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Hollister Hills SVRA

Trail Erosion Surveys

Summer 2017

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Executive Summary

In 2012 environmental scientists at Hollister Hills State Recreational Vehicle Area (SVRA) issued a report prioritizing trail condition and sustainability based upon a three-level visual assessment and professional judgment. In collaboration with the park's environmental scientists, a representative subset of those trails (18 sites) was selected for more detailed work aimed at quantifying trail erosion through time serial surveys. The sample sites were selected to include variability in trail use: road, all-terrain vehicle (ATV), and single-track; soil type: clay and granitic; and trail sustainability: green, yellow, and red. In 2013 a baseline digital elevation model was created for each site using ArcGIS. In 2015 and 2016 the surveys were done using structure from motion, low-altitude photogrammetry. The present report presents and analyzes data from June 2017, again using photogrammetric techniques. Changes in the elevation of sites were computed by raster subtraction in ArcGIS. The trails experienced relatively high rainfall (26.09 in), the highest annual precipitation since the surveys commenced in 2013.

The results this year were complicated by having half of the 18 sites mechanically-, or hand-graded, leaving fewer data for meaningful assessment of the three-level assessment criteria. One site was not assessed because of benchmark loss. The grand mean for ungraded sites was 0.002 m of erosion, nearly undetectable change. That average included 0.022 m of deposition on green sites, 0.018 m of deposition on yellow sites, and 0.069 m of erosion on red sites, supporting the three-level trail sustainability criteria. Clay soil sites eroded 0.009 m, while granitic sites had 0.011 m of deposition. Roads increased elevation by 0.034 m, ATV trails increased by 0.020 m, and single track trails eroded 0.020 m. Overall soil deposition and very low magnitude erosion were unexpected results, given the context of high annual rain.

This year's results provide the first assessment of grading activities on trail elevation. The grand mean for graded sites was 0.021 m of net deposition. Of the sites in this study, no single-track sites were graded. Graded roads lost 0.003 m of elevation, while ATV tracks gained 0.040 m.

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1 Introduction

In 2012 Hollister Hills State Recreational Vehicle Area (SVRA) (Fig. 1) resource managers created an index to rate the sustainability of the trails in the park: green (acceptable), yellow (marginal), and red (action needed). The rating index was based on a visual assessment of the road's physical context and condition (HHSVRA 2012). This effort was undertaken to inform best management practices that would optimize soil conservation in the park. While the rating system was based upon observations of parameters that are understood to foster or retard erosion, they recognized the need to quantitatively validate and calibrate the system.

In 2013, park staff collaborated with Cal State Monterey Bay (CSUMB) to study the annual erosion of a subset of trails that had been indexed. The study includes 18 sites across the SVRA to account for geologic substrate (Granitic and Clay), vehicle use types (Single Track, ATV, and Road), and trail erodibility index (Green, Yellow and Red) (Fig. 2). The first trail surveys set the baseline topography in 2013 (Teaby et al. 2013). In each year thereafter, repeat surveys have estimated the annual and cumulative vertical erosion in each study site (Silveus et al. 2014; Chow et al. 2015, 2016; Smith et al 2016). This report documents the changes surveyed in summer of 2017, following one the wettest year of the multi-year study.

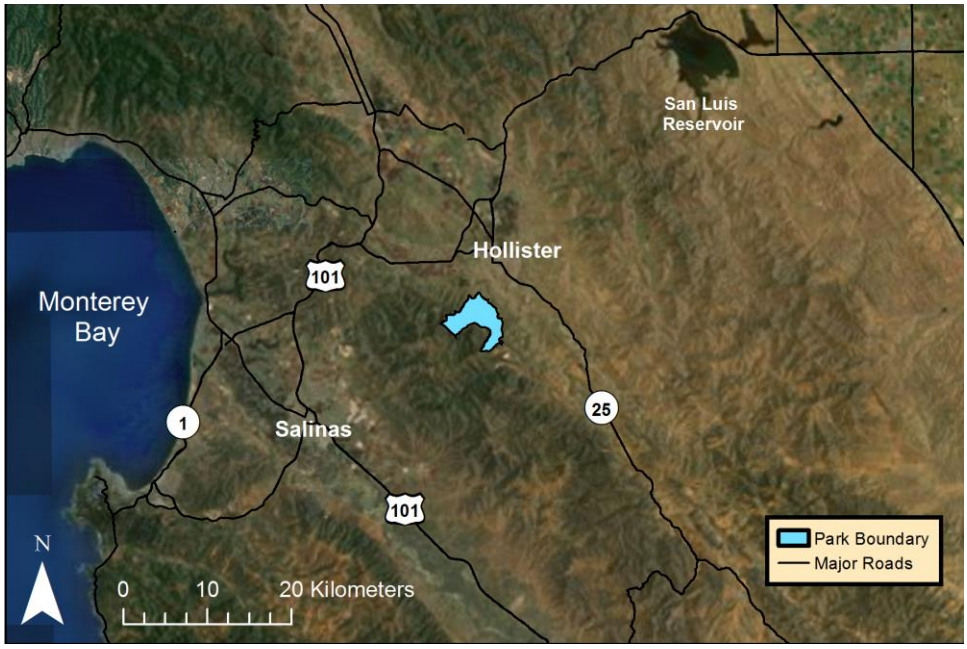

Figure 1. Hollister Hills State Vehicular Recreation Area is found northeast of Salinas.

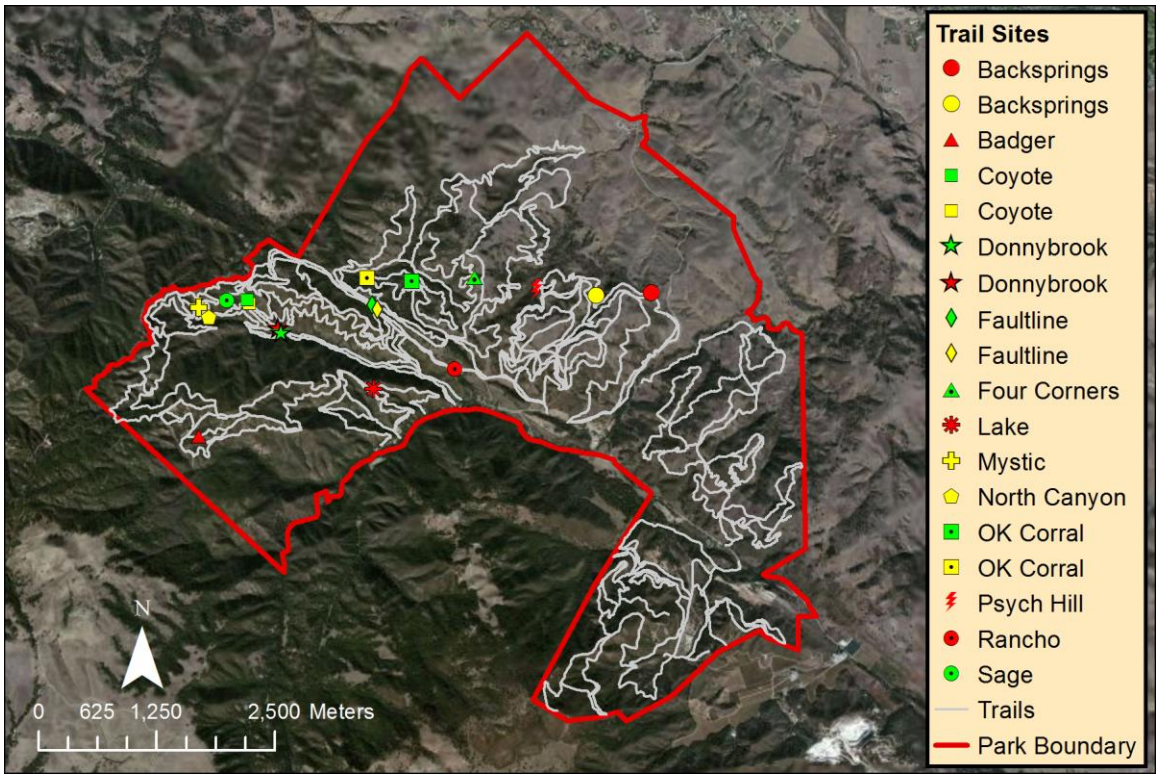

Figure 2. Trail site locations within Hollister Hills State Vehicular Recreation Area, Hollister, CA.

