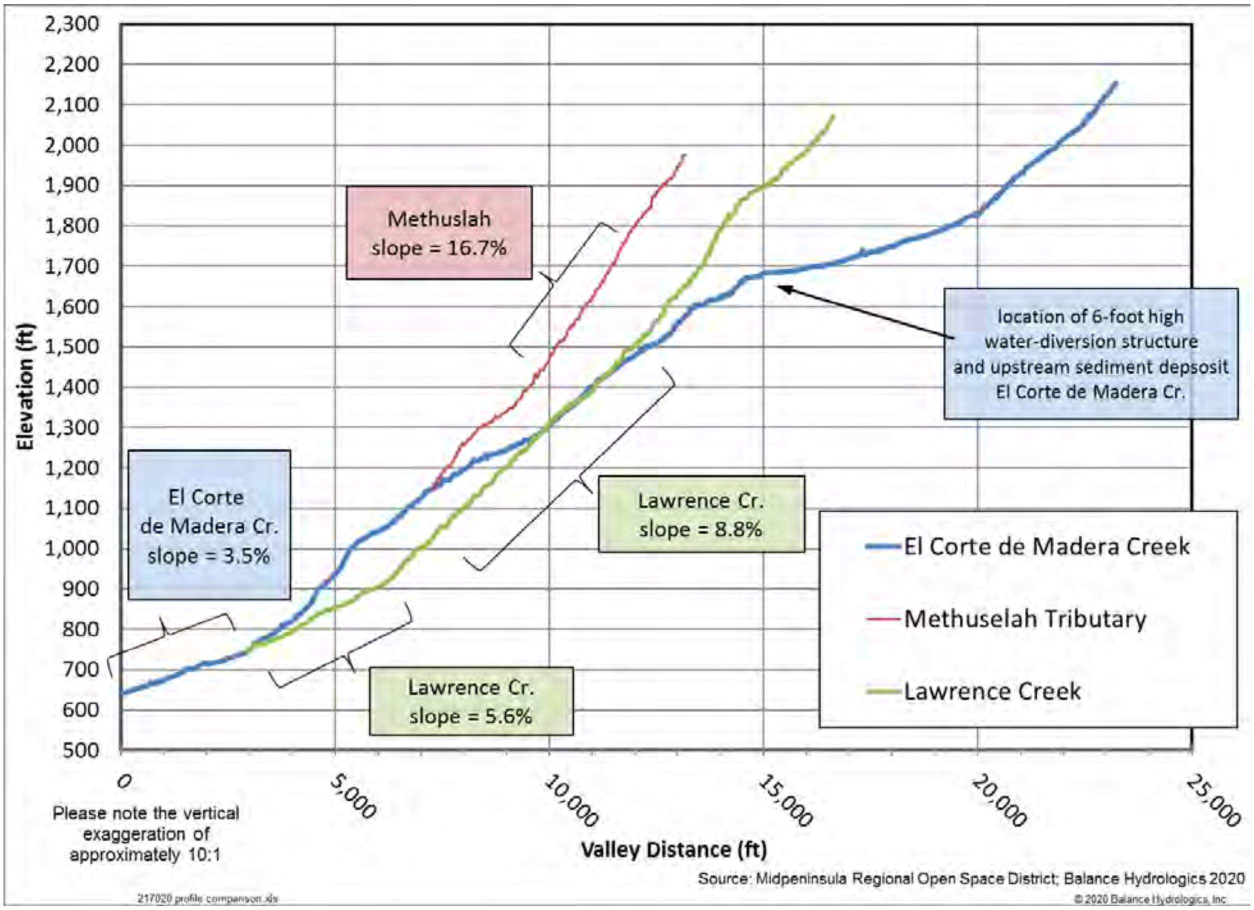


Figure 2-4 Creek valley slopes for El Corte de Madera Creek, Lawrence Creek, and the designated Methuslah tributary: El Corte de Madera Creek Preserve. The changes in slope along El Corte de Madera Creek are likely mainly geologic in origin. The creek profiles diverge at their confluences. Creek valley slope will typically be steeper than the local creek slope, because the valley slope calculation does not fully account for meanders and smaller scale twists and turns in the creek channel.

The steepness of the terrain within ECDM suggests that colluvial (hillslope) processes such as landslides and debris flows are the dominant geomorphic process for the landscape evolution. Alluvial (creek) processes then carry away the fine material delivered to the creek by the hillslope processes. As evidence of colluvial processes, we see many tilted stumps and landslide scars throughout the watershed, especially in steeper areas.

2.4.2 Geology

The majority of the ECDM and La Honda Preserves watersheds are underlain by Butano sandstone, designated as “Tb” (Brabb and Pampeyan, 1972) in Figure 2-5. The sandstone weathers and erodes in many ways, appearing as large boulders, cobbles and sand in the creeks (Hecht and Rusmore, 1973). A portion of the uppermost mainstem of El Corte de Madera Creek is underlain by Vaqueros sandstone (designated “Tvq”) and Lambert shale (“Tla”), which tend to weather to fine-grained sand, silt and clay. Although not shown on the geologic map, dikes and sills of mainly basaltic composition occur throughout all three rock types. These intrusive rocks are coeval (of the same age) with Mindego basalts, which outcrop immediately downstream of the Preserve; collectively, they are an important part of the stream framework, constituting about 6 to 8 percent of the cobbles and pebbles on the bed of El Corte de Madera Creek downstream from the confluence with Lawrence Creek, where we assessed their prevalence.

Most of the pebbles, cobbles, and boulders on the beds of the ECDM Preserve streams originate from the Butano formation; the sand and silt which constitutes the fine sediment filling the pools (and runs, glides, and riffles as well) have their sources in all three formations with the recognizable orange-tinged, poorly-sorted and often-angular sands originating in the Butano unit being obviously dominant. All three rock types generate soils with erosion hazards designated as ‘high’ and ‘extreme’ by the Natural Resources Conservation Service. Hecht and Rusmore (1973) note that the Butano formation is the most common source of pool-filling sands in the central Santa Cruz Mountains. Additional information relevant to the erodibility of formations in the El Corte de Madera Creek watershed is available in the report by Best (2002).

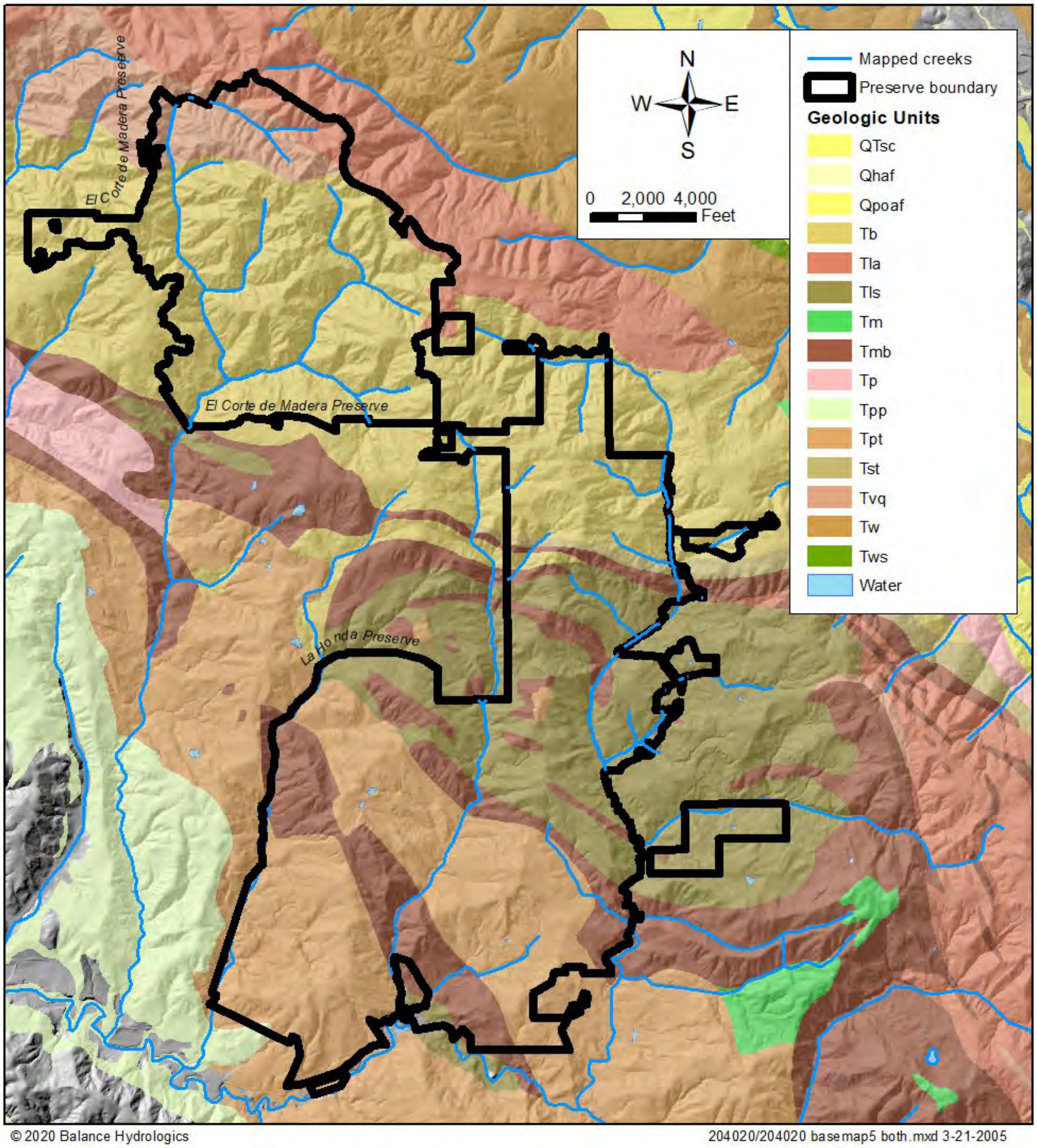


Figure 2-5 Geologic Map of the vicinity. The main geologic units are Butano (Tb) and Vaqueros (Tvq) sandstone. Some Mindego Basalt (Tmb) appears in the creek channel near the bottom of ECDM. The sandstone geology weathers to boulders, gravel, and sand-sized sediment. (Brabb, and Pampeyan, 1972, and Brabb, Graymer, and Jones, 1998)

The main geologic units are two types of sandstone. These rock types typically weather to creek sediment that is mostly boulders and sand[2]. Cobbles and gravel are also present, but the typical look of creek segments are boulder fields with sand between the boulders. This aspect led us to use the V* method, in which it is important to distinguish between the long-term creek-bed and sediment in regular transport. At ECDM, the long-term creek bed consists of boulders and cobbles in most places, while the sediment in transport is mainly sand with some gravel; because it is easy to tell the difference between cobble and gravel or sand, the V* method seems like it would be relatively easy to use in a repeatable manner (because different people would all be able to tell the difference between cobbles and sand).

2.5 Hydrology

ECDM Preserve contains the headwaters of El Corte de Madera Creek, Lawrence Creek and a number of unnamed tributaries; for this study, we informally called the tributary that parallels the Methuslah trail “Methuslah Creek”. Together, these tributaries are within a 4.4 square-mile sub-watershed that contributes to the 51.6 square-mile San Gregorio watershed. The La Honda Preserve contains the upper reaches of La Honda Creek, Harrington Creek, and several unnamed tributaries that drain to La Honda Creek; all of these tributaries are also within the San Gregorio watershed (Figure 2-1).

A section of El Corte de Madera Creek is shown in Figure 2-1; this section is near the Methuslah tributary. The creek bed here is mainly boulders with some large wood and patches of sand.

Average annual rainfall for the watershed ranges between 36 to 40 inches, depending on elevation (Saah and Nahn, 1989), and supports perennial flow in the mainstem channels during a normal rainfall year. Rainfall typically occurs October through May. Fog drip and mist can contribute a small, but measurable, component of flow to the ecosystem and stream system. Figure 2-7 shows the measured hydrograph for water year 2006, plotted with USGS data from the San Gregorio Creek station (station ID#11162570).

[2] Bed-material measured as an add-on to V* measurements later confirmed our initial observations, with pool bed surfaces consisting of approximately 50% sand and 25 to 30% boulders (see Figure 4-6). We did not measure non-pool sections, but those would have more boulders and less sand.

Figure 2-6 Section of El Corte de Madera Creek (2018). Looking upstream, near Methuslah tributary. Note redwoods and bedrock cliff at the right edge.

There are very few impervious surfaces within the Preserve, although paved roads along some ridgelines do drain into the preserve. The impact of paved roads can be locally important for erosion near runoff outfalls, but their impact on overall hydrology appears to be small.

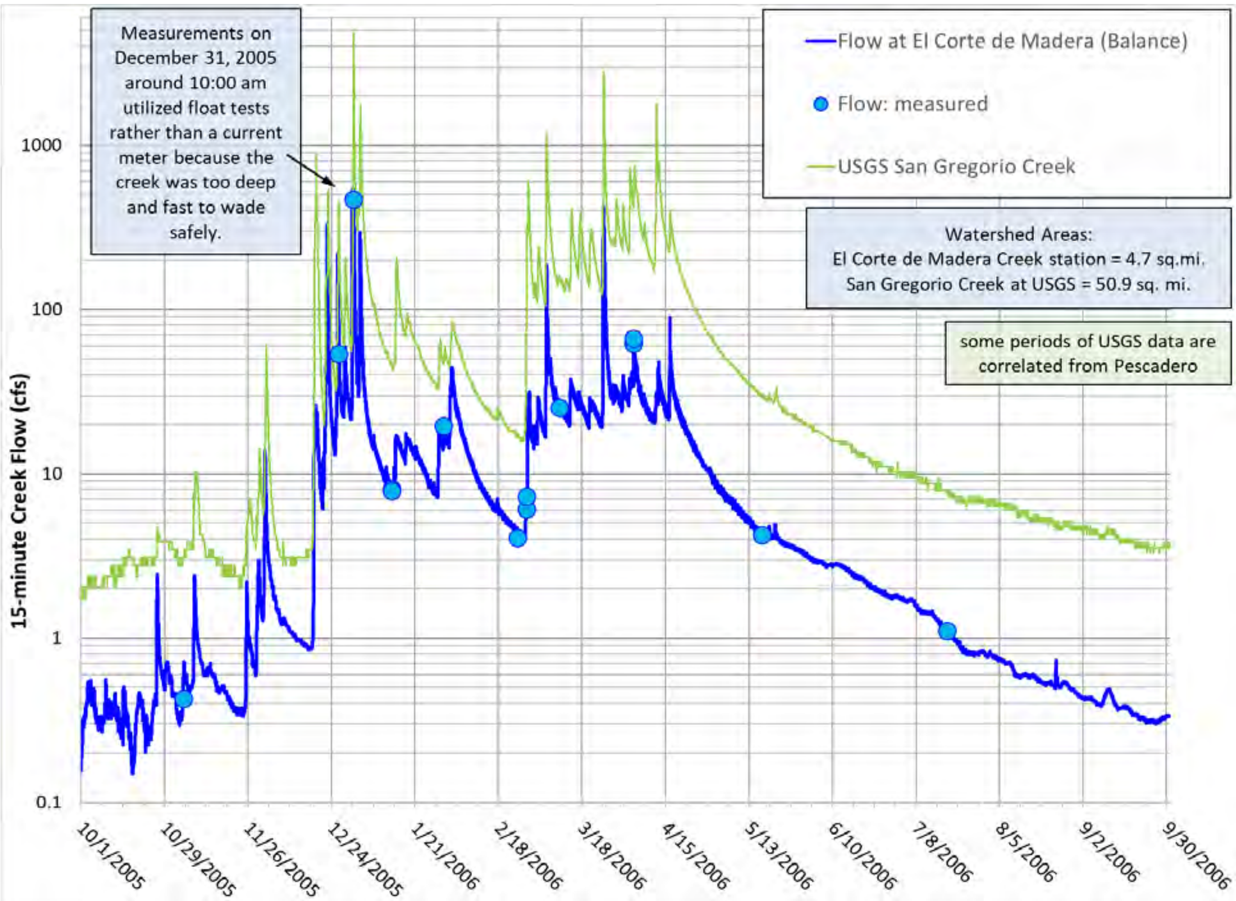


Figure 2-7 Flow hydrograph recorded for water year 2006: El Corte de Madera Creek at Virginia Mill bridge. Water year 2006 was a wet year with several large storms; the largest occurred December 31, 2005, with a peak flow of 548 cfs (which equates to roughly a 13-year storm).

We used our stream gaging data to create a correlation from San Gregorio Creek USGS flow to ECDM flow. In Figure 2-8 we use the correlation to rank 50 years of annual peak flow on San Gregorio creek and relate those to an estimated equivalent flow at ECDM. This analysis allows us to assign approximate return periods to the large storms that occurred before and/or during the period of our measurements. The largest storm in the 50-year period is from WY 1998; the 4th largest is from WY 2006 (13-year storm) on a day we visited the site and made measurements; WY 2017 was a wet year for total rainfall and ranked as a 5.7 year storm.

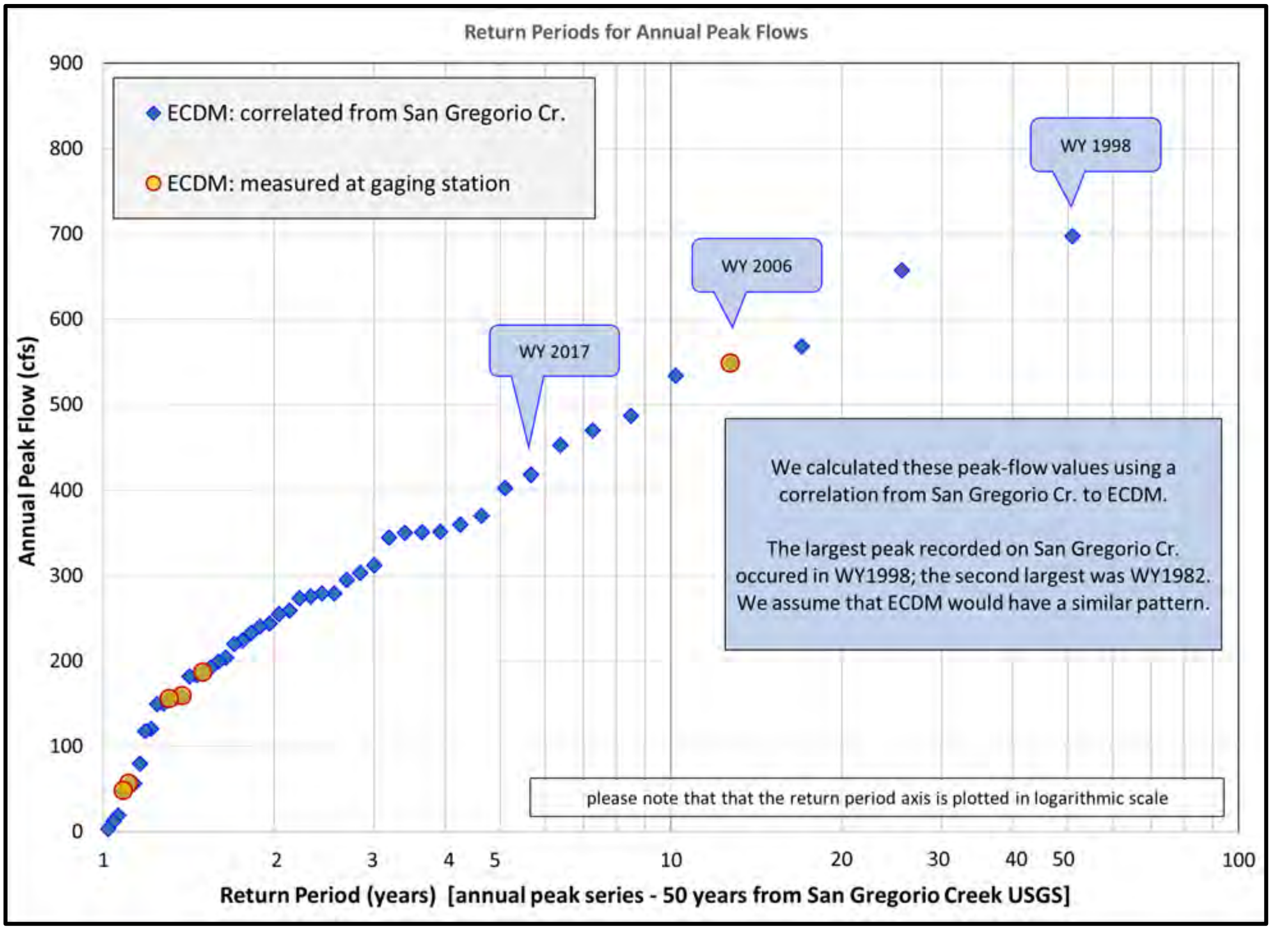


Figure 2-8 Return periods for peak flow correlated from San Gregorio Creek data. We use these correlated data to put our measured peak flows in context of the longer-term record. This also shows that the peak flow of 1998 was the largest peak over the 50 years of data for San Gregorio Creek. The 548 cfs peak flow that we recorded for WY2006 plots as a 13-year storm. The WY2017 peak correlates to 418 cfs (5.7-year storm). The peak flows for WY2018 and WY2019 rank as 1.5 and 1.4 year storms.