2 Methods

2.1 Field Survey

All 18 sites that were surveyed in 2013 were revisited and surveyed using the same local benchmarks (BM) for horizontal and vertical referencing. At each site, one BM was occupied by a 3" Nikon total station, and a backshot to a second BM establish the horizontal angles.

Within the survey footprint of the 2016 survey, 10 cm x 10 cm, plastic square ground control points (GCPs) were placed every 2 meters in a zigzag pattern throughout the trail and temporarily nailed in place with a spike. The local coordinate of each GCP was found with the total station.

Low altitude aerial photos were captured with a Hero 3+ GoPro in a "mowing the lawn" pattern at different angles to ensure sufficient photo overlap and that each photo contained multiple GCPs. Altitude of each aerial photograph was approximately 2.8 meters. The photos for each site were processed using Agisoft Photoscan structure-from-motion (SfM) software.

2.2 Surface Modeling

For each site, we selected photos that contained multiple GCPs, had a clear view of the trail from different locations, and minimal vegetation interference to upload into Agisoft Photoscan. Parameters were adjusted to account for the fisheye lens of the GoPro camera. Within the workflow of the software, photos were aligned and GCPs were manually placed for each site. Each GCP was optimized based on RMS error. A dense cloud was created using mild depth filtering to retain as much surface microtopography as possible without encouraging spurious points. A DEM and orthophoto were exported for each site. Workflow for DEM creation using Agisoft is further elaborated in the Agisoft tutorial (Agisoft 2014). Table 1 summarizes all of the inputs that were used in DEM creation with Agisoft Photoscan as well as the resulting resolution.

The DEMs were based upon tens of thousands of independent elevation estimates per square meter of trail (Table 1). Resulting horizontal resolution was a few mm/pixel, and vertical precision of ground control points was typically a few mm (Table 1).

Table 1: Table showing the locations, site condition, usage, soil type, 2017 area and input parameters (number of photos, number of GCPs, and approximate flying altitude), as well as resulting GCP root mean square error (RMSE), GCP Z error, resolution and point density for each site's DEM.

Trail Location	Condition	Usage	Soil Type	2017 Area (m^2)	# photos	# GCPs	Altitude (m)	GCP RMSE (m)	GCP Z error (m)	Res. (mm/pix)	Point Density (points/ m^2)
OK Corral_1	**Green**	Single Track	Clay	242	75	8	2.5	0.023	0.003	5.35	34900
Donnybrook_2	**Green**	Single Track	Granite	160	62	8	1.9	0.014	0.008	4.07	60500
4 Corners	**Green**	ATV	Clay	899	72	14	4.6	0.014	0.005	6.91	20900
Coyote_1	**Green**	ATV	Granite	261	68	12	2.8	0.015	0.006	5.34	35100
Faultline_2	**Green**	Road	Clay	244	68	10	2.4	0.014	0.006	5.03	39600
Sage	**Green**	Road	Granite	119	51	10	2.9	0.015	0.007	5.68	31000
OK Corral_2	**Yellow**	Single Track	Clay	167	55	5	2.2	0.009	0.005	4.17	57400
Mystic	**Yellow**	Single Track	Granite	170	63	7	2.4	0.014	0.006	4.95	40800
Backsprings_2	**Yellow**	ATV	Clay	534	73	10	5.5	0.010	0.004	5.86	29100
Coyote_2	**Yellow**	ATV	Granite	340	85	12	2.8	0.008	0.003	5.38	34500
Faultline_1	**Yellow**	Road	Clay	144	92	8	1.9	0.016	0.005	4.17	57500
North Canyon	**Yellow**	Road	Granite	832	122	21	3.4	0.019	0.005	6.41	24300
Psych Hill	**Red**	Single Track	Clay	216	124	8	2.4	0.014	0.011	4.30	54000
Donnybrook_1	**Red**	Single Track	Granite	94	74	11	1.6	0.018	0.009	3.27	93500
Backsprings_1	**Red**	ATV	Clay	170	63	5	2.7	0.011	0.001	5.16	37500
Badger	**Red**	ATV	Granite	256	74	13	2.7	0.019	0.008	4.44	50700
Rancho	**Red**	Road	Clay	585	112	13	2.4	0.013	0.008	4.76	44200
Lake	**Red**	Road	Granite	260	77	9	2.5	0.019	0.007	4.66	46100

2.3 Analysis

ArcMap (v. 10.1) was used to create a difference of DEMs (DODs) for every site by using *Raster Calculator* to subtract the 2017 DEM from the 2016 DEM. Due to the size difference of the 2017, 2016, and 2013 DEMs the DOD of every site is the extent of the smallest raster. A mask was created for each raster to restrict the DOD analysis to the trail tread. The area and average vertical change of each site were extracted from ArcMap. The 2017 elevations, areas, and volumes obtained from this process were compared with those of 2016, 2015, 2014, and 2013 values to quantify both annual and total change. Microsoft Excel was used to analyze the data and R Software was used to generate graphs of the data using the "ggplot2" package (R Core Team 2013). Precipitation data were obtained from the Hollister Hills Weather Monitoring Station within the park boundary Western Weather Group 2017).

3 Results

3.1 Precipitation

Water year 2017 was the wettest year since the rain gages were installed at the park (Table 2), in keeping with high values throughout Central California. Approximately 26.04 inches of rain that fell between the 2016 and 2017 trail surveys. The value is slightly less than the total 2017 water year because of the light September 2017 rain that post-dated the June 2017 survey.

Table 2: Hollister Hills SVRA precipitation data obtained from Western Weather Group (2017).

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Total**
2011	0.89	2.29	4.15	1.81	4.07	4.57	0.20	1.11	0.37	0.00	0.00	0.00	**19.46**
2012	0.83	1.96	0.11	2.28	0.62	2.62	2.18	0.03	0.06	0.03	0.00	0.00	**10.72**
2013	0.27	2.54	4.35	0.98	0.75	0.60	0.21	0.00	0.00	0.00	0.00	0.08	**9.78**
2014	0.11	0.28	0.34	0.20	2.72	1.56	0.76	0.00	0.00	0.00	0.00	0.08	**6.05**
2015	1.05	0.51	5.23	0.00	1.26	0.17	1.14	1.24	0.00	0.02	0.06	0.08	**10.76**
2016	0.18	3.42	2.97	5.67	0.88	5.23	0.87	0.08	0.00	0.00	0.00	0.00	**19.30**
2017	2.76	1.53	2.20	9.70	6.27	1.91	1.55	0.06	0.06	0.00	0.00	0.05	**26.09**
Monthly Average	**0.87**	**1.79**	**2.76**	**2.95**	**2.37**	**2.38**	**0.99**	**0.36**	**0.07**	**0.01**	**0.01**	**0.04**	
Annual Average		**14.59**											

3.2 Trail Erosion

Tables 3 and 4 provide the spatially-averaged annual vertical changes measured at each site, parsed by soil type, vehicle usage, classification, and whether or not the site had been graded. The time-series behavior of each site can be tracked in Appendix A.

Table 3: Annual average elevation change by site, condition, usage, soil type and annual change in elevation (m) for each year of in the study (2013 – 2017). Site condition is from HHSVRA (2012): Green (acceptable), Yellow (marginal), and Red (action needed). Sites with insufficient data are denoted by "N/A." Greyed out sections are sites that have been altered by hand or mechanical grading before the survey was completed. Positive numbers indicate deposition and negative numbers indicate erosion.

				Δ Elev (m)			
Trail Location	Condition	Usage	Soil Type	16-17	15-16	14-15	13-14
OK Corral_1	**Green**	Single Track	Clay	0.037	-0.04	0.00	-0.01
Donnybrook_2	**Green**	Single Track	Granite	-0.015	0.01	-0.04	-0.04
4 Corners	**Green**	ATV	Clay	0.020	0.01	-0.08	-0.01
Coyote_1	**Green**	ATV	Granite	0.042	-0.03	0.00	-0.02
Faultline_2	**Green**	Road	Clay	0.046	-0.03	-0.04	-0.02
Sage	**Green**	Road	Granite	0.040	-0.03	0.00	-0.01
OK Corral_2	**Yellow**	Single Track	Clay	NA	-0.08	0.00	-0.02
Mystic	**Yellow**	Single Track	Granite	0.014	-0.02	-0.02	0.00
Backsprings_2	**Yellow**	ATV	Clay	-0.009	0.07	-0.01	-0.01
Coyote_2	**Yellow**	ATV	Granite	-0.018	0.03	-0.03	NA
Faultline_1	**Yellow**	Road	Clay	0.021	-0.03	-0.05	-0.04
North Canyon	**Yellow**	Road	Granite	0.035	0.08	-0.02	-0.06
Psych Hill	**Red**	Single Track	Clay	-0.171	0.12	NA	NA
Donnybrook_1	**Red**	Single Track	Granite	0.034	-0.17	-0.06	-0.04
Backsprings_1	**Red**	ATV	Clay	0.191	-0.17	0.00	-0.01
Badger	**Red**	ATV	Granite	-0.004	-0.17	-0.04	-0.04
Rancho	**Red**	Road	Clay	-0.025	1.29	-0.03	-0.02
Lake	**Red**	Road	Granite	-0.061	0.02	-0.04	-0.08

*grey shaded cells represent graded sites

Table 4: Annual average elevation change summarized by year, sustainability rating, use and grading. Sites with insufficient data are denoted by "N/A.". Positive numbers indicate deposition and negative numbers indicate erosion.

2013-2014

Averages	Overall	red	yellow	green	clay	granite	ST	ATV	Road
All Sites	-0.03	-0.04	-0.03	-0.02	-0.02	-0.04	-0.02	-0.02	-0.04
Graded Sites	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ungraded Sites	-0.03	-0.04	-0.03	-0.02	-0.02	-0.04	-0.02	-0.02	-0.04

2014-2015

Averages	Overall	red	yellow	green	clay	granite	ST	ATV	Road
All Sites	-0.03	-0.03	-0.02	-0.03	-0.03	-0.03	-0.02	-0.03	-0.03
Graded Sites	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ungraded Sites	-0.03	-0.03	-0.02	-0.03	-0.03	-0.03	-0.02	-0.03	-0.03

2015-2016

Averages	Overall	red	yellow	green	clay	granite	ST	ATV	Road
All Sites	0.05	0.15	0.01	-0.02	0.13	-0.03	-0.03	-0.05	0.22
Graded Sites	0.24	0.38	0.07	0.01	0.45	-0.07	NA	-0.03	0.65
Ungraded Sites	-0.03	-0.07	0.00	-0.02	-0.04	-0.02	-0.03	-0.06	0.00

2016-2017

Averages	Overall	red	yellow	green	clay	granite	ST	ATV	Road
All Sites	0.010	-0.006	0.009	0.028	0.014	0.007	-0.020	0.037	0.009
Graded Sites	0.021	0.025	0.003	0.041	0.052	0.006	NA	0.040	-0.003
Ungraded Sites	-0.002	-0.069	0.018	0.022	-0.009	0.011	-0.020	0.020	0.034

Over the course of four years, green and yellow sites had similar erosion values, whereas red sites have significantly more erosion (Fig. 3). The high rainfall of winter 2017 resulted in net deposition on green and yellow sites, but somewhat deep erosion on red sites (Fig. 3).

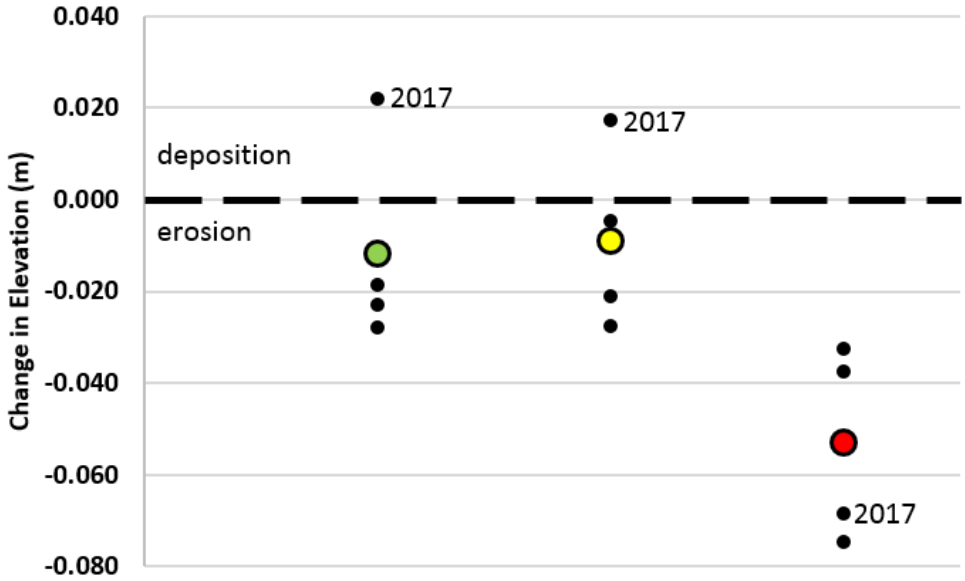

Figure 3. Annual average elevation changes for each sustainability rating. Green, Yellow and Red sites. Black dots are individual years. Colored dots are grand means for all years. "2017" indicates changes during WY 2017. Data restricted to ungraded sites.

Roads and ATV trails had net deposition in 2017, whereas single track sites showed moderate erosion (Fig. 4). In 2017 Granite sites had modest net deposition and clay sites had modest erosion. On average over the four year study, clay and granite sites have the similar erosion rates. Before the deposition episode of 2017, granite sites consistently eroded more than clay sites.

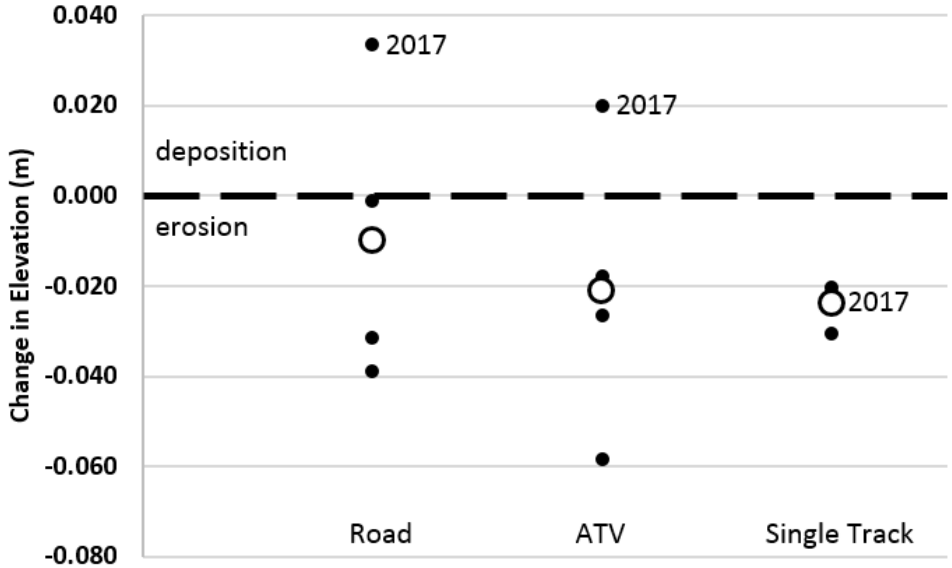

Figure 4. Annual average elevation changes for each trail use category. Black dots are individual years. Circle is mean for all years. "2017" indicates changes during WY 2017. Data restricted to ungraded sites.

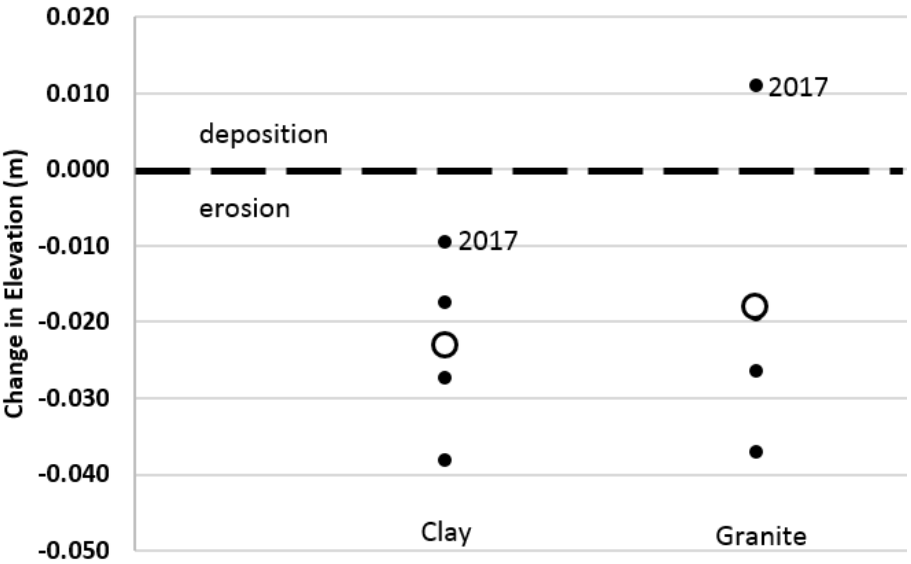

Figure 5. Annual average elevation changes for each soil type. Black dots are individual years. Circles are grand means for all years. "2017" indicates changes during WY 2017. Data restricted to ungraded sites.