2.6 Role of Large Wood

Much of the large wood is redwood (*Sequoia sempervirens*) and Douglas fir (*Pseudotsuga menziesii*), with some regions of tanoak/tan-bark oak (*Notholithocarpus densiflorus*) (tan oak die off has increased due sudden oak death). Old stumps, whole trees, and smaller pieces of wood often fall into creek channels individually, and/or with landslides and bank failures.

Individual pieces of large wood are often structural elements of the creek channel morphology, but wood jams that consist of multiple logs play a more substantial role in trapping sediment, sorting sediment, creating pool habitat and cover habitat. The creek channels of ECDM have more numerous, taller, and larger wood jams than most other local watersheds (Figure 2-9 and Figure 2-10).

Figure 2-9 Typical sediment deposit behind a wood jam in El Corte de Madera Creek Preserve (2018). Flow is from left to right; this photo shows the recent sand deposit (much of which is still soft), and some winnowing to a coarser surface layer in the center of the channel. Only the top of the wood jam is visible.

Figure 2-10 Typical wood jam in El Corte de Madera Creek Preserve (2004). Looking downstream: showing gravel deposit in the center, a sand deposit to the right, and a higher, partially-vegetated sand deposit to the left. Some wood jams are much larger than this example.

Noticeable large pieces of the wood appear to be from the original logging era (stumps with spring-board notches, hand-squared logs, logs with metal spikes from mill structures). Thus, we conclude that the key pieces of some wood jams can last for a long period of time, and therefore may store sediment for a long period of time. However, observations also suggest that the amount of sediment trapped by long-lived wood jams may wax and wane as smaller wood pieces may be trapped and then decompose or become dislodged over time, and that this process may repeat itself.

Large wood that falls and fully spans a creek channel above the water level may not initially affect sediment, but eventually, many creek spanning logs fall into the creek.

2.7 Roads and Trails and Recent Trail Use

Because of the steep terrain, almost all the roads and trails are built on cuts into hillslopes. Many road sections also appear to be "half-bench" roads where approximately half the road is on a *cut* surface and half the road is on a *fill* surface. The wider road sections appear to be generally inherited from the more modern logging activities (1960s and 1970s), although some of the modern roads appear to have been widened from older logging roads. Trails are often located on segments of older logging roads that are narrower and in poor condition, and often have been partially colonized with tree growth.

In 2004, the distance of roads within ECDM was 11.8 miles and the distance of trails was 17.1 miles. The current (2020) distance of roads and trails is listed as 35.9 miles, by MROSD. There are single-track trails (2' wide tread), ATV-accessible trails (6' wide tread), and roads with a 10-20' tread.

Prior to MROSD improvements, from an erosion perspective, roads (contrasted with trails) tended to have:

- more width of bare soil
- less canopy cover, allowing more rain-splash erosion on bare soil
- more rills and gullies

Both roads and trails often capture runoff with water flowing *along* the surface instead of *across* the surface.

The MROSD began WPP road and trail improvements in 2004 that continued through 2019; this program improved drainage features, recontoured roads and trails, decommissioned some, and built or relocated other trails. During this period, this preserve has gained popularity among trail users, particularly among mountain bikers, and attracts outdoor enthusiasts from across the San Francisco Bay area. Ongoing maintenance and improvements also may occur.

The following figures provided by MROSD (from Best, 2002 and 2006), show some typical road and trail improvements that were implemented with the WPP (Figure 2-11 and Figure 2-12).

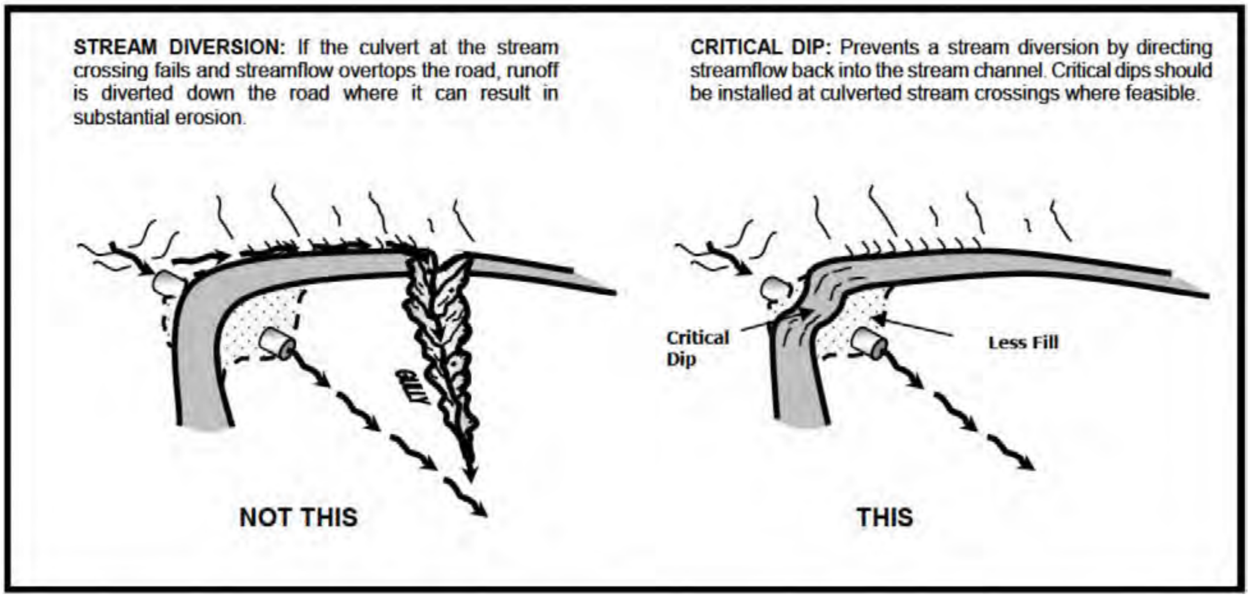


Figure 2-11 Typical sketch for using a critical dip with a culvert at a drainage/trail crossing. (from Best, 2002) A critical dip allows water to flow across the trail and back into the drainage, if the culvert were to become obstructed, rather than flowing along the trail for some distance.

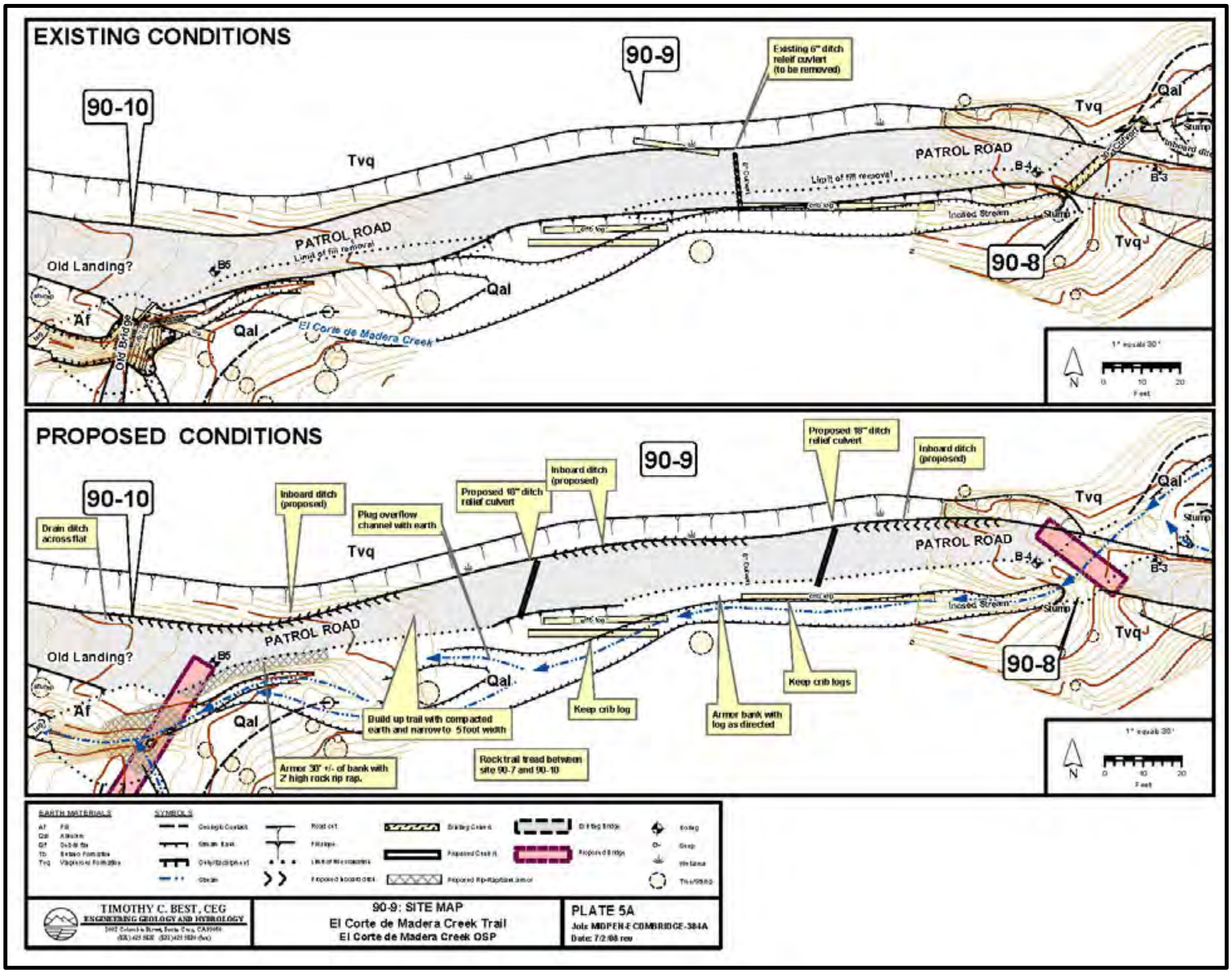


Figure 2-12 Example sketch of a trail segment and the suggested improvements to reduce erosion and improve sustainability (from Best, 2006).

3 METHODS AND APPROACH

At the start of the project, we originally envisioned the first 2 main methods to measure and monitor creek and sediment conditions, and a third method was added starting in water year[3] 2006 (WY 2006):

1. V* to characterize pool-filling sediment (Lisle and Hilton, 1992)
2. Sediment-source inventory to quantify natural and road-influenced slides and bank failures, as well as stored sediment.
3. Streamflow and sediment gaging at the Virginia Mill trail, near the bottom of the watershed and the Preserve.

Based on the time and budget available, we focused the sediment-source and storage sampling area to the main stem of El Corte de Madera Creek and two main tributaries (Lawrence Creek, and the project-designated "Methuslah tributary"). These choices were based on initial reconnaissance of observed landslides, and the locations where definable pools were observed (generally in creek segments with larger watershed area and less-steep channels). Balance staff surveyed most the creek system for potential V* pools and rated their quality by their likely durability over time (e.g. pools defined by rotting wood or gravel vs boulders). V* pools were generally located towards the bottom of the watershed to measure cumulative change and because larger, higher quality pools were more abundant there. The stream gage was sited towards the downstream edge of the property in order to capture changes from the WPP. The site for gaging and sampling was selected based on its relatively geomorphic stability, relative ease of access, and in a location the Preserve users were unlikely to notice.

The time frame of these approaches are shown with a plot of annual and peak flow in Figure 3-1.

[3] Most hydrologic and geomorphic monitoring occurs for a period defined as a water year, which begins on October 1 (of the year prior) and ends on September 30 of the named year. For example, water year 2006 began on October 1, 2005 and will end on September 30, 2006.

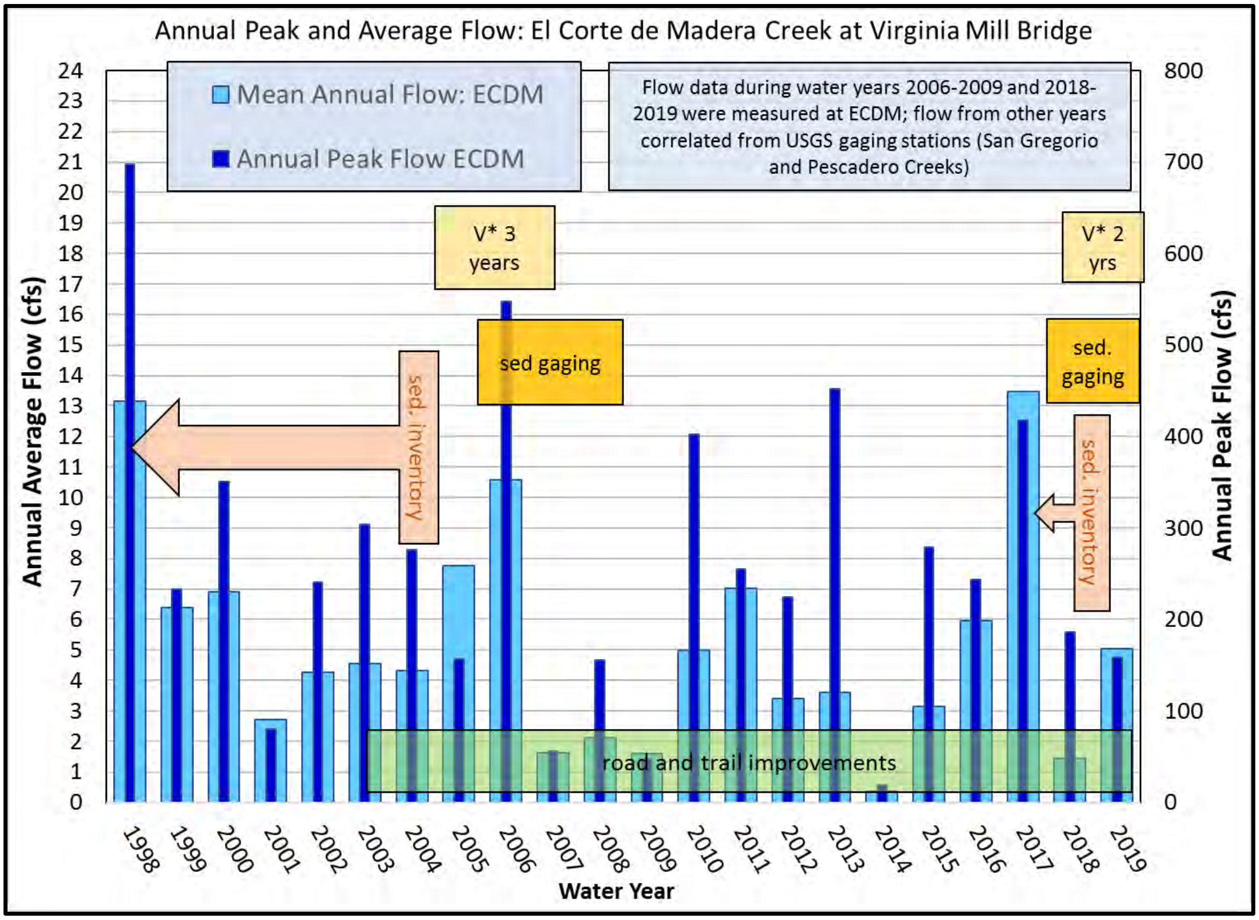


Figure 3-1 Periods of measurement approaches overlaid with a chronological plot of average annual flow and annual peak flow. The sediment inventory looks back several years to when landslides and bank collapses occurred (1998 and 2017). Water year 2006 was also a disruptive year in terms of the peak flow and bed changes, which overlapped with the V* measurements and flow and sediment gaging.

3.1 V* Method, Applicability, and Method Checks

3.1.1 V* Method

V* or V-star[4] was developed by geomorphologists Hilton and Lisle (see Lisle, T.E., and Hilton, S., 1992 and 1999, and Hilton, S., and Lisle, T.E., 1993).

[4] V* (pronounced "V-star") is a method developed by geomorphologists (Lisle, 1991; Lisle and Hilton, 1993), is frequently applied to evaluate sedimentation of pools. It is most effectively used in streams with large contrasts between bed material and the fine sediment that fills pools (Lisle, 1999). The streams in ECDM tend to have cobbles or small boulders as the dominant bed material, and to be filled with fine to medium sand. We believe it suitable for many purposes at ECDM.

3.1.2 V* Applicability to Bed Material and Time Scale

This method works best with a well-defined pool bottom, and may be more subjective with minor gradations between pool-*forming* and pool-*filling* sediment sizes (such as trying to differentiate between large gravel and small gravel. Based on initial observations, this method seemed as though it would work well at ECDM with the dominant size classes of boulders and sand, with boulders forming the underlying pool shape, with sand being the “pool-filling” material.

Smaller cobbles and gravels that partially define a pool (either at depth or along the downstream end of a pool) and that may be mobilized in large storms events would be more difficult to assess using the V* method; if the pool itself (often the riffle crest) changes substantially over the study period, the relative percent of sediment in the pools becomes difficult to interpret.

Cobbles do not appear to move frequently in ECDM (except in very large storms), due to the relatively small scale of the watershed. In portions of ECDM, consolidated gravels sometimes defined the bottom of the pool (as probed by the measuring instrument) and which may be mobilized in large storm events. These materials could also be moved aside by the instrument with enough force. Being able to push through an initial resistant layer to a deeper pool bottom appeared to be a rare occurrence in ECDM, and did not appear to affect the data in the individual pools meaningfully, but could be an issue in some geomorphic settings with a greater abundance of gravels or in which storms regularly mobilized gravels.

3.1.3 V* Depth Measurements

A grid system is set up to measure the water depth and total depth (sediment depth is calculated by subtraction). This delineation between pool-forming and pool-filling material is important for the repeatability of measurements, and also relates to the time-scale of the study being performed.

At the outset, the time scale of this study was thought to be on the order of 10 years, because that was a time scale to have a range of flow conditions and the expected duration of the WPP for road and trail improvements. Over this time frame, we expected

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The method tends to be applied especially to those pools supporting salmonids (c.f., Flossi and others, 2004); although barriers preclude steelhead from reaching and using the ECDM pools, V* remains a useful and suitable metric in El Corte de Madera Creek for monitoring bed sedimentation in pools.

mainly sand and gravel to be transported, while we expected boulders and cobbles to be largely stable, based on our observations of bedload-abrasion and moss-growth patterns on boulders. If a longer timescale were being studied, such as the impact of the logging period, or the maximum depth of sediment behind wood jams, then deeper, more forceful probing through cobbles down to boulders or bedrock would be more appropriate and necessary.

This initial assessment of sediment mobility was tested- and largely confirmed- following the peak flow of WY2006 (548 cfs, approximately a 13-year storm), when we noted that some cobbles had been moved by the flow and that most boulders had been stable. This observation was largely based on the orientation of moss growth (moss on top and horizontal if stable, and tilted or inverted if the cobble had moved).

3.1.4 Pool Selection

While walking the creek channels during the sediment inventory, we ranked pools subjectively based on our initial assessment of how stable we thought they would be over time (e.g. larger material at downstream riffle crest tends to be more stable). We wanted to have pools in several of the main creek branches, and we also wanted a distribution of large, medium, and small pools.

3.1.5 Grid Spacing

The grid spacing is customized to each pool to best describe the shape of the pool volume, and can differ longitudinally and laterally, for example a long-skinny pool would have different spacing than a wide round pool. We typically targeted 100 to 125 measurement points per pool, although large pools often had more points, and the smallest pools sometimes had fewer points. Lisle recommended 7 to 10 cross sections (data collection lines perpendicular to flow). We generally erred towards more cross sections and data than the original method recommended, where time permitted.

The following schematics (Figure 3-2 and Figure 3-3) help explain the method.

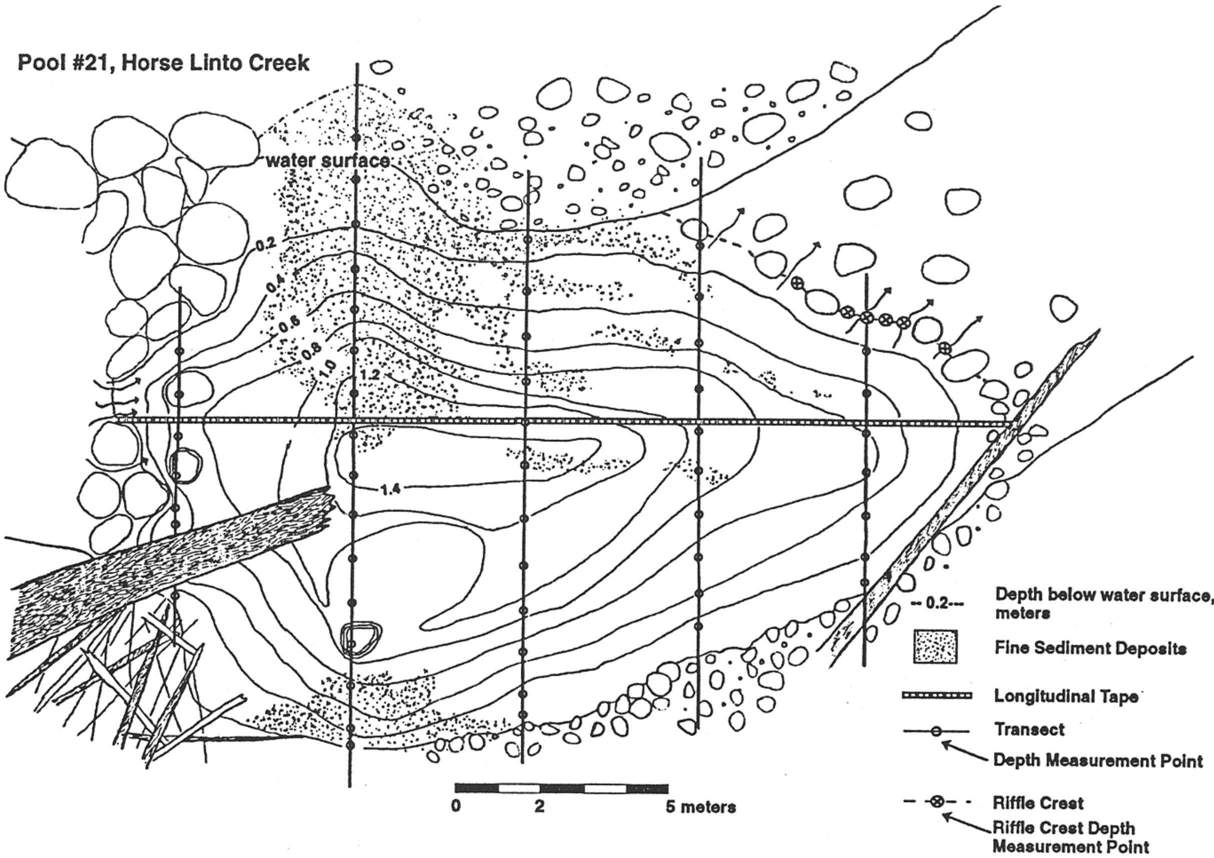

Figure 3-2 Plan View of an example pool to illustrate the V* method. Observers define the pool, set up a grid system of the longitudinal tape and transects, and perform sediment probing to measure the water depth and total depth to the bottom of finer sediment (from Hilton, S., and Lisle, T.E., 1993).

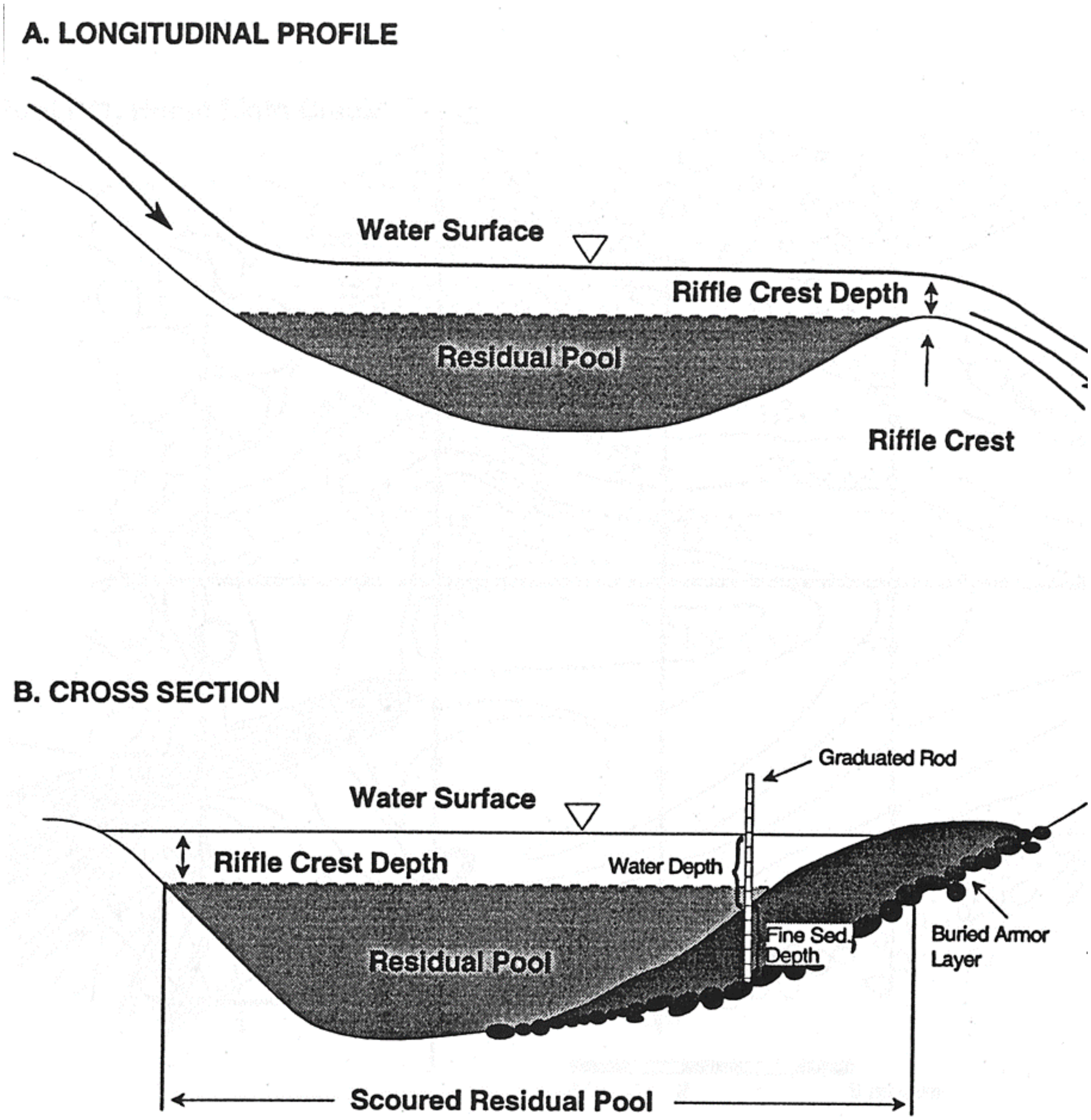

Figure 3-3 Sections of example pools illustrating the V* method. Observers define the pool and riffle crest, set up a grid system of the longitudinal tape and transects, and perform sediment probing to measure the water depth and total depth to the bottom of finer sediment at approximately 100 points (from Hilton, S., and Lisle, T.E., 1993).

V* for a given pool is then defined as the “fine-sediment” volume divided by the total volume of the “scoured residual pool” volume. The resulting value is a decimal fraction of the amount of the pool that is filled fine sediment.

After walking most of the creek channels, we chose a subset of pools within ECDM and the La Honda Creek Preserve, on which to apply the V* method. We were generally successful in relocating the same pool locations year after year, although some pools changed too much to still be considered pools, and one location was not able to be relocated. Additional V* pools were added in 2018 and 2019. The transect and tape are shown in Figure 3-4.

Figure 3-4 V* measurements being performed by MROSD interns: El Corte de Madera Creek Preserve, 2019. The downstream end of the pool (riffle crest) was defined here at approximately 3 feet on the tape, where the small boulders separate the flat pool surface from the moving water surface. The dog was a “volunteer” who had wandered into the Preserve, and was reunited with his owners- with assistance from MROSD rangers- at the end of the day (dogs are not permitted in ECDM).

3.1.6 V* Method Checks

Various checks on application and optimization of the method were conducted:

- Physical tests were conducted to replicate measurements at the same pool approximately 1 month after the first measurement (without attempting to duplicate the exact grid spacing or probe locations). MROSD interns performed replicate measurements and found that the 2nd measurements yielded V* values within 0.04 of the original value, and sometimes only 0.01 different.

- Numeric tests were conducted by MROSD to evaluate how V* might change if fewer points were recorded per pool, by removing sections of data. This was done to evaluate if we were recording not enough or too many points. Because removing cross sections did not substantially change the V* values, it was concluded that more than enough points were being collected.

- Variations in the amount of force applied to the rod were also tested. Because the method was performed by a mix of the same people and different people throughout the study period, and because the sensation of differentiating between pool-forming and pool-filling sediment can be subjective, the amount of force that different people apply to the rod can vary. Variations tested also included the amount of side-to-side wiggling applied to the top of the rod to get deeper through sediment and using a mallet to drive the rod deeper.

3.1.7 SEDIMENT TEXTURE FREQUENCY

As an add-on to the V* depth measurements, we recorded the surface material at each depth location as a sediment size class, for example sand, gravel, cobble, or boulder (see Figure 3-5). These data were recorded in the field along with the V* data, and later analyzed by MROSD. These data represent the surface material that the sediment probe first touched, as opposed to the material that was deeper under the surface.

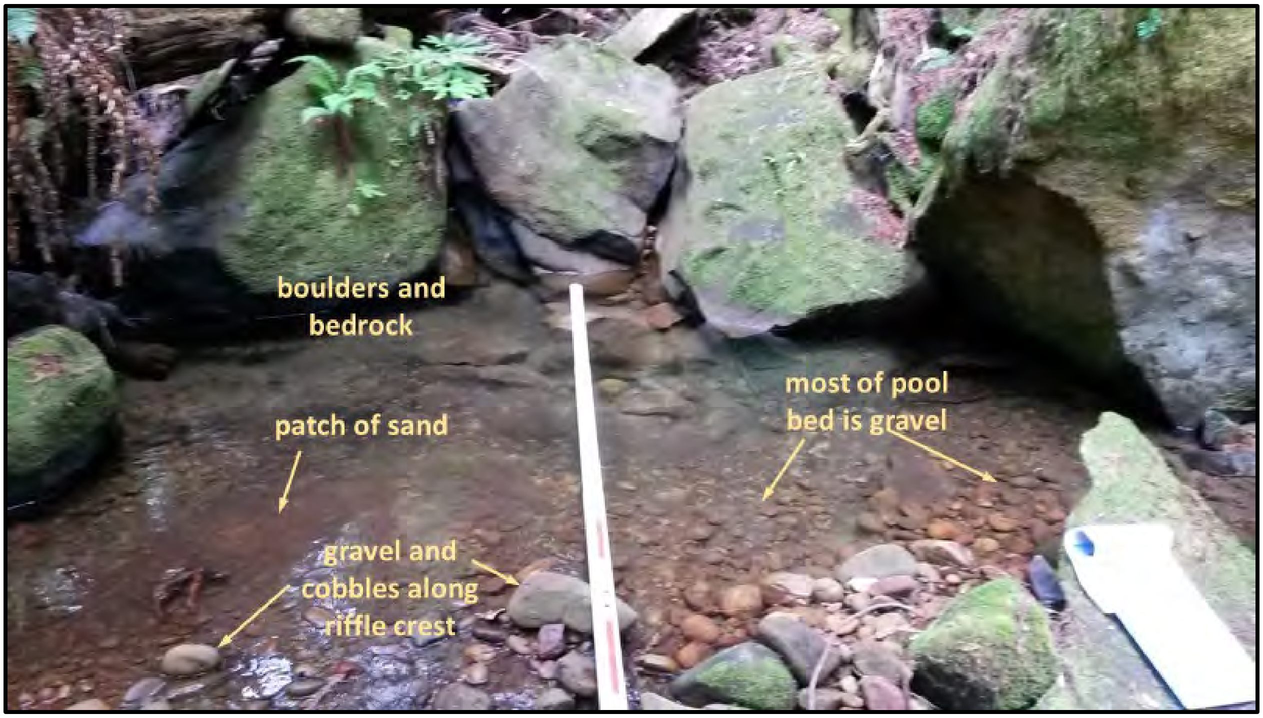

Figure 3-5 V* pool showing different types of bed sediment that were recorded as part of the sediment-texture analysis. Photograph from 2018 when little sand was on the bed; the V* value of this pool was measured to be 0.13 at the time.

3.2 Sediment-source Inventory Method

We inventoried large sediment sources near the channel, generally within the inner gorge, that were delivering sediment directly to the creek. The inventory included landslides, debris flows, bank failures, and gullies, plus selected other features (see Figure 3-6).

Based on the large number of large sediment sources and deposits encountered, we also set a lower limit on the size of sources or deposits to quantify, map, and record. Therefore, these estimates undercount that total amount of sediment sources and storage areas.

For sediment stored behind wood jams, in 2018, freshly deposited bedload sediment from 2018 and 2017 was easily identifiable as soft and not yet consolidated. However, in 2004, bedload sediment from 1998 that was found behind log jams was already consolidated and we did not attempt to differentiate stored 1998 bedload sediment older stored bedload sediment.

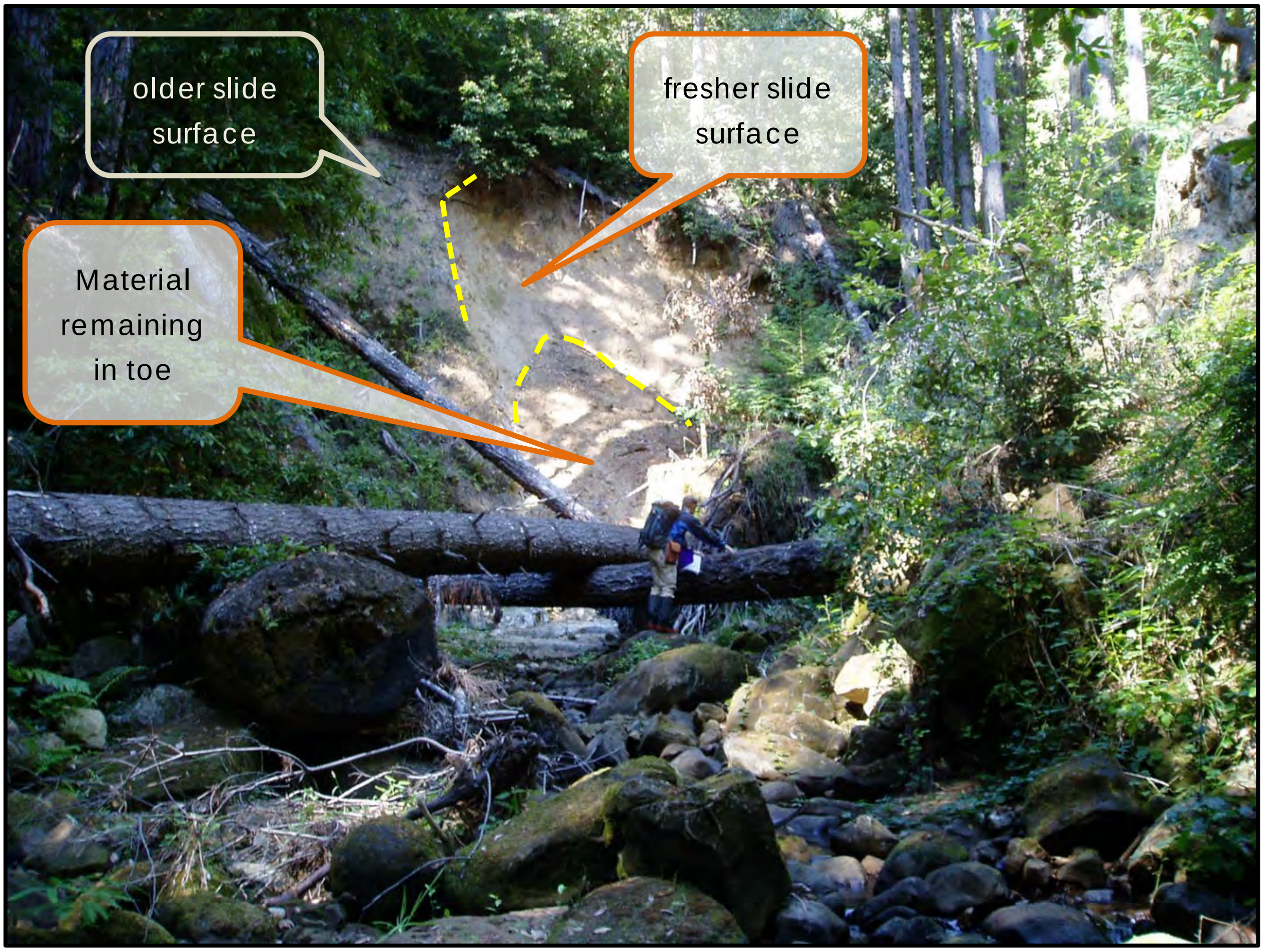

Figure 3-6 Typical sediment source that was measured, mapped, and inventoried: El Corte de Madera Creek Preserve. This photograph is from 2004; at least two episodes of sliding are visible in the photo, and a substantial portion of the sediment material remains at the toe of the slide. In the 2018 inventory, the hillslope above this location had also failed.

In addition to mapping locations of sediment sources and storage we quantified the dimensions of the source (missing sediment) and stored/deposited sediment. Recently stored/deposited sediment was identified by being loose and soft to stand on- or dig through.

Based on field observations of the soil and rock conditions at each site, we estimated the amount of each sediment source that had been composed of sand and coarser material.

Based on field assessment of revegetation, sediment density and other factors we attempted to assign a year to the origination of the sediment source. For large landslides, we confirmed our estimated dates with sequential aerial imagery.

3.3 Streamflow and Sediment Gaging

Creek flow data is an intermediate step to calculating sediment transport at the station. The end product of the creek gaging and sediment sampling effort is twofold:

1. Compare the rates of sediment transport (as a function of flow) from early in the WPP to sediment-transport rates after the road and trail work has been largely completed.

2. Calculate annual sediment loads that can be compared quantitatively to the other measures of sediment volume (V* and sediment sources)

Flow data was collected during water years 2006 through 2009 and 2018 through 2020; sediment sampling was conducted during water years 2006 through 2008 and 2018 through 2019.

3.3.1 Streamflow Gaging

Starting with water year 2006 (fall 2005), we added a gaging station to the lower section of El Corte de Madera Creek (near the Virginia Mill Trail). The station consists of a staff plate and electronic probes connected to a datalogger. The data are adjusted based on regular visits, observations, and manual measurements. Flow is calculated from the record of water height on the staff plate and applying an empirical equation that is based on manual flow measurements.