4 Discussion

The Universal Soil Loss Equation and other soil conservation metrics are calibrated to model higher erosion with higher rainfall. The high rainfall of 2017 was therefore anticipated to bring widespread erosion to the Hollister Hills SVRA trails. Very precise photogrammetric measurements of 18 sites representing two soil types, three use classes, and three sustainability ratings show that the study sites had generally lower than average erosion, and in some cases deposition (Figs. 3, 4 and 5). This unexpected result suggests that the physical processes, and sediment routing patters are more complex than simple models would predict.

5 References

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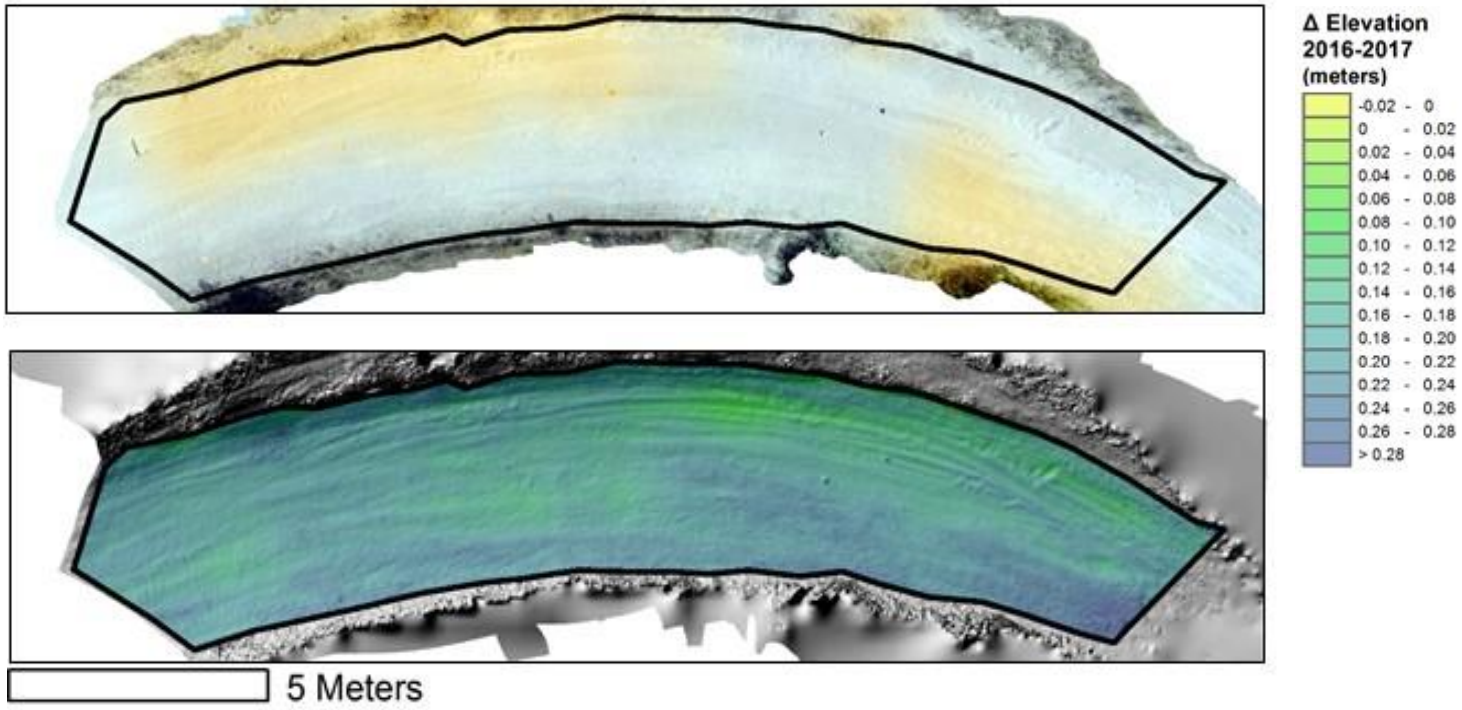
6 Appendix A

The following appendix shows the results of analysis of the surveys with ArcGIS for all 18 sites.

The top image for each site shows 2017 (black polygon) extent overlaid on the photomosaic photo of the site. The bottom image shows 2017 extent over a "difference of DEM" (DOD) raster generated by subtracting the 2017 raster from the 2016 raster. Positive values indicate sediment deposition and negative values indicate erosion.

Each site has a table describing the overall change in elevation (2013 – 2017) for all years, graded years, and ungraded years, in addition to the 2017 GCP Z error. The graph shows the annual and cumulative elevation change for each site.

Backsprings 1 (CAR)



2013-2017 Elelvation Change (m)						Backsprings 1 (CAR)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.001
0.011	-0.180	0.191	0.003	-0.060	0.191	
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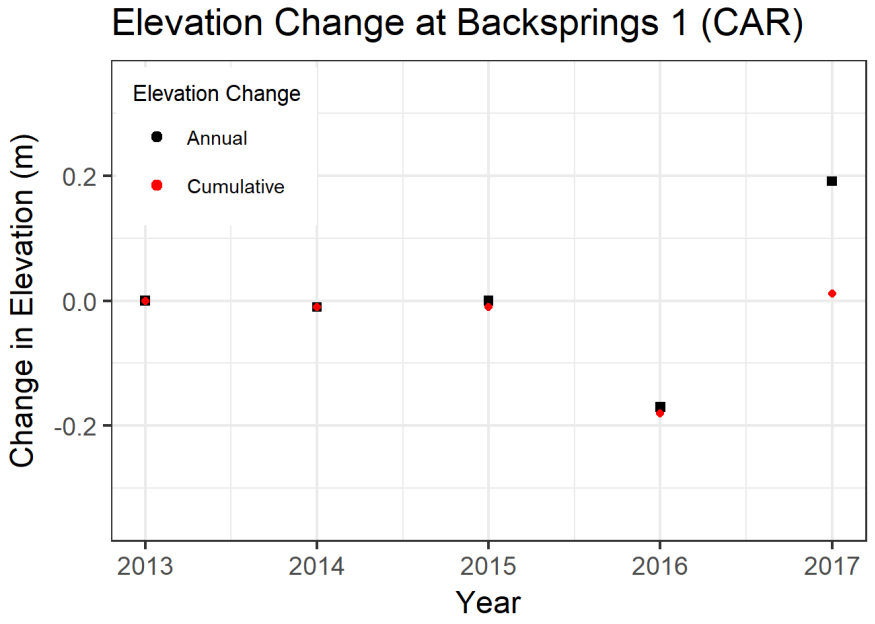
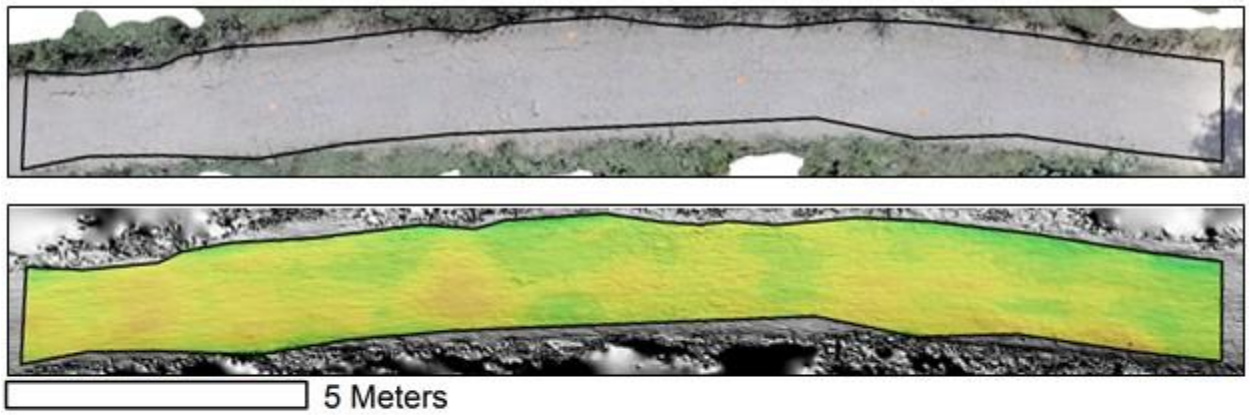
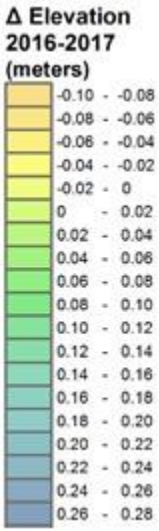
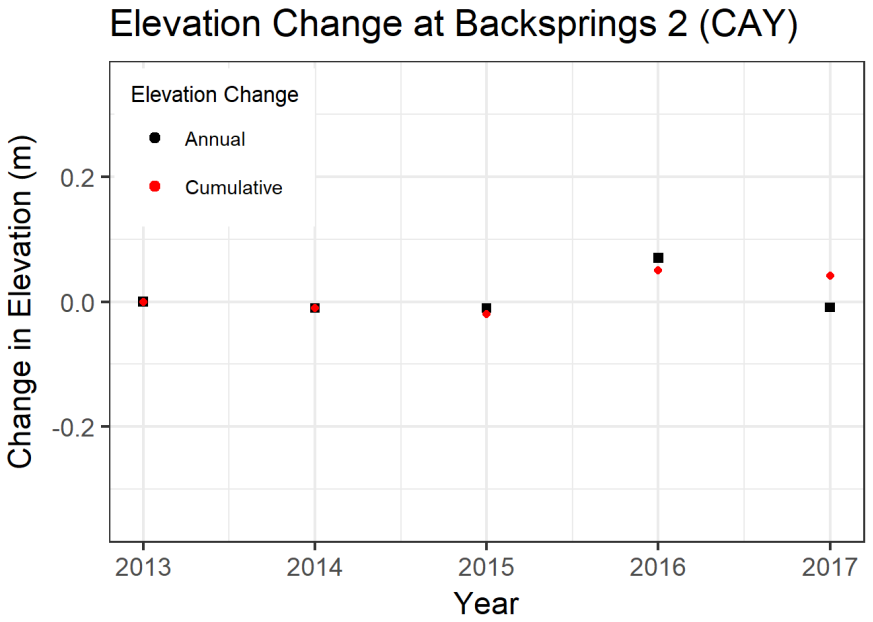


Backsprings 2 (CAY)

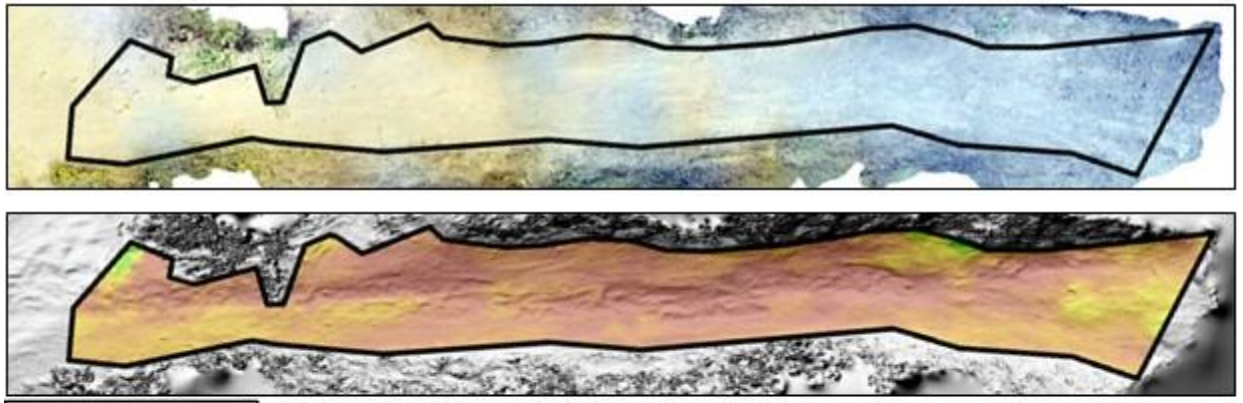


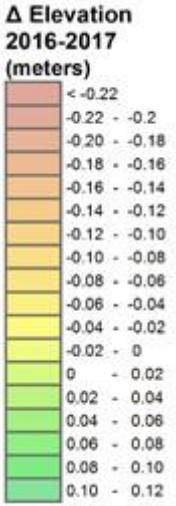


2013-2017 Elelvation Change (m)						Backsprings 2 (CAY)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.002
0.041	-0.020	0.061	0.010	-0.010	0.031	
			n=4	n_u=2	n_g=2	



Psych Hill (CSR)





2013-2017 Elelvation Change (m)						Psych Hill (CSR)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.001
-0.051	-0.051	NA	-0.026	-0.026	NA	
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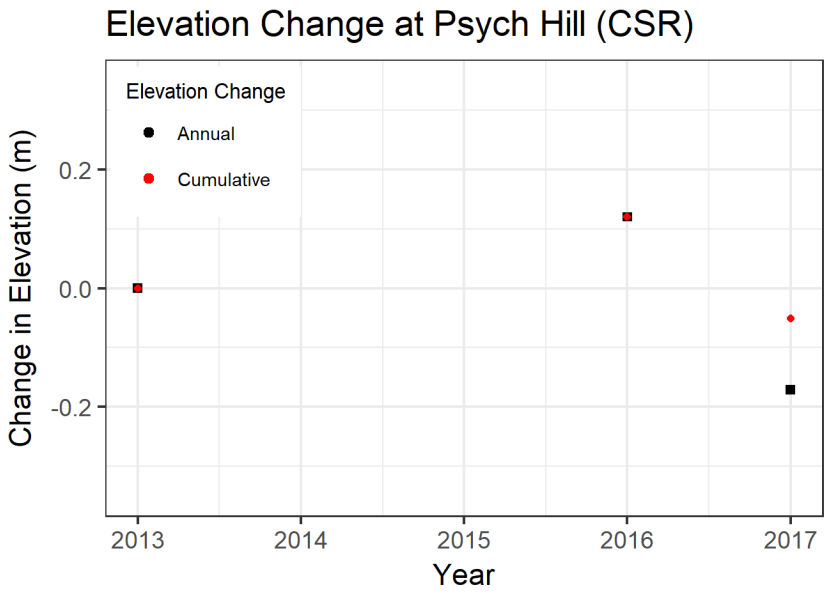
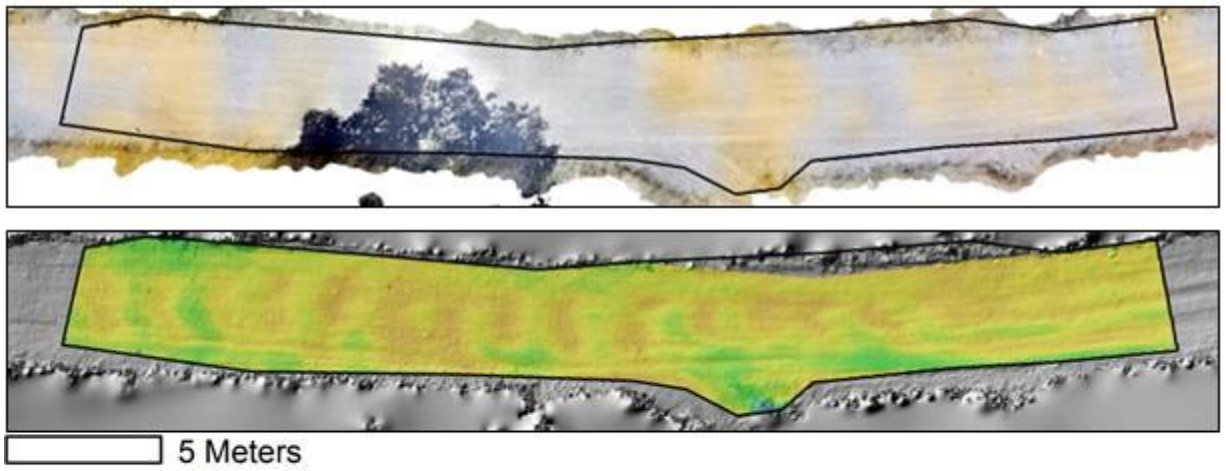
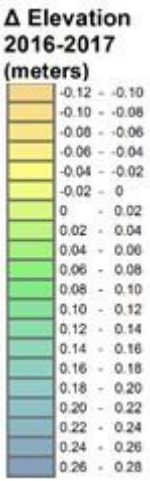
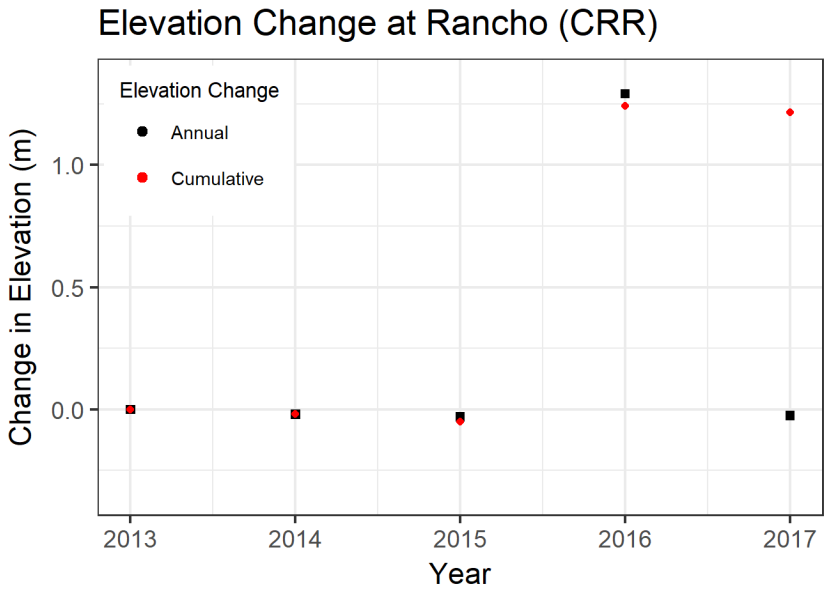