The flow record allows us to assign a flow value to the time when sediment samples were collected. The flow record also allows us to create a correlation to other local gages, such as the USGS stream gage on San Gregorio Creek. That gage has a much longer period of record, which allows us to use the correlation to extrapolate additional data for use in interpreting the ECDM record. For example, we correlated annual peak flow from 50 years of data to estimate return period and peak flows at ECDM.

3.3.2 Sediment-Transport Sampling

We distinguish two types of sediment in transport: bedload sediment and suspended sediment.

- Suspended sediment is supported by the turbulence of the water and is transported at a rate approaching the mean velocity of flow.
- Bedload sediment is supported by the bed; it rolls and saltates along the bed, commonly within the lowermost 3 inches. Movement can be either continuous or intermittent but is generally much slower than the mean velocity of the stream. In El Corte de Madera Creek, bedload consists primarily of sands and gravels, with some cobbles at higher flow.

Sediment data collection at this site was conducted by Balance and MROSD staff during water years 2006 through 2008, and water years 2018 and 2019, with suspended- and bedload-sediment sampling conducted during high-flow periods (Figure 3-7 and Figure 3-8).

Figure 3-7 Sample in collection bottle and typical conditions during moderate to high flow: El Corte de Madera Creek at gaging station. Water is turbid and well mixed. We collected width- and depth-integrated suspended-sediment samples with a DH-48 sampler that we then analyzed for turbidity and suspended-sediment concentration.

Figure 3-8 Bedload measurement near the peak flow of WY2018. We sampled bedload by wading across the creek and using a Helley-Smith bedload sampler at intervals across the active bed.

Standard methods and equipment reviewed by the Federal Interagency Sedimentation Project (FISP) were used to make measurements of sediment transport. Field measurements of sediment transport are made either by hand samplers applied in transects across the channel at wadable flows, or from the edge-wading in partially- at higher flows that are not safe to wade. We use Helley-Smith 3-inch bedload samplers, and DH-48 or DH-81 suspended-sediment samplers. Bedload- and suspended-sediment samples are taken at multiple verticals across the creek to collect a representative sample (c.f., Emmett, 1980; Edwards and Glysson, 1999, and older references cited therein). For bedload-sediment sampling, we first establish the active-bed width by observation and/or preliminary sampling, then sample within that portion of the creek. For suspended-sediment sampling, we use two sampling methods depending on conditions; both methods are used by the USGS to collect suspended-sediment samples that are representative of the mean sediment concentration of a stream. The two methods are the equal-discharge-increment method (EDI) and the equal-width-increment method (EWI) (Edwards and Glysson, 1999). With both methods we collect depth-integrated samples at multiple verticals across the creek.

Suspended-sediment samples are analyzed by Soil Control Lab in Watsonville, California, a state-certified laboratory. Bedload samples are dried and weighed at Balance's office.

4 RESULTS AND DISCUSSION

Results from measurements and monitoring near the beginning of implementation of the WPP (2004 through 2008) are compared here to results from the same methods repeated again near the conclusion of the WPP (2018 and 2019).

4.1 V* Results

V* results are presented below, and show substantial year-to-year variability. We suspect that much of the year-to-year variability is due to differences in winter storm magnitude and patterns. Some of the variability may be due to sediment availability within upstream creek reaches and watersheds. Other variability may be due to variation in how much force individual observers applied to the sediment probing rod (with more force leading to higher V* values).

Pool-by-pool V* results from WY2019 are shown in Figure 4-1.

Average V* results for a group of pools can be presented as “weighted” or “unweighted” values. Weighted V* uses the total amount of sediment and total pool volumes for all the pools in the group, thus large pools are weighted more heavily than small pools. The multi-year pattern of average and weighted V* values is shown in Figure 4-2.

It should be noted that variations in application of the V* technique, and some localized changes to conditions upstream of some pools in the La Honda Creek Preserve also impact the results. The variations to the V* technique (amount of force applied to the sediment probe) tended to affect the results for larger pools more than for smaller pools.

An alternate way to evaluate V* results is to use the median value instead of the average or weighted values. Using the median is less prone to skewing by a small number of pools with high V* values, but does not take weighting of large pools into account. Median V* values are shown with average values in Figure 4-3.

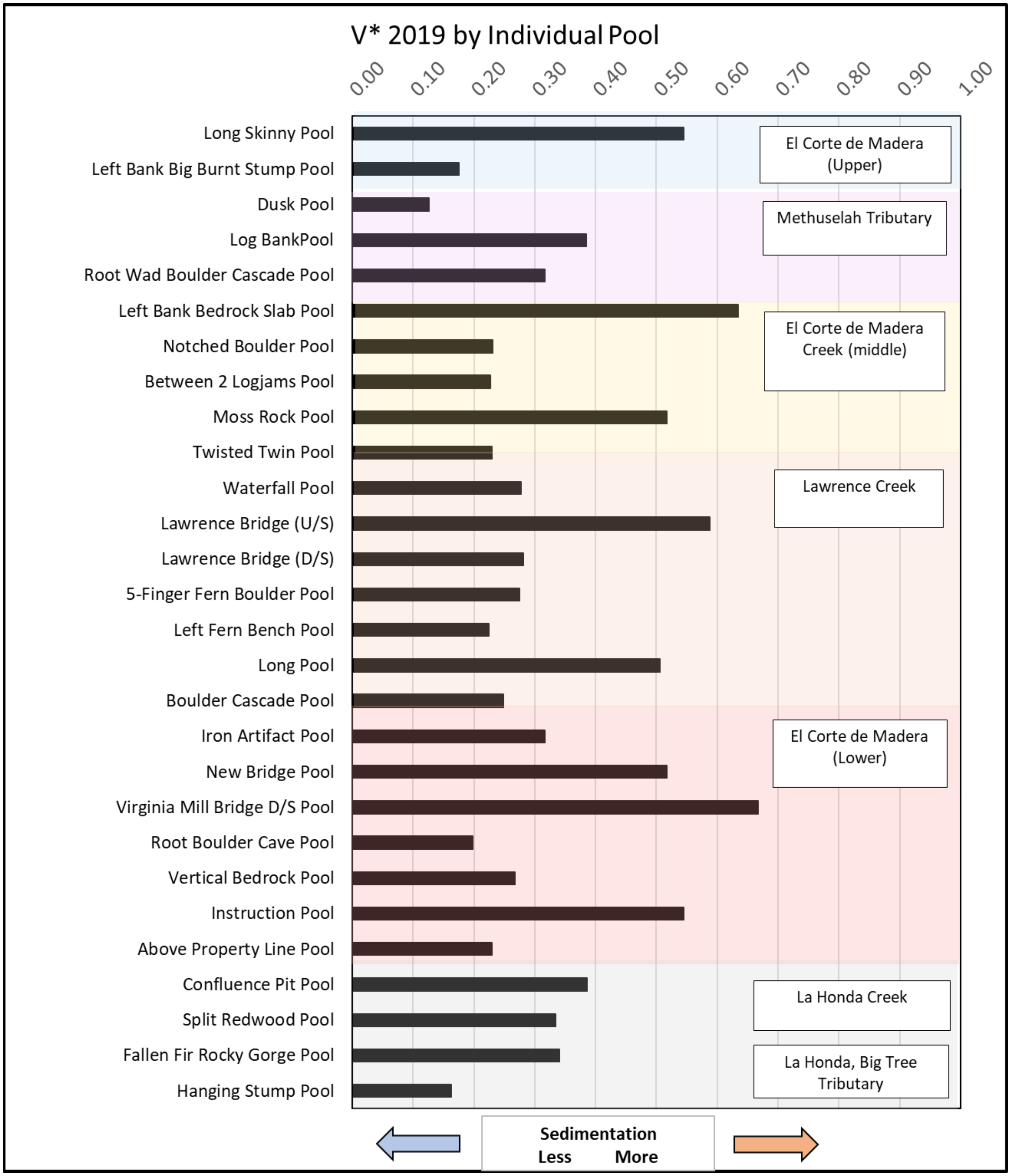

Figure 4-1 Plot of V* values by individual pool from 2019, grouped by creek reach. There is substantial pool-to-pool variability, thus year-to-year comparisons are more important than a numeric value for an individual pool or a creek reach. V* field work, data entry, data validation, and calculations largely performed by MROSD staff, rangers, and interns.

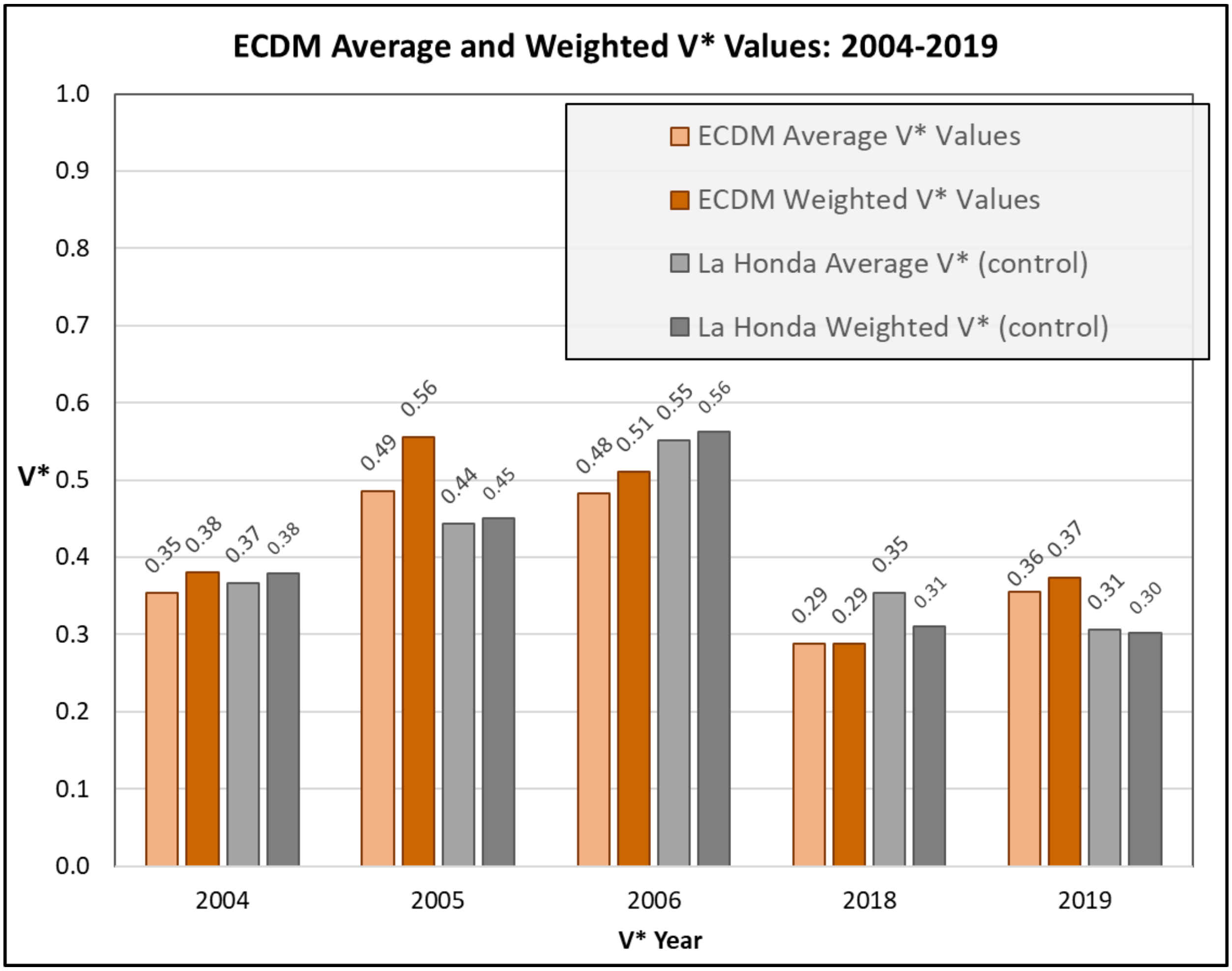

Figure 4-2 Average and weighted multi-year V* results from El Corte de Madera Creek Open Space Preserve. V* results (pool sedimentation) from 2018 and 2019 are similar to- or slightly below values from 2004, and well below results from 2005 and 2006. Results from the "control site" (although a smaller number of pools) largely mirror the year-to-year patterns, suggesting that year-to-year hydrologic patterns may play some role in variability. Weighted V* values put more weight on larger pools. V* field work, data entry, data validation, and calculations largely performed by MROSD staff, rangers, and interns.

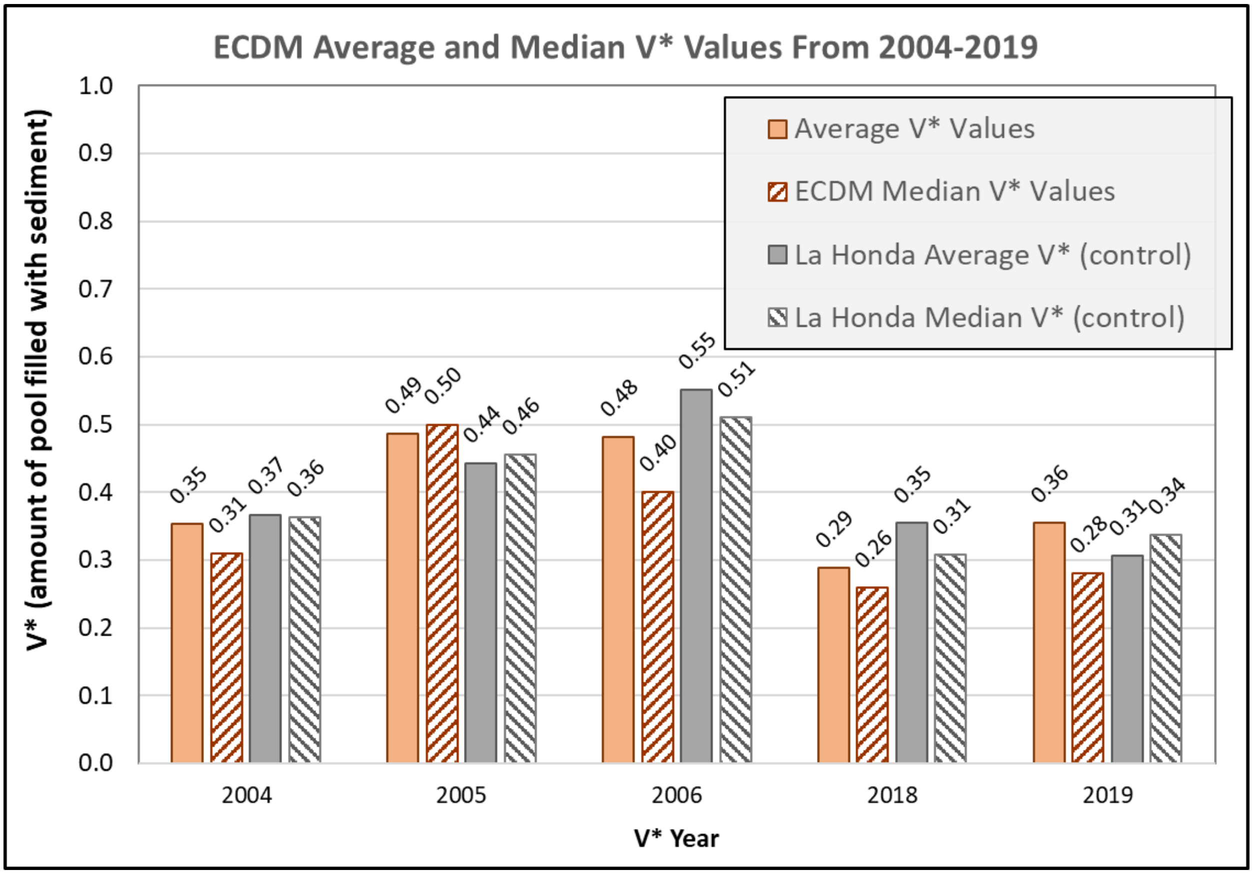

Figure 4-3 Average and median multi-year V* results: El Corte de Madera Creek Open Space Preserve. Median V* values from 2018 and 2019 are similar to or slightly lower than from 2004, and well below 2005 and 2006. Median V* values tend to be lower than average values in ECDM because a small number of pools often have high V* values. Results from the "control site" largely mirror the year-to-year patterns, suggesting that year-to-year hydrologic patterns may play some role in V* variability. V* field work, data entry, data validation, and calculations largely performed by MROSD staff, rangers, and interns.

Median V* values represent conditions in the *average pool*; average V* values represent *average conditions* across many pools; weighted V* values represent the total volume of sediment compared to the total pool volume for all the measured pools.

The V* pool locations are shown in Figure 4-4, along with plots of the 5-years of results. In general, we selected more pools for measurements toward the downstream portion of the creek system.

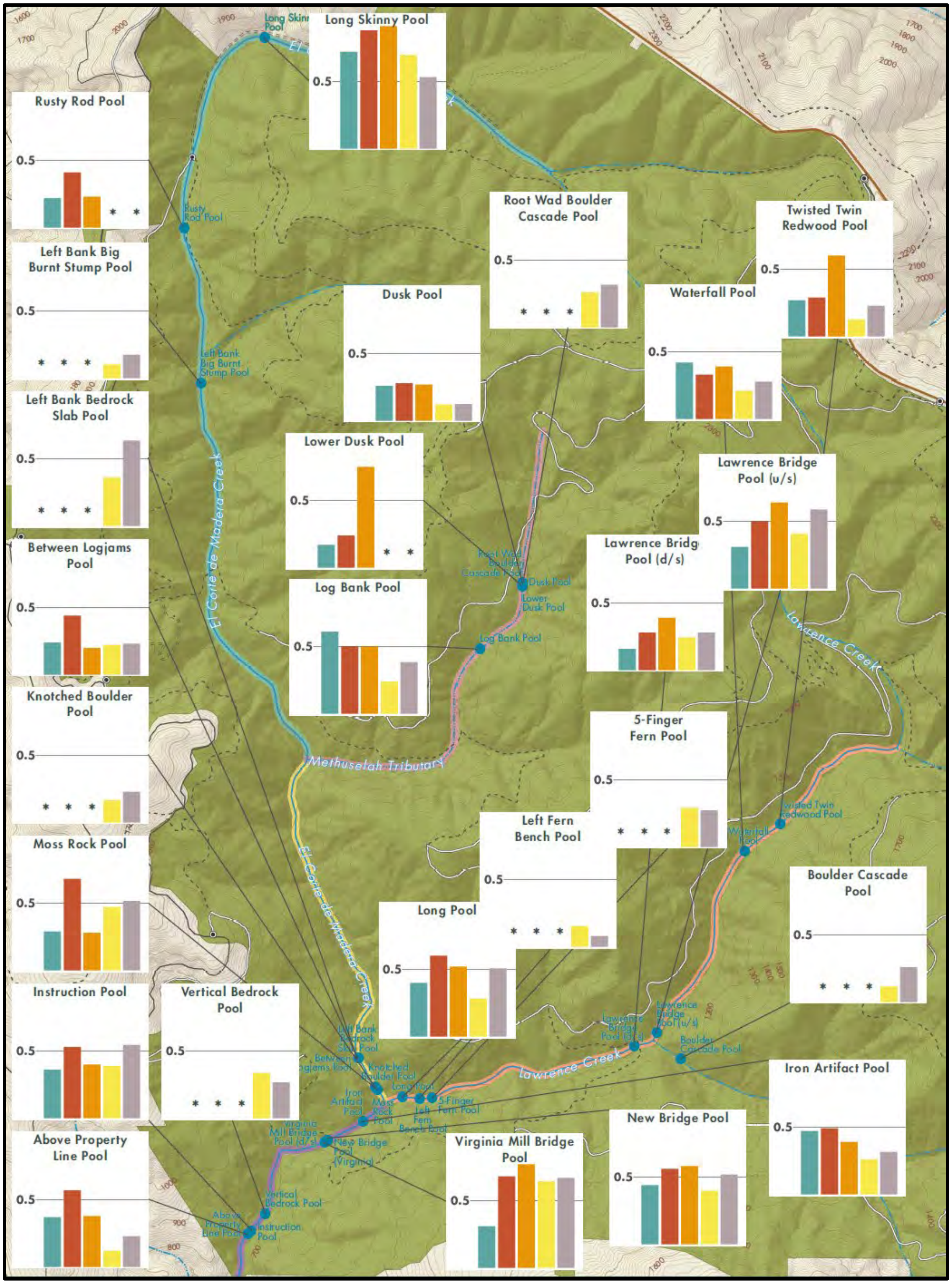

Figure 4-4 Locations of V* pools 2019 and 5 years of measurement results: El Corte de Madera Creek Preserve. Prepared by MROSD.

Definitive conclusions about the causation of changes in V* values are difficult to make because of the many environmental factors that can influence pool sedimentation. On a year-to-year basis the V* results make it relatively clear that pool sedimentation in 2018 and 2019 is similar to- or slightly lower than- 2004, and substantially lower than 2005 and 2006.

When we average the first sets of measurements (2004 through 2006) together and compare them to the second sets of measurements (2018 and 2019), this shows a decrease in V* from 0.48 to 0.33 (decrease of 0.15) for ECDM weighted values, and a decrease from 0.46 to 0.31 (decrease of 0.16 [with extra decimal places]) for La Honda Creek Preserve weighted value (see Figure 4-5). Non-weighted and median values show similar levels of decrease over the WPP study period.

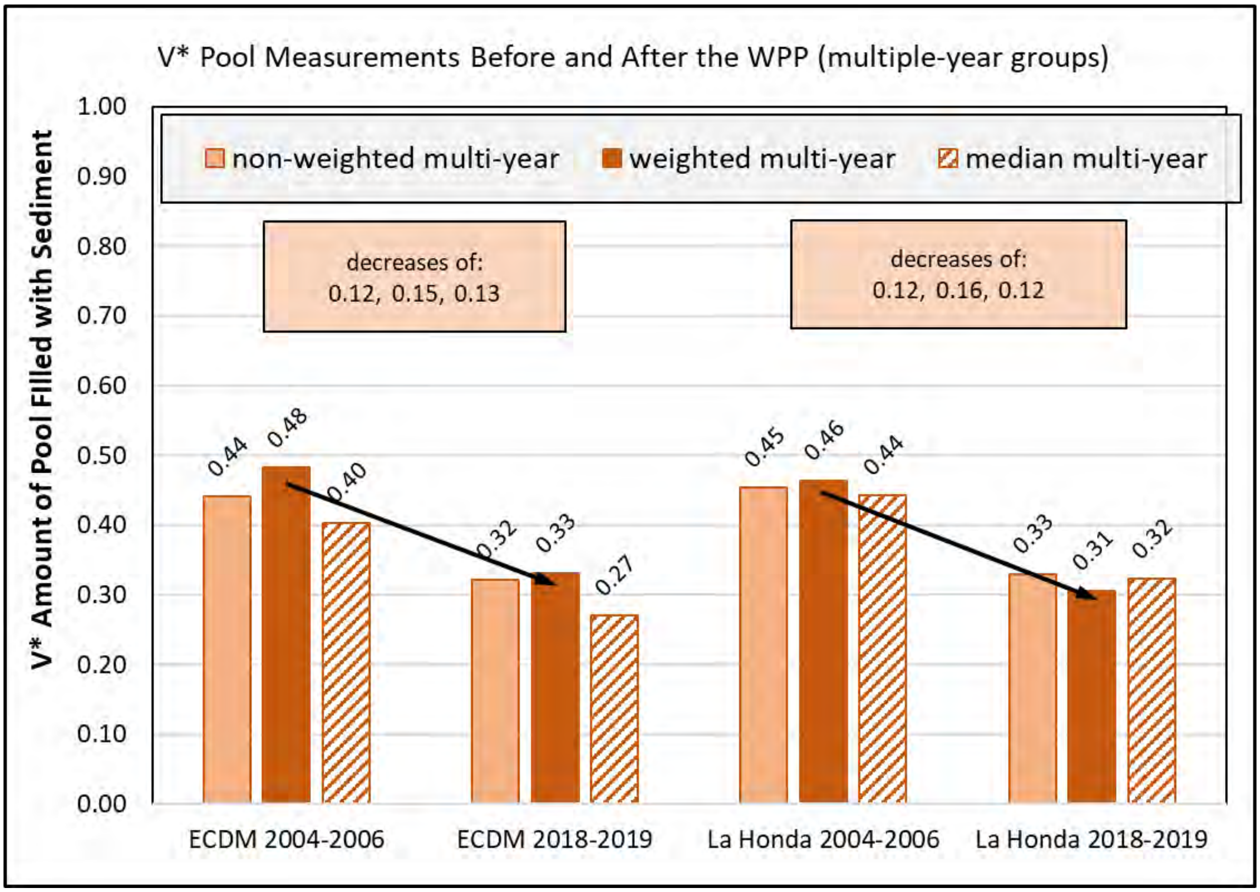

Figure 4-5 Changes in grouped V* values from the start to the end of the WPP study; El Corte de Madera Creek Preserve.

4.1.1 Sediment Texture Frequency

As a supplement to the V* depth measurements, we recorded the surface material at each depth location as a sediment size class, for example sand, gravel, cobble, or boulder. The change over time in pool-sediment texture was analyzed by the MROSD and is shown in Figure 4-6.

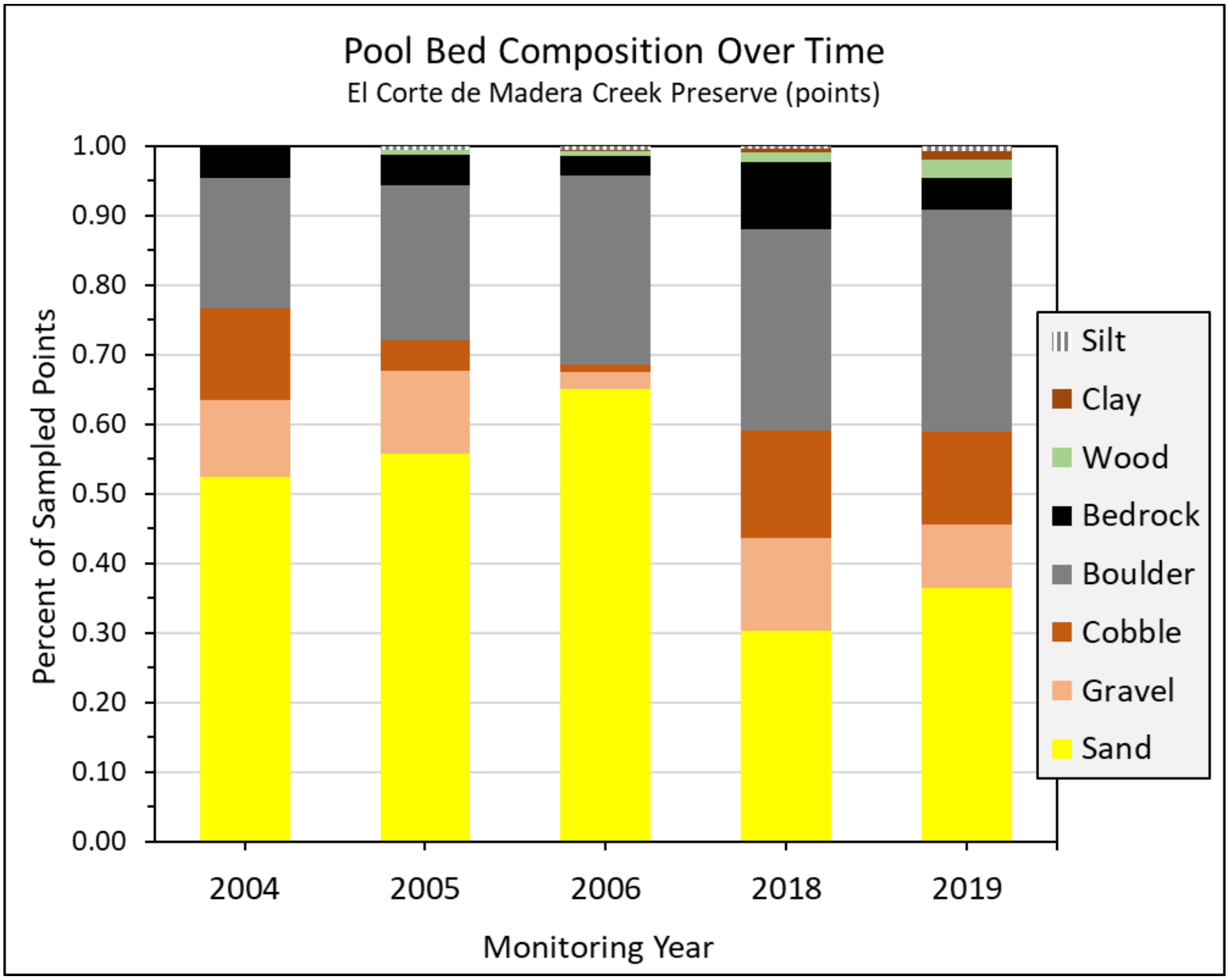

Figure 4-6 Change in pool bed material over time (by measurement point): El Corte de Madera Creek Preserve. This plot shows that the occurrence of sand in pool bottoms decreased from the 2004-2006 monitoring period to the 2018-2019 monitoring period, and that cobbles and boulders increased. These results largely mirror the V* results. This plot also shows that the two main sediment sizes in pools are boulders and sand.

When we average the first sets of measurements (2004 through 2006) together and compare them to the second sets of measurements (2018 and 2019), this shows a change in pool-bed texture for ECDM during the course of this study (see Figure 4-7).

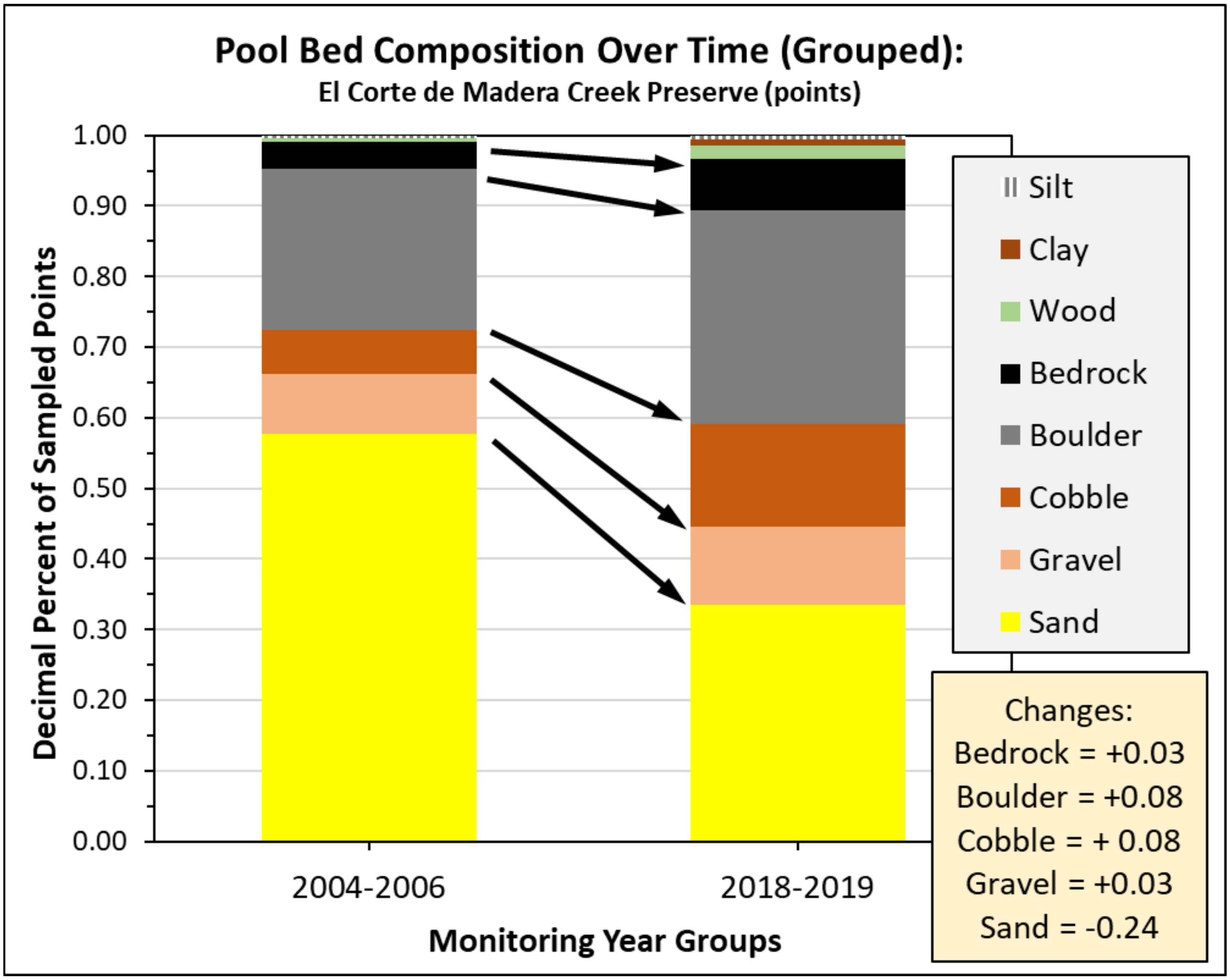

Figure 4-7 Change in grouped pool-bed composition from the start to the end of the WPP study; El Corte de Madera Creek Preserve. Percent of sand in pools decreased and other size classes increased, with percent of cobbles and boulders increasing the most.

4.2 Sediment Inventory Comparison

4.2.1 Sediment Inventory Mapping 2018

Performing the field work, it was immediately apparent that far fewer large fresh sediment sources were active in 2018 than had been inventoried in 2004 (which included landslides dating back to 1998). Landslides, bank failures, and sediment storage that we mapped in 2018 were quite fresh looking (and feeling) and we assumed they had largely occurred during the wet winter and large storms of water year 2017. The largest slide occurrence was also confirmed to have occurred between November 2016 and May 2017, based on sequential aerial imagery. Mapped sediment sources and storage from 2018 are shown in Figure 4-8. Sediment sources inventoried in 2004 and 2018 are shown together in Figure 4-9.

When we conducted the sediment inventory during the summer/fall of 2004, many landslides that occurred during 1998 or remained active since 1998 were readily apparent, based on bare soil and/or revegetation that was only a few years old. These totals have been revised or recalculated slightly from their original version, based on parsing of the fine and coarse fractions, and the amount remaining in the toe of the slide (see Table 4-1).

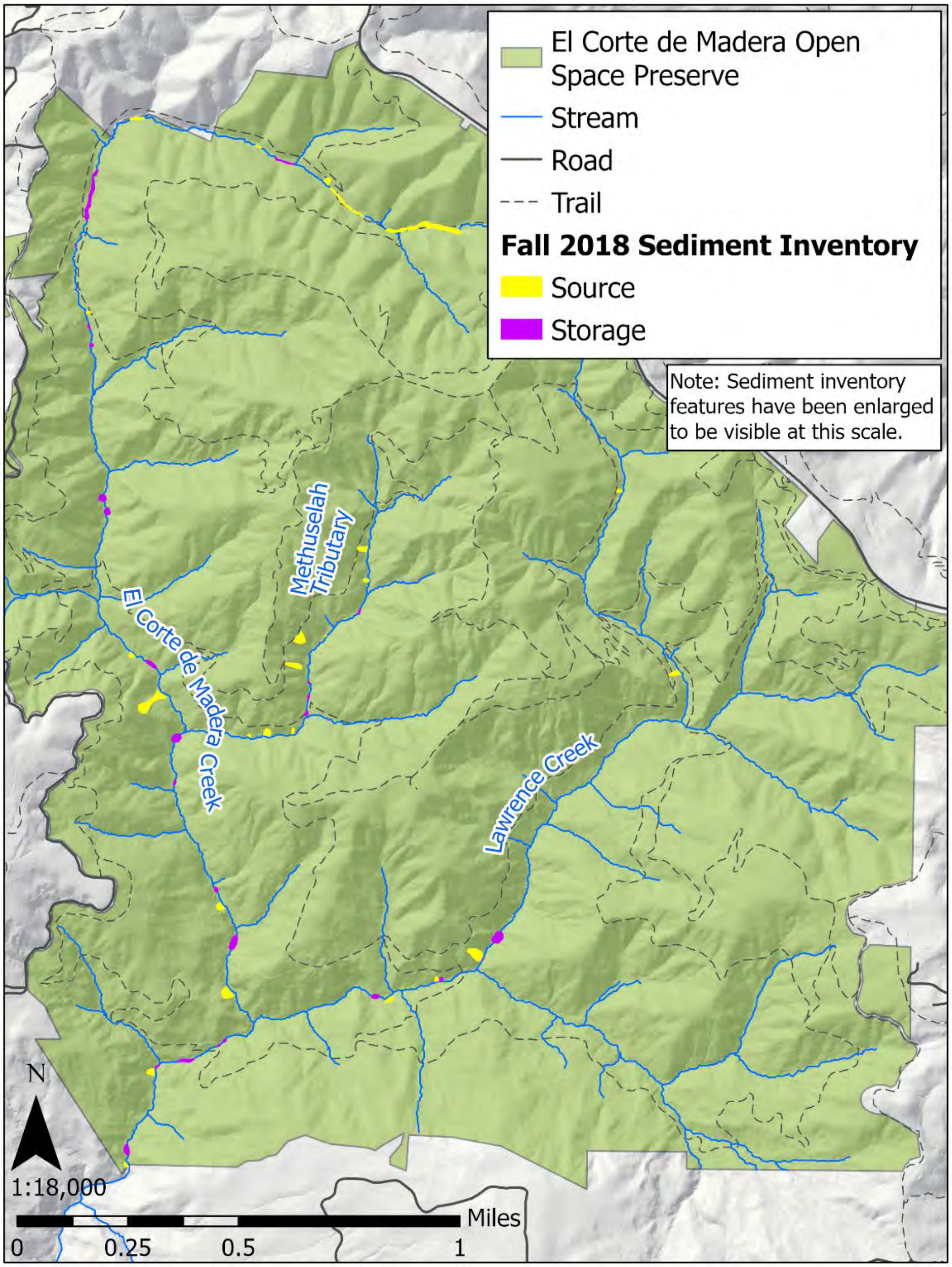

Figure 4-8 Map of large sediment sources and storage from 2018: El Corte de Madera Creek Preserve. Sediment sources are shown as yellow polygons, and storage areas are shown as purple. The sizes of polygons are exaggerated for graphical purposes, in order to be visible at this scale of map.