Rancho (CRR)

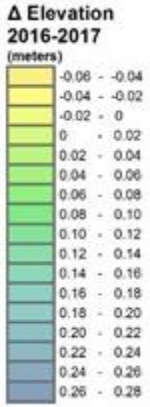




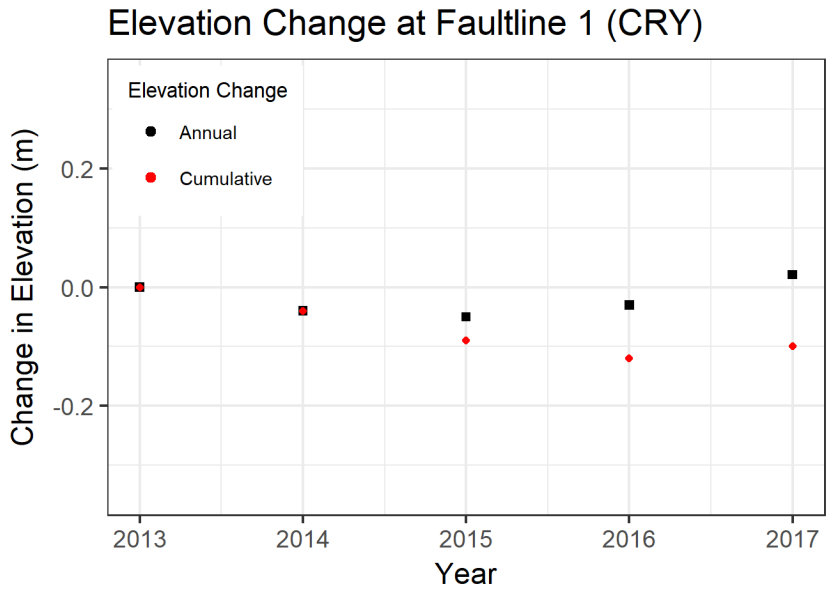
2013-2017 Elelvation Change (m)						Rancho (CRR)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.008
1.215	-0.050	1.265	0.304	-0.025	0.633	
			n=4	n_u=2	n_g=2	



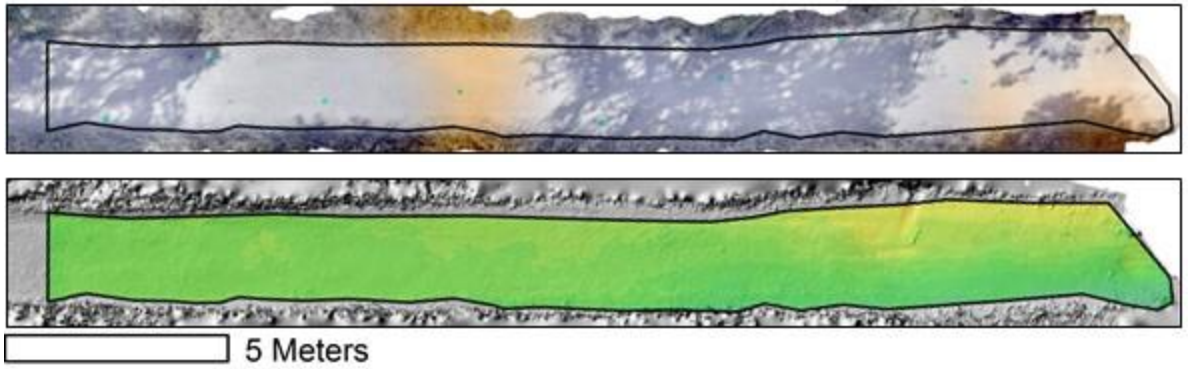
Faultline 1 (CRY)

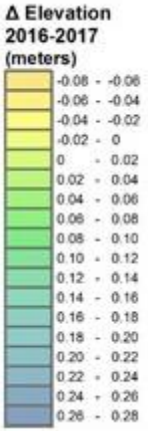


2013-2017 Elelvation Change (m)						Faultline 1 (CRY)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.005
-0.099	-0.120	0.021	-0.025	-0.040	0.021	
			n=4	n_u=3	n_g=1	