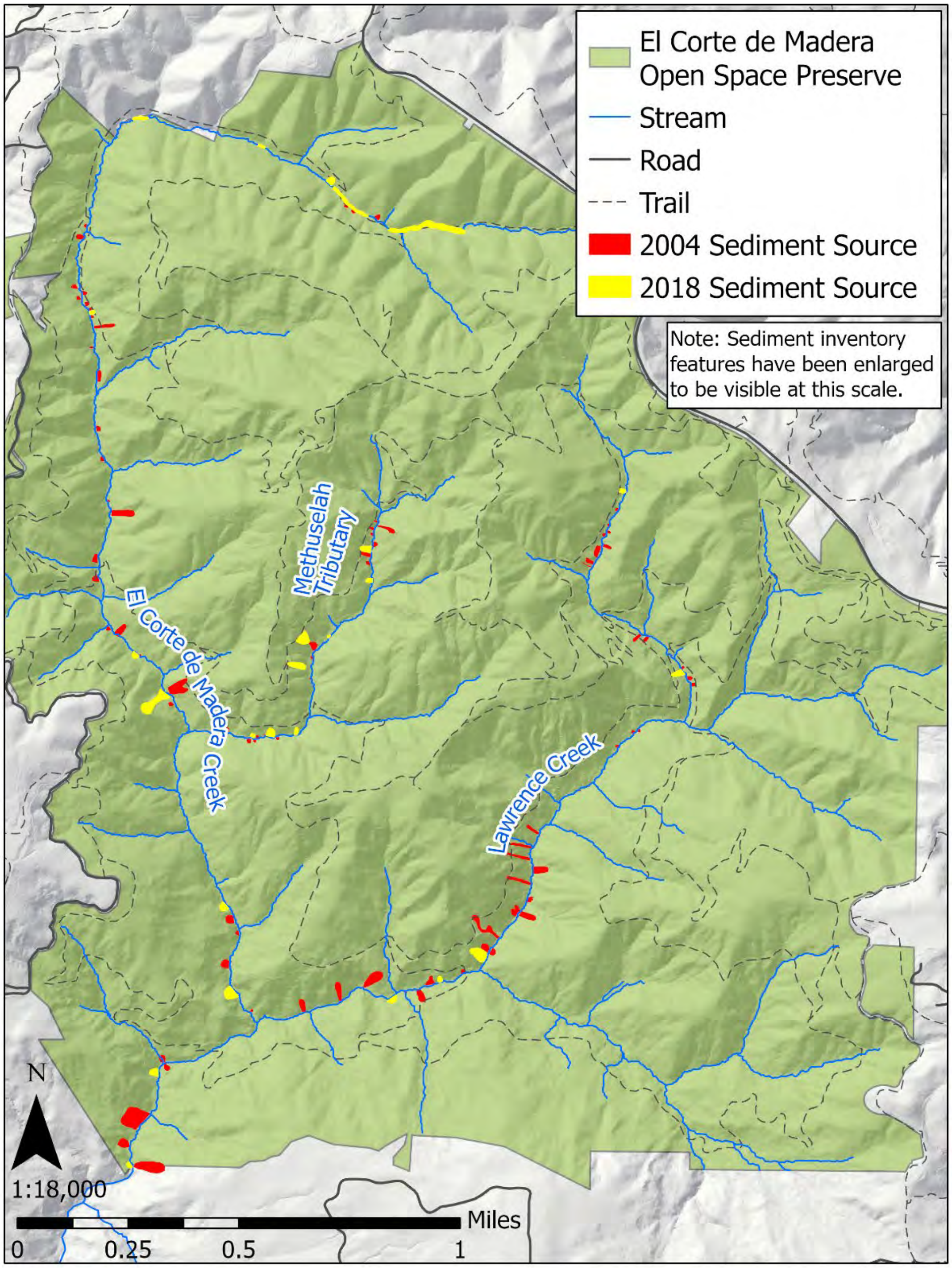

Figure 4-9 Map of large sediment sources inventoried in 2004 and again in 2018. Sediment sources from 2004 are shown as red polygons, and those from 2018 are shown as yellow. The sizes of polygons are exaggerated for graphical purposes in order to be visible at this scale of map.

4.2.2 Sediment Inventory Volumetric Calculations 2018

The volumetric totals from the 2018 inventory are presented in Table 4-1, for both coarse and fine sediment.

For comparisons to V* values and the bedload-sediment totals, we are most interested in "coarse" sediment (such as sand that settles in pools or gravel trapped behind wood jams). The values in Table 4-1, and discussed below, are only the percent of the sediment sources that was assessed to be sand-sized or larger material (also referred to as "coarse", in this context).

For comparisons to roads and trails, and the suspended-sediment totals, we are most interested in the "fine" fraction of sediment (silt and clay in this context).

Because we did not walk all of the creek channels, we scaled up the inventoried volumes by 23%, based on the remaining percent of large channels unassessed.

This inventory revealed that there were a modest number and magnitude of new sediment sources generated during the wet winter of WY2017 (3,200 cubic yards of total material with 1,700 cubic yards of coarse material). However, we found [5] that approximately half of that sediment was still remaining at the toe of the slides/slumps (810 cubic yards), leaving 850 cubic yards of coarse material having washed downstream. A similar amount of fresh coarse sediment was found to have been recently deposited behind wood jams (1,070 cubic yards).

For comparison, a standard dump truck holds about 10 yards of material.

This means that based on the sediment sources that we found, an equivalent volume of sediment was temporarily trapped and stored by instream wood jams. This rough balance between sediment sources and sediment storage highlights the importance of wood jams for a creek system; if the wood jams were not there, much more sediment would likely have filled pools or washed downstream. While it is tempting to conclude that this means wood jams more than offset natural sediment sources during this period, there is a considerable range of uncertainty in the inventory estimates. Also, non-

[5] We compared the estimated "missing" volume of the landslide scarp to the volume material at the base of the landslide. If those volumes matched, then all the material was still in the toe; in most cases the landslide volume was larger than the material remaining in the toe, because much of the material had landed in the creek and been washed away.

inventoried sediment sources in other tributaries, and upland sediment would have also contributed additional coarse sediment, as well as sediment in the creek channel itself.

This sediment temporarily stored behind wood jams may be mobilized in the future during a wet winter with large storms, or when wood is dislodged- or decays- from the wood jams.

Additionally, 650 yards of fine material washed downstream (fine material is not typically subject to being trapped by wood jams in a narrow canyon system, although slow backwaters or small floodplain section could trap some fine sediment).

4.2.3 Sediment Inventory Comparison Between 2004 and 2018

In Table 4-1, we also compare the two sediment inventories, both as percent of the total inventoried, and on a per-year basis. Direct comparison between totals of the sediment inventory can be useful but can also be misleading. Please keep in mind that the 2004 inventory included sources back to water year 1998 (a 7-year period), while the 2018 inventory only went back to 2017[6] (a 2-year period).

The total amount of inventoried sediment sources was 2.3 times higher on a per-year basis in 2004 than 2018.

The amount of *coarse* sediment washed downstream was 1.7 times higher on a per-year basis in 2004 than 2018. This coarse sediment is similar to bedload sediment in ECDM but is not completely comparable, because some sand travels as suspended sediment at high flow and as bedload at medium and low flow.

[6] This method of sediment inventory relies upon being able to visually assign a year to when a sediment source was most recently activated, thus years with large or numerous landslides and/or bank failures are natural time-stamp markers (e.g. 1998 and 2017). While water year 2006 also generated some landslides and debris flows, the time that had passed, and the revegetation that had occurred would have made accurate identification in 2018 of those 2006 scarps difficult and would have had a low degree of accuracy.

Table 4-1 Summary of sediment inventories conducted during 2004 and 2018: El Corte de Madera Creek Open Space Preserve. This inventory revealed that there were a modest number and magnitude of new sediment sources generated during the wet winter of WY2017. For 2017-2018, we found that the volume of coarse sediment washed into the creeks was slightly less than the volume of fresh coarse sediment was found to have been recently deposited behind wood jams.

Category	Calculations from Sediment Inventory	2004 Inventory (1998-2004)	2018 Inventory (2017-2018)		2018 volume as percent of 2004	2018 volume as percent of 2004 (per year)	factor by which 2004 volume > 2018 (per year)
1	***Coarse and fine*** material produced by sources (including toe of slide/slump)	**26,000**	**3,200**	*(cu. yards)*	12%	43%	**2.3**
2	***Coarse*** material produced by sources (including toe of slide/slump)	**7,900**	**1,700**	*(cu. yards)*	22%	75%	**1.3**
3	***Coarse*** material stored in toe (temporary)	**2,900**	**810**	*(cu. yards)*	28%	98%	**1.0**
4	***Coarse*** material washed into creek system (toe subtracted)	**5,000**	**850**	*(cu. yards)*	17%	60%	**1.7**
5	***Fine*** material washed into creek system (toe subtracted)	**11,400**	**650**	*(cu. yards)*	6%	20%	**5.0**
6	***Coarse*** material stored behind wood jams (temporary)	**3,900**	**1,070**	*(cu. yards)*	27%	na	na
7	Net volume of ***coarse*** material after storage is subtracted	**> + 1,100**	**-220**	*(cu. yards)*	na	na	**6.0**
8	Sum of ***coarse*** material stored in toe of slides and behind wood jams	**6,800**	**1,880**	*(cu. yards)*	28%	97%	**1.0**

Notes:
Volumes have been scaled up, based on this inventory having been conducted along 77% of the main creek channels.
The 2004 volumes have been revised slightly compared to the volumes presented in 2005.
Due to the approximate nature of the measurements and estimates, the calculations should only be evaluated to 2 significant figures; additional precision is neither intended nor implied.
Negative values indicate net storage of sediment.
For the purpose of these calculations, "coarse" includes sand and larger particles.
For the purpose of these calculations, "fine" includes silt and smaller particles.
"per year" calculations assign a 7-year period to 1998-2004 and a 2-year period to 2017-2018.

The amount of *fine* sediment washed downstream was 5.0 times higher on a per-year basis in 2004 than 2018. This fine sediment is similar to suspended sediment in ECDM but is not completely comparable, because some sand travels as suspended sediment at high flow and as bedload at medium and low flow.

Please note that in 2004 we were not able to differentiate bedload sediment deposited in 1998 from older sediment (because the 1998 bedload sediment was already consolidated so a similar level as older sediment), so the 1,100 yards of excess coarse sediment is likely a minimum value; we assume that some of that wood jam storage may have already been filled prior to 1998.

4.3 Creek and Sediment Gaging

4.3.1 Sediment Rating Curves

The principal purpose of the sediment sampling for this project is to develop an annual empirical relationship of the amount of sediment transported at a given flow, near the bottom of the watershed within ECDM. These “sediment-rating curves” are the basis for calculating the volume of sediment transported by the creek past the gaging station for each 15-minute period and hence for each day, and each year.

The rating curves are also diagnostic of the processes of sediment movement through the stream system. As the position of the curve changes, a different relationship between streamflow and sediment transport is expressed, indicating limitations or increases in sediment supply. Sediment transport at a given flow may change over short periods, such as during rising and receding hydrograph limbs, and will also generally change whenever watershed or channel conditions upstream make sediment more or less available for mobilization.

More sediment is transported at higher flow, and the sediment rating curve describes the rate at which sediment transport increases while flow increases. A sediment rating curve is constructed by plotting sediment transport rates (based on the weight of samples collected) plotted as a function of flow (at which the sample was collected). Sediment rating curves naturally differ between watersheds, even when accounting for the size of the watershed or rainfall differences, due to slope, geology, and other processes.

The sediment rating curves are used with the creek flow record to calculate the amount of sediment transported, which can be looked at during a storm (Figure 4-10 and Figure 4-11), a series of storms, or a water year.

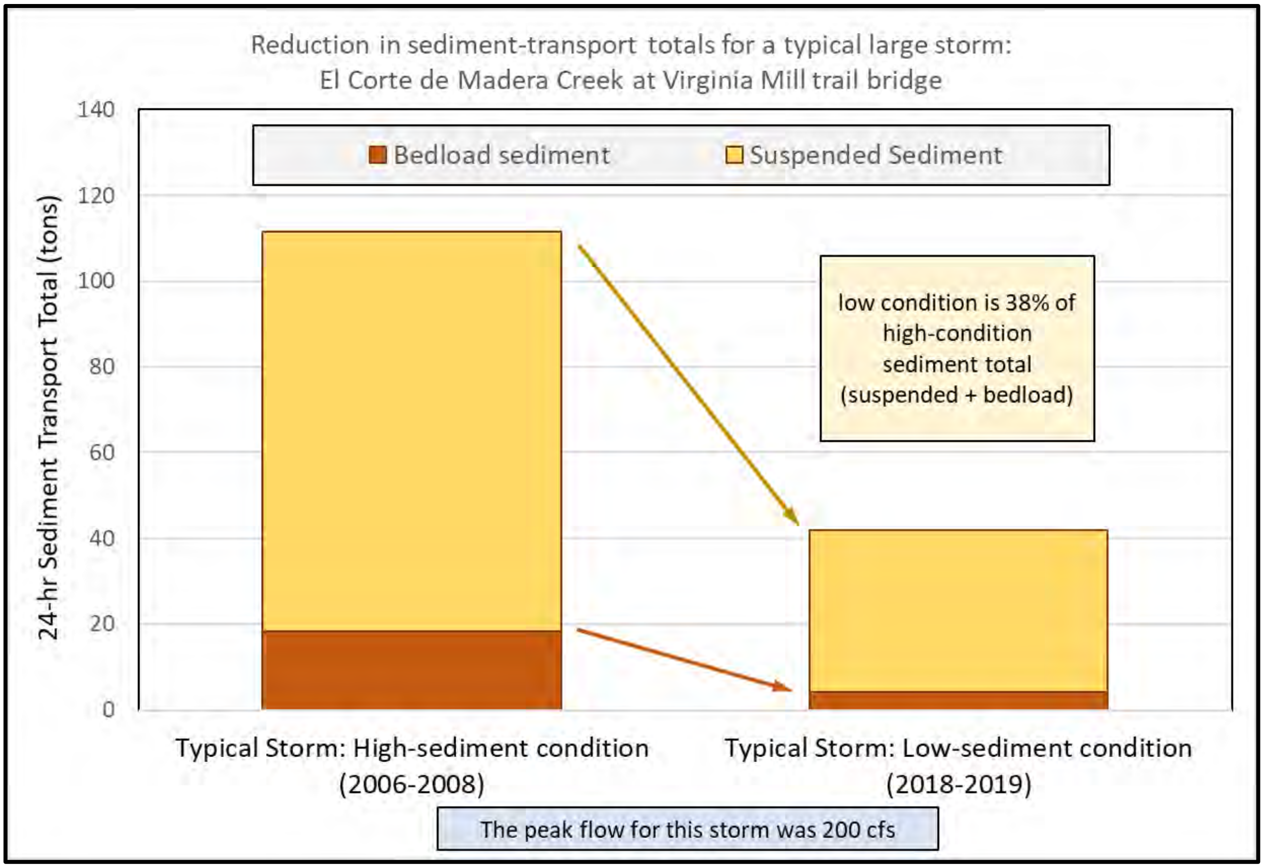

Figure 4-10 Reduction in the amount of sediment transported during a typical large storm. For this storm hydrograph, the amount of sediment transported now would be 38% of the sediment transported during the first sampling period. The 24-hour flow record used for this calculation occurred December 26, 2005. A storm peak of 200 cfs equates to a 1.6-year storm.

The hydrograph for an example typical storm is shown in Figure 4-11 with sediment transport rates through the storm for “high” and “low” sediment conditions. “High” refers to larger amounts of sediment being transported during 2006-2008 than during 2018-2019 (the “low” condition), at the same flow rate.

So, when we calculate high and low sediment transport for the same storm, more sediment transported when the creek is in a *high* sediment condition than when the creek is in a *low* sediment condition. For this report, the high condition represents volumes present in the 2006-08 period and the low condition represents volumes present in the 2018-19 period. Between the data gathering periods, volumes likely changed response to the WPP and the water years, but are assumed have to generally ramped down from the high to low period. The data derived from the high and low condition calculations contextualizes all other measured volumes in the project, like V* pool volume, landslides, and storage."

As was seen from the sediment inventory, more sediment was produced and available in the creek in the 1998-2004 time period, than was produced during the 2017-2018 period. Likewise, the 2006-2008 sediment rating curves are higher than the 2018-2019 rating curves (low). The high and low sediment rating curves are shown in Figure 4-12 and Figure 4-13).

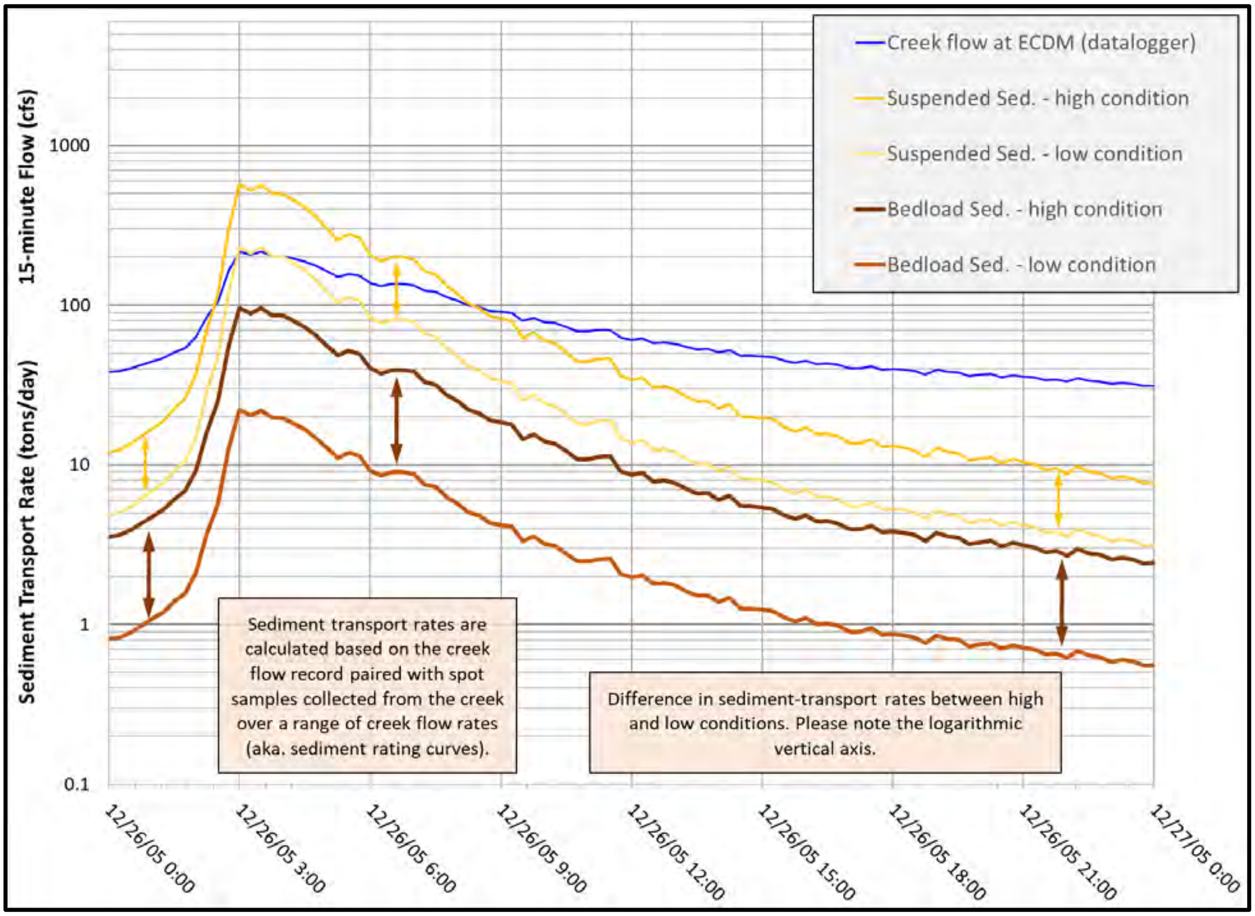

Figure 4-11 Sediment-transport rates during an example storm. In this example storm, the difference in sediment-transport rates between *high*- and *low*-sediment conditions are indicated by the arrows, for both bedload- and suspended-sediment rates.

Comparison between sediment-transport data collected 2006 through 2008 is plotted with suspended-sediment transport data from 2018 and 2019 in Figure 4-12, and with bedload-sediment data in Figure 4-13.

Suspended-sediment transport rates appear to have decreased by a factor of approximately 2.4 (ratio of the coefficients 0.0037/0.0015).

Bedload-sediment transport rates appear to have decreased by a factor of approximately 4.3 (ratio of the coefficients 0.0035/0.0008). There is more scatter in the bedload-sediment data than in the suspended-sediment data, suggesting that bedload-sediment transport is more irregular, and is also more difficult to sample repeatably in a boulder-bed creek.

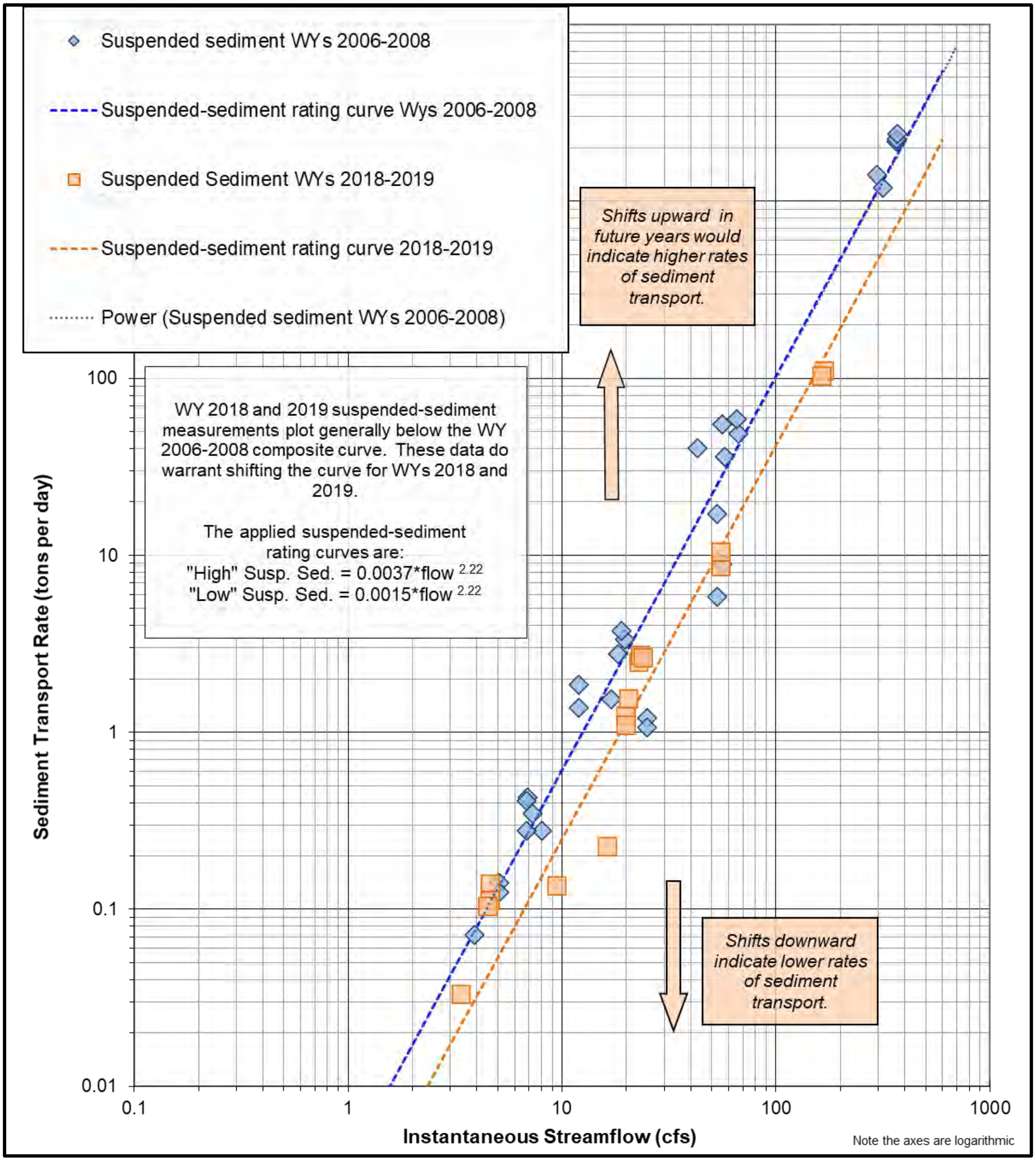

Figure 4-12 Suspended-sediment transport measurements and rating curve: El Corte de Madera Creek at Virginia Mill Trail. Blue symbols are samples collected during water year 2006 through 2008; orange symbols are sample collected during water years 2018 and 2019. Suspended-sediment sampling indicates that there has been a noticeable decrease in the amount of suspended sediment entrained over the range of flow.

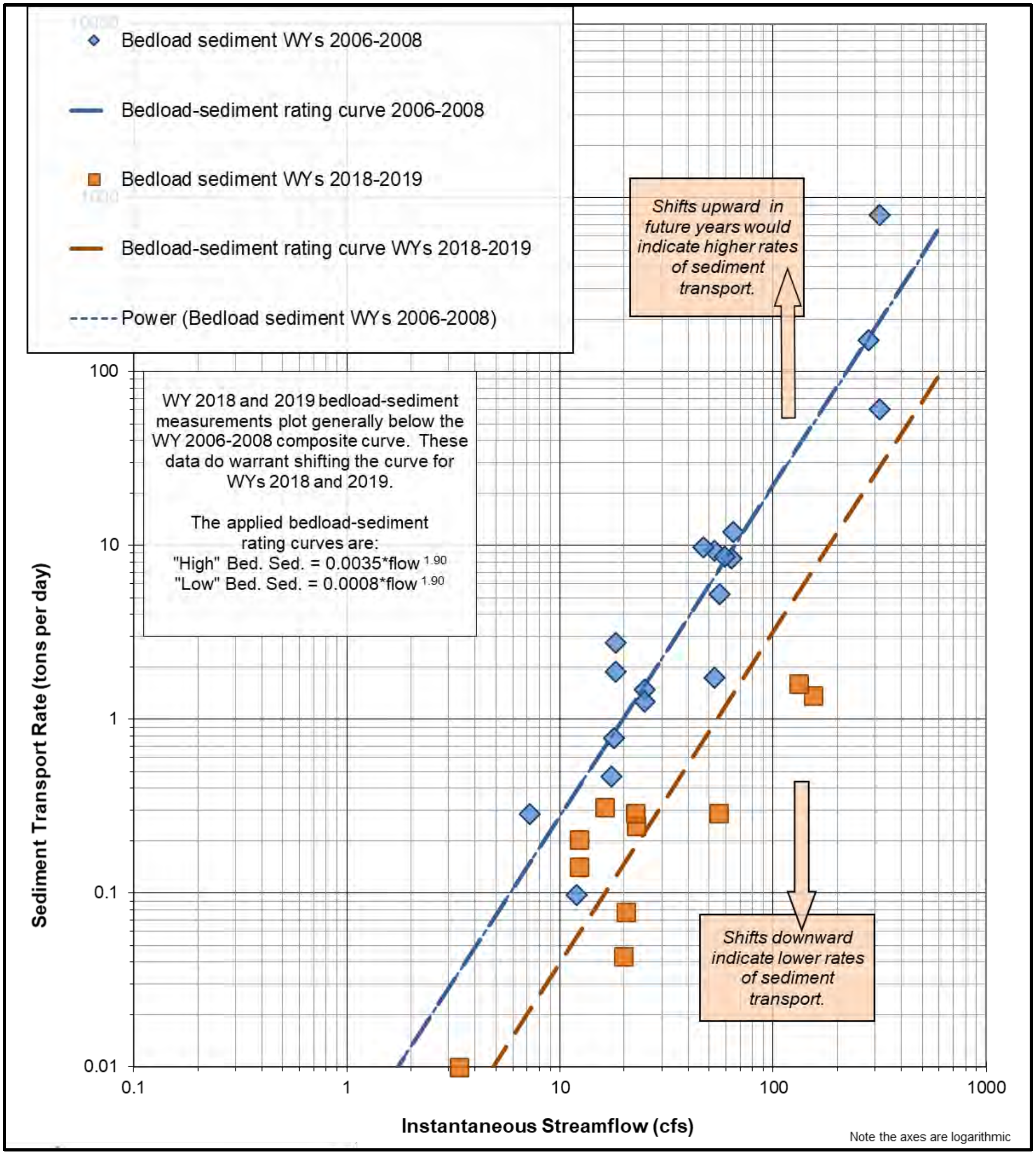

Figure 4-13 Bedload-sediment transport measurements and rating curve: El Corte de Madera Creek at Virginia Mill Trail. Blue symbols are samples collected during water year 2006 through 2008; orange symbols are sample collected during water years 2018 and 2019. Bedload-sediment sampling indicates that there has been a noticeable decrease in the amount of suspended sediment entrained over the range of flow.

We interpret the high sediment rating-curve conditions in 2006-2008 as being related to recovery following the large influx of sediment from water year 1998 (as described in the sediment inventory). When larger amounts of sediment are available, more sediment will be transported at a given flow rate than when less sediment is readily available.

4.3.2 Turbidity Probe Data

For water years 2018 through 2020, one of sensors attached to the datalogger was an optical backscatter “OBS 3+” turbidity probe. The submerged probe sends a light beam out into the creek water and then records how much light returns to the sensor, via bouncing off sediment particles in the creek water. Clear water causes very little light to return to the sensor, while water with more particles scatters more light back to the sensor. The probe takes a reading every three minutes and the average value over 15 minutes is stored in the datalogger. A 2-month period of turbidity and flow is shown in Figure 4-14.

Balance staff collected water samples over the course of water years 2018 and 2019, which were analyzed for turbidity and suspended sediment concentration. During data processing, we then adjust the turbidity sensor data to be consistent with the laboratory values of turbidity. Turbidity probes can drift into less accurate readings over time as algae, abrasion, or other processes affect the sensor; adjustments to the data and factory recalibration is necessary over a long-term project.

We also find it useful to plot the same turbidity and flow data with turbidity as a function of flow, as shown in Figure 4-15. This Figure shows how the relationship between flow and turbidity changes storm to storm and within a storm (note that the first storm of the period has higher turbidity than later storms). It also shows where the bulk of the data points fall, which indicates the dominant pattern.

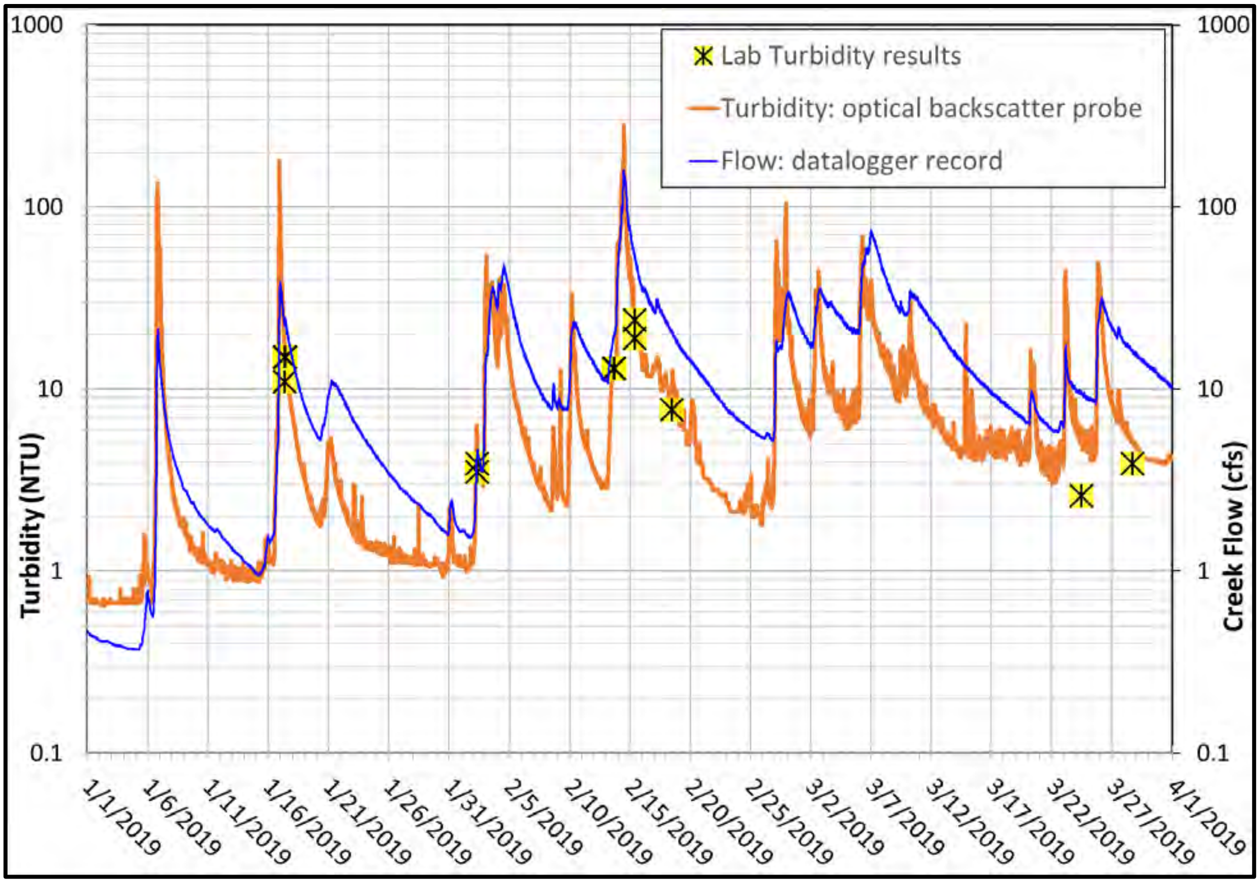

Figure 4-14 Turbidity record and hydrograph from water year 2019: El Corte de Madera Creek. Turbidity is low before storms, then rises quickly as creek flow rises, with the highest levels at the peaks of storm flow, and then declines following storms. Laboratory results of collected samples were used to adjust the sensor data. Values of 1 and 2 NTU look visibly clear.

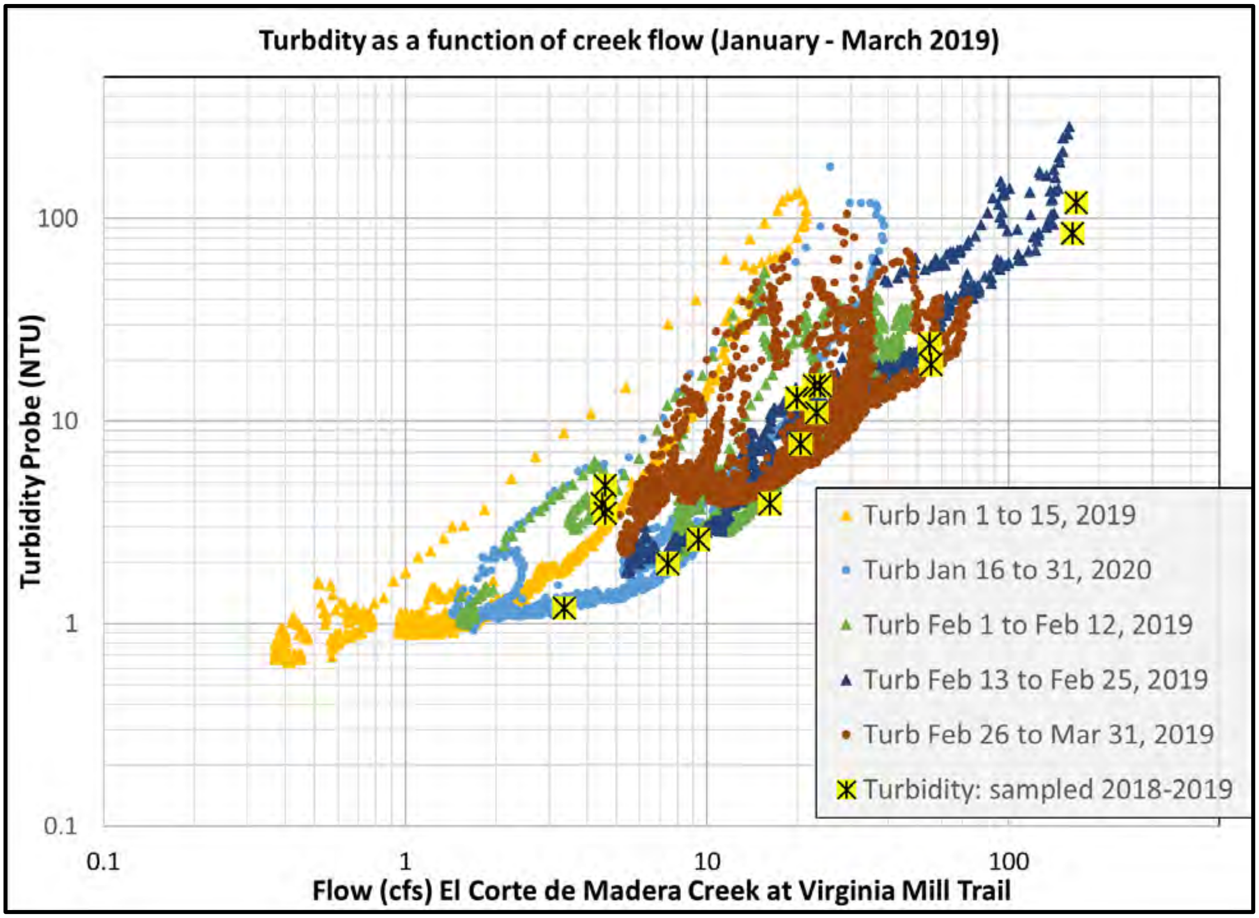

Figure 4-15 Turbidity as a function of creek flow (January - March 2019): El Corte de Madera Creek Preserve. This format for plotting data shows that the rate at which turbidity rises and falls compared to creek flow can be slightly different from one storm to the next. This is typical for all creeks for which we have collected data; in addition, the pattern of rising turbidity at the beginning of a storm is usually different that the pattern for decreasing turbidity after a storm. Data that plots higher has more turbidity for the same level of flow.

4.3.3 Annual Sediment Load Totals

Based on the creek gaging flow record and the sediment-transport samples collected at ECDM (sediment rating curves), we calculated annual sediment loads for the period for which we had data. We also correlated flow data from USGS gaging stations (mostly San Gregorio Creek with some Pescadero Creek data) to the ECDM location for periods of data when we were not operating the gaging station. We constructed 15-minute records of flow and sediment-transport from WY 1998 through WY 2019; with Balance’s data used for the directly gaged period (water years 2006-2009 and 2018-2019). The annual sediment-transport totals[7] for suspended and bedload sediment are shown in Table 4-2, along with the annual mean and maximum flow.

The summary period of annual loads at the bottom of Table 4-2 correspond to the two inventoried periods of landslide activity (WYs 1998–2004 and WYs 2017-2018). We calculated the annual loads for the first inventory period using the “high” version of the sediment rating curve and the “low” version of the second inventory period. As discussed with the sediment rating curve.

There is a large difference in the sediment load transported in wet years with large storms (such as 2006 and 2017) compared to dry years with small storms (such as 2007 and 2018), (see Figure 4-16). Large year-to-year variability of rainfall patterns, creek flow, and sediment transport is typical in coastal California. The high and low versions of the sediment rating curves are shown above.

[7] For converting between tons and cubic yards, one US ton of sediment (dry) is roughly equivalent to 0.719 cubic yards of landslide material; one cubic yard equates to 1.39 US tons.

Table 4-2 Annual sediment load totals for El Corte de Madera Creek at Virginia Mill Bridge, water years 2004 through 2019. There is a large difference in the sediment load transported in wet years with large storms and dry years with small storms.

Annual sediment load totals based on sediment rating curves

	Suspended Sediment		Bedload Sediment		Flow	
Water Year	**Susp. Sed. Low**	**Susp. Sed. High**	**Bedload Low**	**Bedload High**	**Mean Flow**	**Max. Flow**
	(tons)	*(tons)*	*(tons)*	*(tons)*	*(cfs)*	*(cfs)*
1998	2,055	5,069	207	904	13.1	697
1999	315	777	44	191	6.4	233
2000	658	1,624	78	341	6.9	351
2001	55	135	10	44	2.7	80
2002	171	423	25	108	4.3	240
2003	247	609	32	142	4.5	303
2004	318	785	39	171	4.3	276
2005	334	823	51	225	7.8	157
2006	1,520	3,750	150	657	10.6	548
2007	15	36	3	14	1.6	56
2008	62	152	10	43	2.1	155
2009	20	48	4	18	1.6	48
2010	307	757	38	168	5.0	403
2011	598	1,474	73	318	7.0	255
2012	202	498	27	117	3.4	224
2013	520	1,283	52	228	3.6	452
2014	1.3	3	0.4	2	0.4	19
2015	345	852	38	168	3.1	279
2016	415	1,024	55	241	5.9	244
2017	1,517	3,742	177	776	13.5	418
2018	64	158	8	37	1.5	186
2019	149	368	25	108	5.0	159
Total	**9,889**	**24,392**	**1,147**	**5,019**		
Average	**449**	**1,109**	**52**	**228**	**5.2**	**263**
Median	***311***	***767***	***38***	***168***	***4***	***242***

Summary Periods Corresponding to Sediment Source Inventory

	Susp. Sed. Low	**Susp. Sed. High**	**Bedload Low**	**Bedload High**
1998 - 2014		**9,423**		**1,900**
		(tons)		*(tons)*
2017 - 2018	**1,581**		**186**	
	(tons)		*(tons)*	

Notes: Flow records were correlated from USGS gage data to the ECDM location for years when the ECDM gage was not operated (with 15-minute data).
The "high" versions of the sediment rating curves are based on sediment-transport data from water years 2006 through 2008. The "low" versions are based on data from 2018 and 2019.