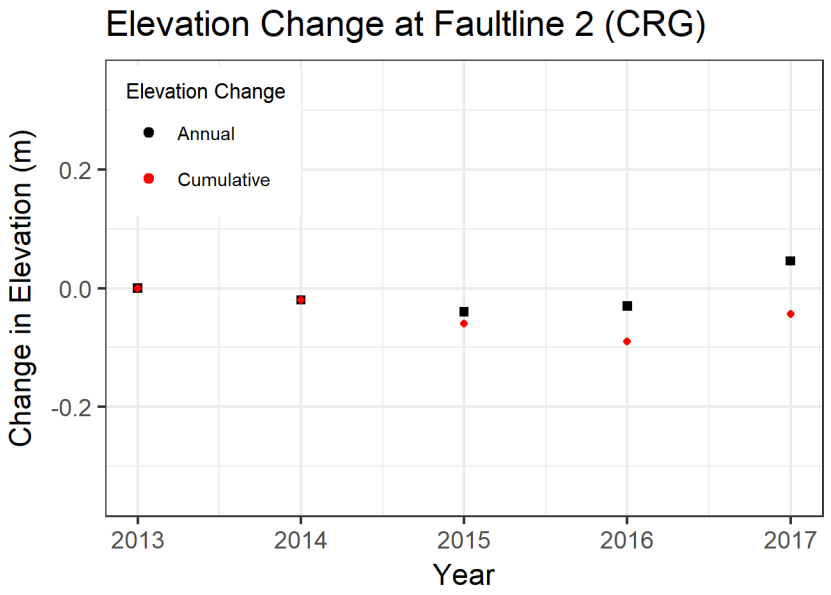


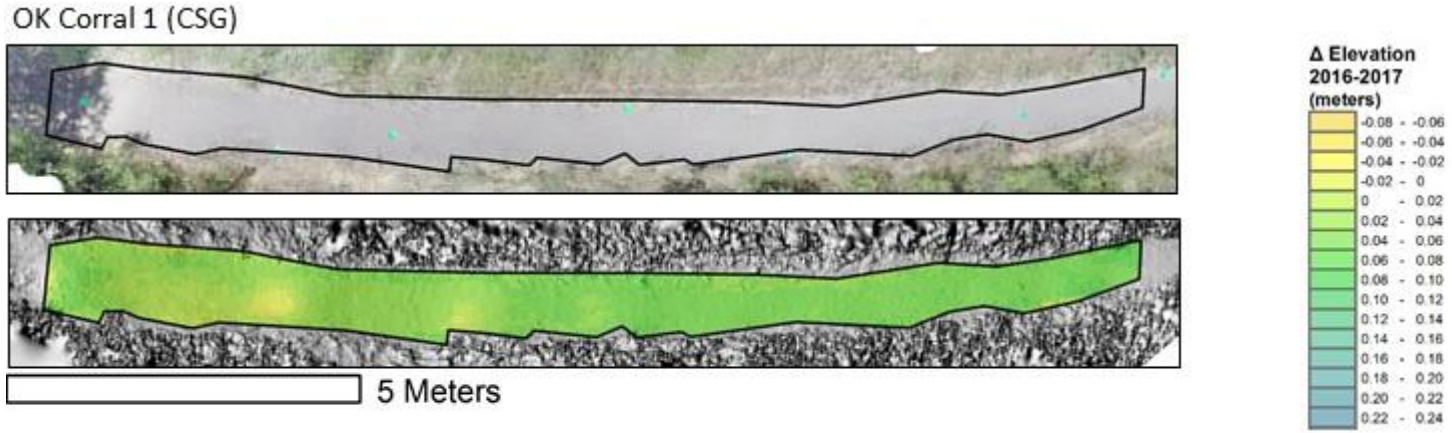
Faultline 2 (CRG)



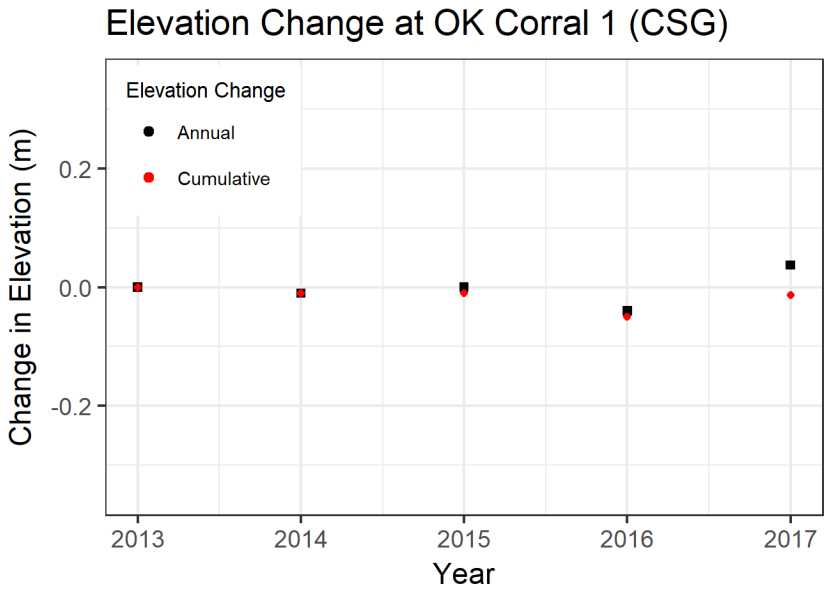


2013-2017 Elelvation Change (m)						Faultline 2 (CRG)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.006
-0.044	-0.044	NA	-0.011	-0.011	NA	
			n=4	n_u=4	n_g=0	

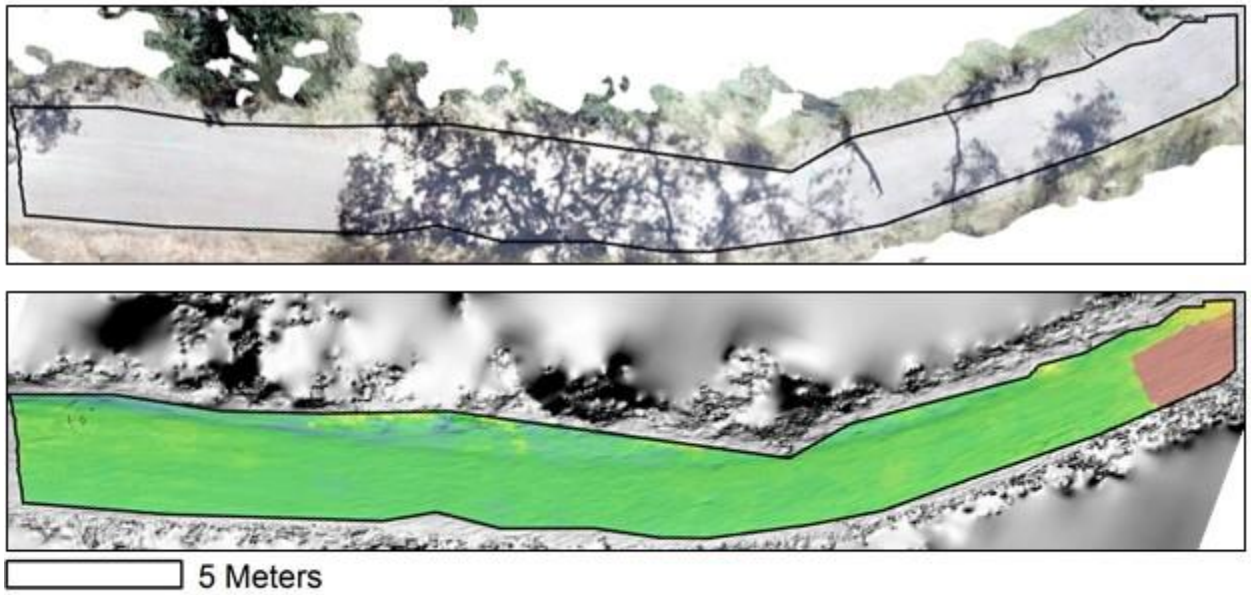




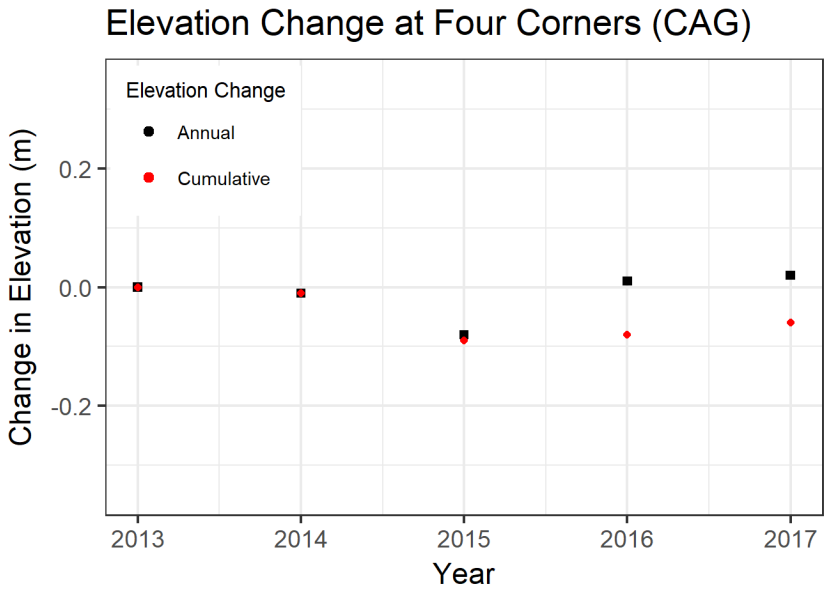
2013-2017 Elelvation Change (m)						OK Corral 1 (CSG)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.003
-0.013	-0.013	NA	-0.003	-0.003	NA	
			n=4	n_u=4	n_g=0	