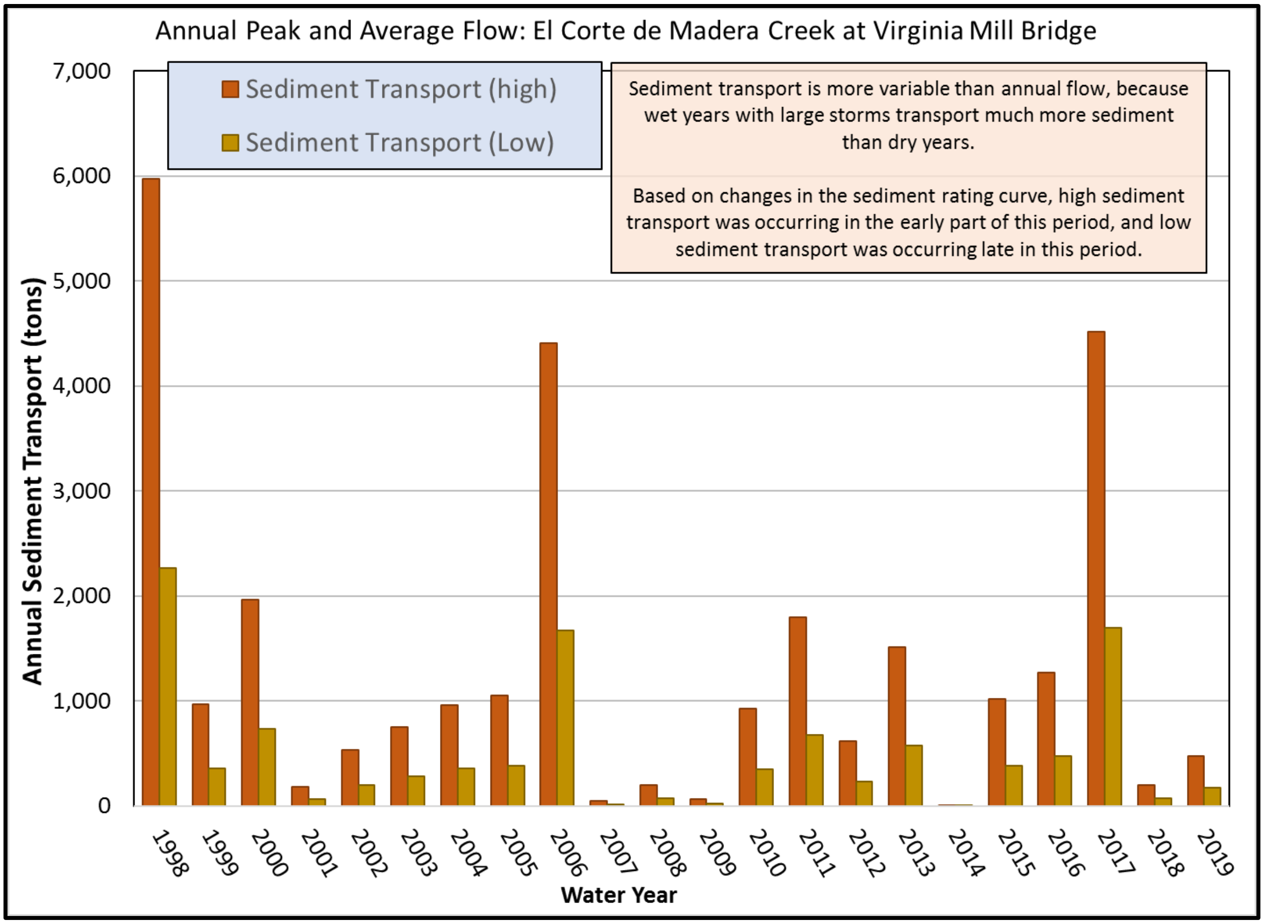

Figure 4-16 Calculated annual sediment transport: El Corte de Madera Creek at Virginia Mill bridge. Sediment transport is more variable than annual flow, because wet years with large storms transport much more sediment than dry years. Based on changes in the sediment rating curve, high sediment transport was occurring in the early part of this period, and low sediment transport was occurring late in this period.

In general, the annual sediment transport numbers are much larger than the volume of an individual pool, and seem to be at a similar order of magnitude compared to the sediment source volumes.

5 COMPARISONS AND CONCLUSIONS

In order to tie together the 3 prongs of the approach, we compare volumes, time periods, and processes.

5.1 Comparison of Pool Volumes to Sediment Source Volumes

The residual scoured volume (water plus sediment) of the largest pool (often the "Above Property Line" Pool) was measured at a maximum 1,320 cubic feet (49 cubic yards). The average residual scoured volume of all the ECDM pools over the 5 years of V* collection is 214 cubic feet (8 cubic yards).

The most relevant sediment source value seems to be the volume of coarse material that was washed downstream into the creek system. The 2017-2018 value is 850 cubic yards, which would be enough to fill 17 maximum-size pools or 106 average-size pools.

Thus, changes in pool sedimentation during wet years are not likely strictly a function of the total amount of sediment available, but are more likely related to more subtle differences that affect the balance of scour vs. fill in individual pools. But perhaps more importantly, an increase in sediment trapped behind a wood jam decreases the amount of sediment transported downstream. Although we avoided wood jams in selecting V* pool locations, many pools in the lower reaches are (unavoidably) in between large wood jams.

5.2 Comparison of Pool Volumes to Sediment Transport Annual Totals

During wet years, based on annual sediment totals, there is enough bedload sediment being transported (34 tons [24 cubic yards] of bedload sediment in WY 2017) to fill most pools multiple times; this would be even more pronounced with the higher version of the sediment rating curve. Thus, changes in pool sedimentation during wet years are not likely strictly a function of the total amount of sediment available in transport, but are more likely related to more subtle differences that affect the balance of scour vs. fill in individual pools. We speculate that the final storms of a year may play an important role in the V* values captured in the following summer.

In a dry year, such as 2018, the total amount of sediment would still not likely be a limiting factor in how much V* values might change. Water year 2018 transported only 8 tons [6 cubic yards] of bedload sediment past the gage site, but that is enough to fully fill an average size pool, and enough to substantially change a larger pool if that much sediment was either scoured out of- or deposited into any pool.

If we also consider bedload-sediment as quasi steady state (like a conveyor belt), then sediment deposited in one pool (falling off the conveyor belt) would reduce the sediment transported to the next pool downstream. However, sediment washed out of one pool (put onto the conveyor belt) then would increase the sediment in transport to the next pool downstream. This thought experiment highlights how pools may respond in hard-to-predict ways based on subtle shifts in bedload transport or sediment availability.

5.3 Comparison Table of Sources and Loads

In Table 5-1, we compare sediment-inventory totals to sediment-transport totals over matching periods. This is not a direct comparison because fine sediment from sediment sources is not quite the same as suspended sediment and coarse sediment is not quite the same as bedload sediment. However, for an order of magnitude comparison, it is the most applicable data that we collected to be able to compare results between the two methods.

The totals compared below are on the same order of magnitude, and generally agree to a surprising degree.

- During the ***1998 through 2004*** period, ***fine*** material washed into the creeks from sediment sources totaled 11,400 cubic yards; during the same period, calculated ***suspended*** sediment totaled 6,800 cubic yards (using the high-condition sediment rating curve).
- During the ***2017 through 2018*** period, ***fine*** material washed into the creeks from sediment sources totaled 650 cubic yards; during the same period, calculated ***suspended*** sediment totaled 1,100 cubic yards (using the low-condition sediment rating curve).
- During the 1998 through 2004 period, the net volume of ***coarse*** material (after storage is subtracted) totaled *greater than* 1,100 cubic yards; during the same period, calculated ***bedload*** sediment totaled 1,400 cubic yards (using the high-condition sediment rating curve).
- During the 2017 through 2018 period, the net volume of coarse material (after wood-jam storage is subtracted) totaled -200 cubic yards (essentially zero);

during the same period, calculated bedload sediment totaled +130 cubic yards (using the low-condition sediment rating curve).

Table 5-1 Sediment inventory totals compared to sediment transport totals over matching periods: El Corte de Madera Creek Open Space Preserve.

Cat.	Calculations from Sediment Inventory	2004 Inventory (1998-2004)	2018 Inventory (2017-2018)		Sediment rating curve applied to correlated flow	High sediment rating curve 1998-2004	Low sediment rating curve 2017-2018
1	***Coarse and fine*** material produced by sources (including toe of slide/slump)	**26,000**	**3,200**	*(cu. yards)*			
2	***Coarse*** material produced by sources (including toe of slide/slump)	**7,900**	**1,700**	*(cu. yards)*			
3	***Coarse*** material stored in toe (temporary)	**2,900**	**810**	*(cu. yards)*			
4	***Coarse*** material washed into creek system (toe subtracted)	**5,000**	**850**	*(cu. yards)*			
5	***Fine*** material washed into creek system (toe subtracted)	**11,400**	**650**	*(cu. yards)*	**Suspended sediment total**	**6,759**	**1,150**
6	***Coarse*** material stored behind wood jams (temporary)	**3,900**	**1,070**	*(cu. yards)*		*(cu. yards)*	*(cu. yards)*
7	Net volume of ***coarse*** material after storage is subtracted	**> + 1,100**	**-220**	*(cu. yards)*	**Bedload sediment total**	**1,366**	**137**
8	Sum of ***coarse*** material stored in toe of slides and behind wood jams	**6,800**	**1,880**	*(cu. yards)*		*(cu. yards)*	*(cu. yards)*

Notes:
Volumes have been scaled up, based on this inventory having been conducted along 77% of the main creek channels.
The 2004 volumes have been revised slightly compared to the volumes presented in 2005.
Due to the approximate nature of the measurements and estimates, the calculations should only be evaluated to 2 significant figures; additional precision is neither intended nor implied.
Negative values indicate net storage of sediment.
For the purpose of these calculations, "coarse" includes sand and larger particles.
For the purpose of these calculations, "fine" includes silt and smaller particles.
A conversion factor of 0.719 yards/US ton was used to convert sediment transport totals to a volume (assumes 1,650 kg/m3)

5.4 Conclusions

5.4.1 Less Sediment Is Leaving ECDM Than Before The WPP

The comparison of sediment rating curves from 2006 to 2008 against 2018 and 2019 show a substantial decrease in sediment transport rates at a given flow for both suspended-sediment and bedload sediment (Figure 4-12 and Figure 4-13). This is likely due to reduced sediment availability along the creek channel. This could be due to the WPP, or fewer landslides, or a combination of both. The scale of the reduction is more than 60%. The effect of this is that much less sediment is now leaving ECDM than during the baseline period (Figure 4-10).

5.4.2 V* Shows Lower Pool-Sediment Volumes In 2018 And 2019 Than Before The WPP

V* measurements grouped into the time periods of 2004-2006 compared to 2018-2019 show a decrease in pool sedimentation (Figure 4-5); this points to less sediment being available in the creek system. However, changes in V* in ECDM are largely mirrored in the La Honda Creek Preserve (which did not receive WPP treatments), so some of the improvement in pool conditions may be due to natural weather patterns (Figure 4-2). Although the La Honda pools were intended as control pools, other variable factors may not make this a strong, independent comparison.

5.4.3 Sediment Texture In Pools Show Less Sand And More Cobbles And Boulders

Sand on pool bottoms has decreased, generally exposing more cobbles and boulders (Figure 4-7). In addition to less *volume* of fine sediment in pools, less area of the pool bottoms are covered by sand. This also points to less sediment being available in the creek system.

5.4.4 WPP Contributed To Improvement In Creek Conditions

Road and trail improvements of the WPP correspond to- and appear to have contributed to- decreased sediment transport rates in El Corte de Madera Creek.

Because road and trail surfaces appear to be much less eroded now, than at the beginning of the study period, decreased sediment transport rates in El Corte de Madera Preserve can partly be attributed to road and trails-related sedimentation reduction; additionally, the same trail improvements are useful to improve the trail experience for Preserve users.

In wetter years, this sediment 'savings' is estimated to be a smaller percent compared to overall transport. In drier years, the sediment savings are estimated to be more substantial compared to overall transport rates.

5.4.5 Natural Weather Patterns and Fewer Recent Landslides

Less sediment is contributed to the creek system by large sediment sources now (2018 inventory) compared to 16 years ago (2004 inventory). Adjusted to a per year basis, this reduction ranges from a factor of 1.7 (coarse) to 5.0 (fine). See Table 4-1and Table 5-1. Therefore, less sediment in the creeks could also be partially due to natural weather patterns and how those patterns drive natural sediment sources.

5.4.6 Wood Jams Trap Substantial Amounts of Sediment

Wood jams appear to play an important role in moderating influxes of sediment. Based on the 2018 inventory of natural sources, slightly more sediment was trapped by wood jams (160 cubic yards) than was washed into the creek system during the 2017 to 2018 period. This is in contrast to the conditions in 2004, when the sediment washed into the creek system from natural sources exceeded the total amount of sediment trapped by wood jams by at least 1,100 cubic yards (Table 4-1 and Table 5-1) (for comparison, a standard dump truck holds about 10 yards of material). If the wood jams were not there, much more sediment would likely have filled pools or washed downstream.

6 ACKNOWLEDGEMENTS

MROSD staff, rangers, and interns were a key part of this study. They performed a large portion of the field measurements, data entry, data validation, and were enthusiastic and active partners in designing the field program, asking questions, and following up with extra data analyses to check field methods and results. Project manager Aaron Hébert not only managed the 2018-2020 project but also assisted with all aspects of the field work and V* data work up (including sediment sampling days in the rain). Aaron also contributed significantly to the formulation of this report and the information on the history of the Preserve.

Special thanks to the Water Resources Interns, Julia Hathaway and Morgan Williams, for leading the V* fieldwork, and inputting and double-checking all the V* data.

Special thanks to Senior Planner Meredith Manning for overseeing the V* work in 2005-06, retired Senior Resource Management Specialist Matt Baldzikowski for assisting with the stream gaging in 2006-2008, and Natural Resources Manager Kirk Lenington for initiating this study program.

To the many Midpen staff who gathered the V* data: patrol, land and facilities, Midpen volunteers, and the Conservation Biology Interns (Katarina Palermo and Elena Wolff), who were integral partners to the Water Resources Interns.

Many Balance staff performed field work (during both dry weather and in the rain) and/or data entry and analyses; the following team members were consistent contributors with ideas for data analysis, careful observations and off-trail fortitude: Chelsea Neill, Anna Nazarov, Dana Jepsen, Zan Rubin, Emma Goodwin, John Hardy, Barry Hecht, Scott Brown, John Gartner, Brian Hastings, Shawn Chartrand, and Bonnie deBerry.

7 LIMITATIONS

Analyses and information included in this report are intended for use at the watershed scale and for the planning and long-term monitoring purposes described above. Analyses of channels and other water bodies, rocks, earth properties, topography and/or environmental processes are generalized to be useful at the scale of a watershed, both spatially and temporally. Information and interpretations presented in this report should not be applied to specific projects or sites without the expressed written permission of the authors, nor should they be used beyond the particular area to which we have applied them. Estimates of sediment originating from mass wasting, slope sources and/or roads and trails are developed solely for the purpose of providing context for planning the monitoring program; these should not be taken, for the roads in particular, as the long-term yields from individual sediment sources.

Balance Hydrologics, Inc. should be consulted prior to applying the contents of this report to evaluating upland sediment sources, any out-of-stream locations, or any in-stream locations not specifically cited in this report. Results are limited to information needed to plan a long-term monitoring program. In particular, information developed in this report is not intended for use in design of structures, or specific slope or road repairs.

Readers who have additional pertinent information, who observed changed conditions, or who may note material errors should contact us with their findings at the earliest possible date, so that timely changes may be made.

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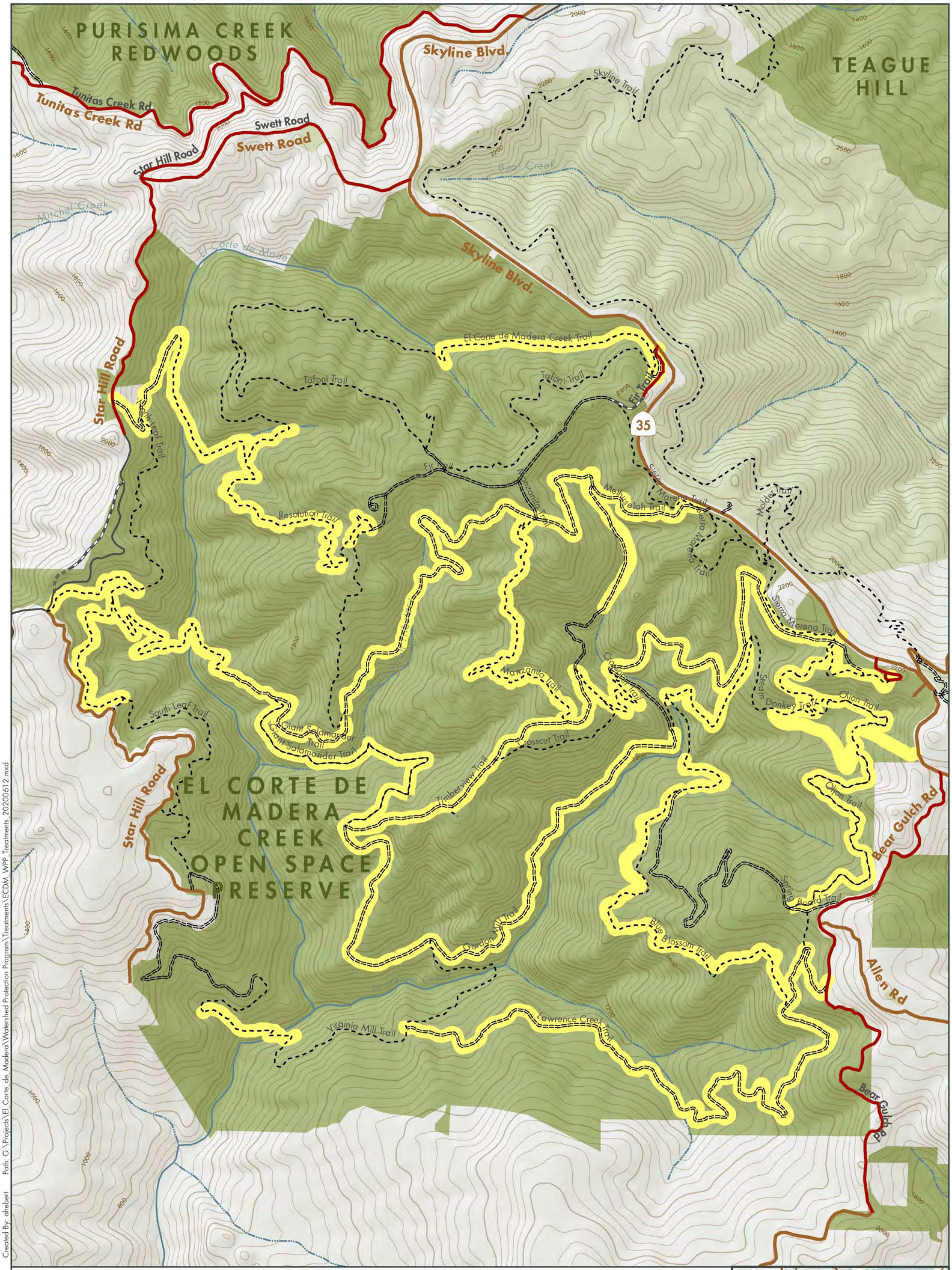

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Watershed Protection Program, Completed Treatments (2003-2020)

- MROSD Preserves
- Other Protected Lands
- Private Property
- Completed Treatment
- Unpaved Road
- Unmaintained Road
- Trail

Midpeninsula Regional Open Space District
(Midpen)
8/18/2020

ATTACHMENT 2

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