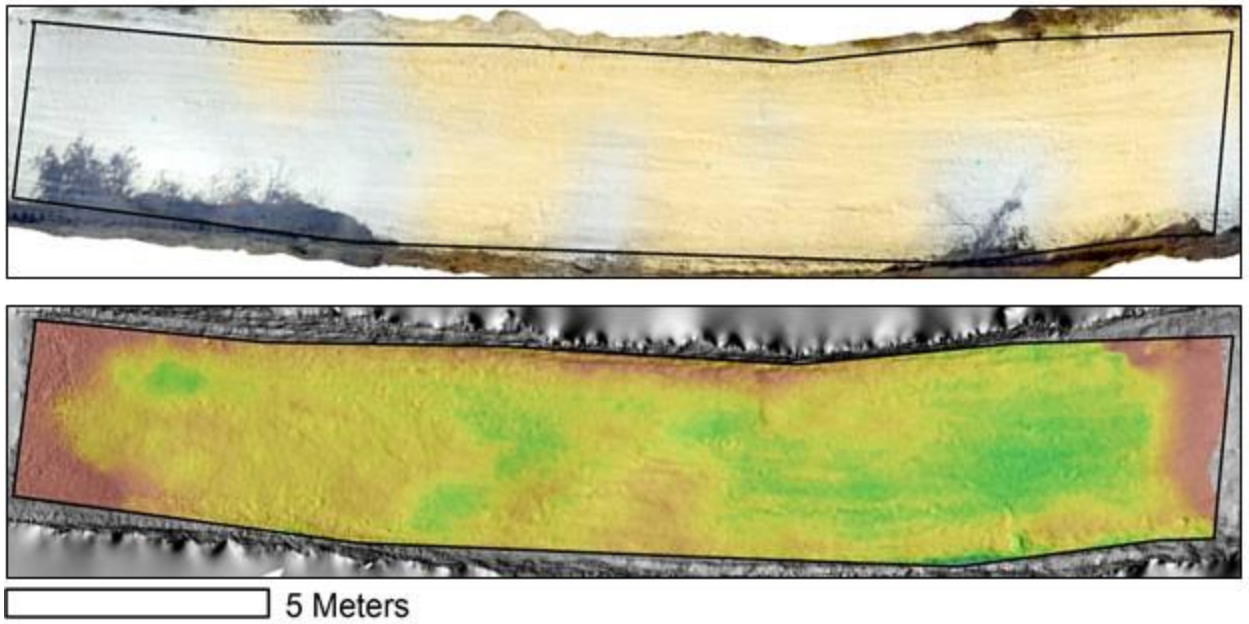
4 Corners (CAG)



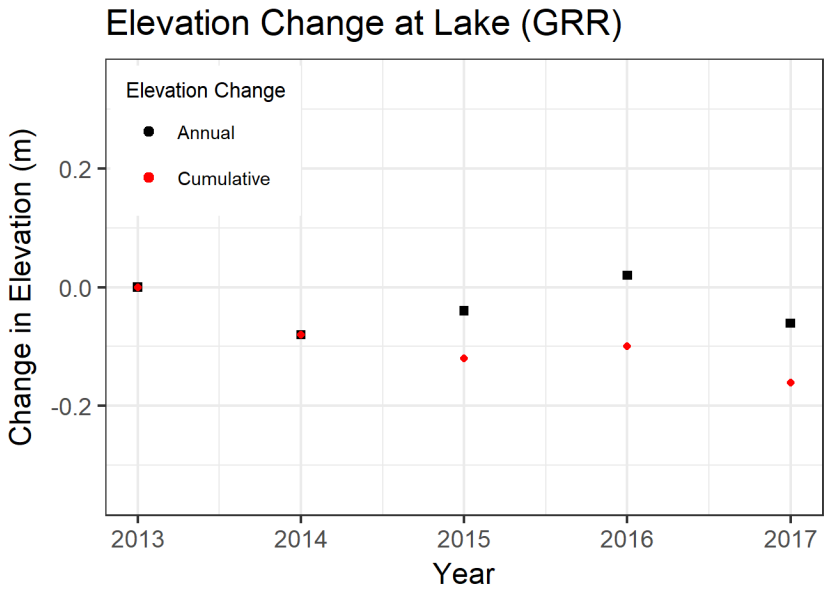
2013-2017 Elelvation Change (m)						Four Corners (CAG)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.005
-0.060	-0.070	0.010	-0.015	-0.023	0.010	
			n=4	n_u=3	n_g=1	



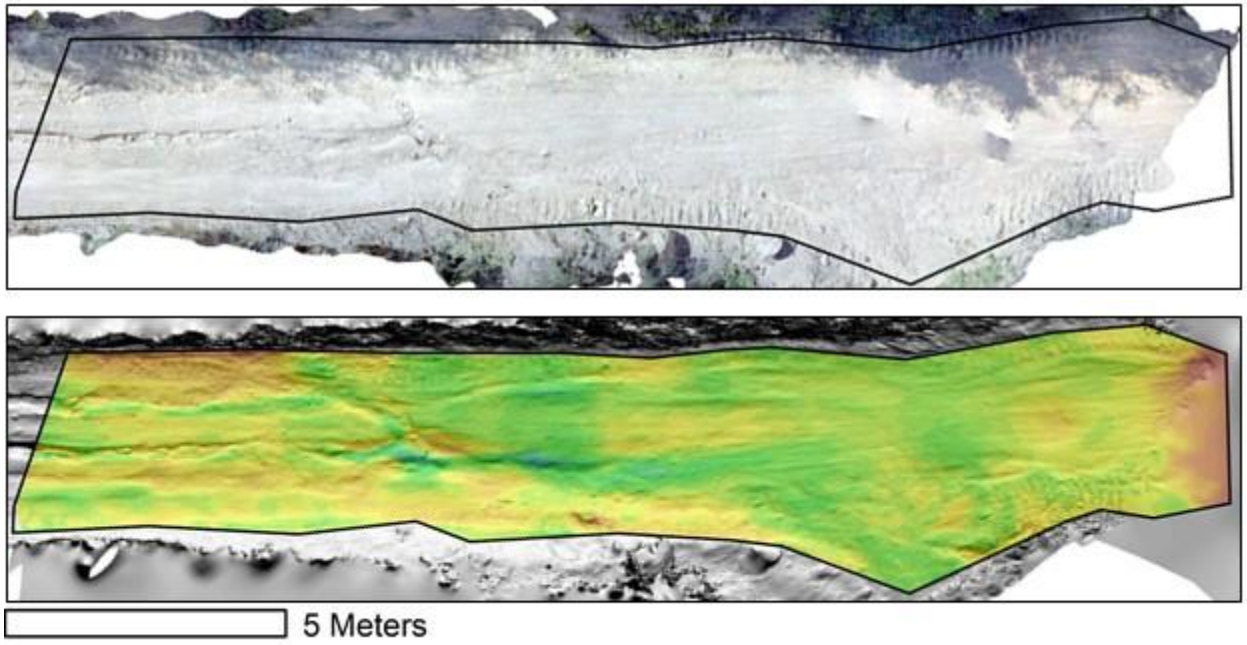
Lake (GRR)



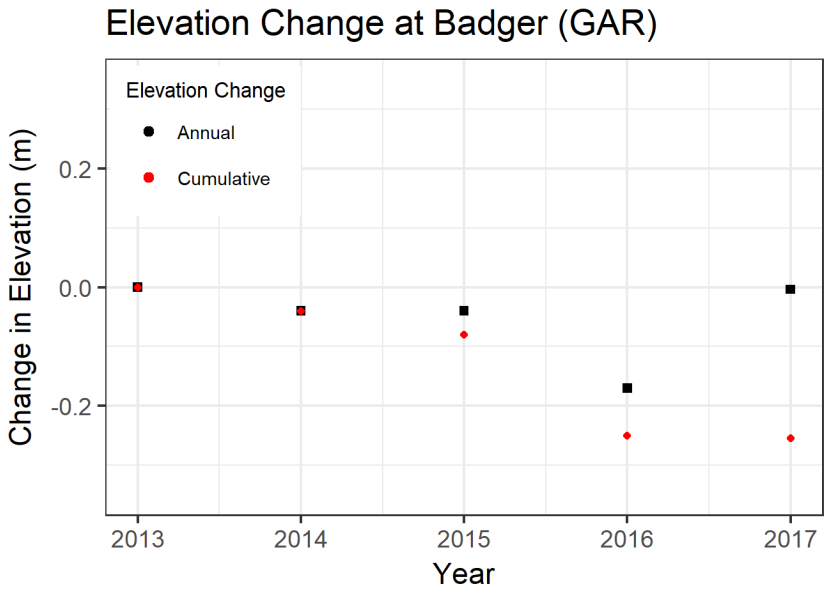
2013-2017 Elelvation Change (m)						Lake (GRR)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.007
-0.161	-0.120	-0.041	-0.040	-0.060	-0.021	
			n=4	n_u=2	n_g=2	



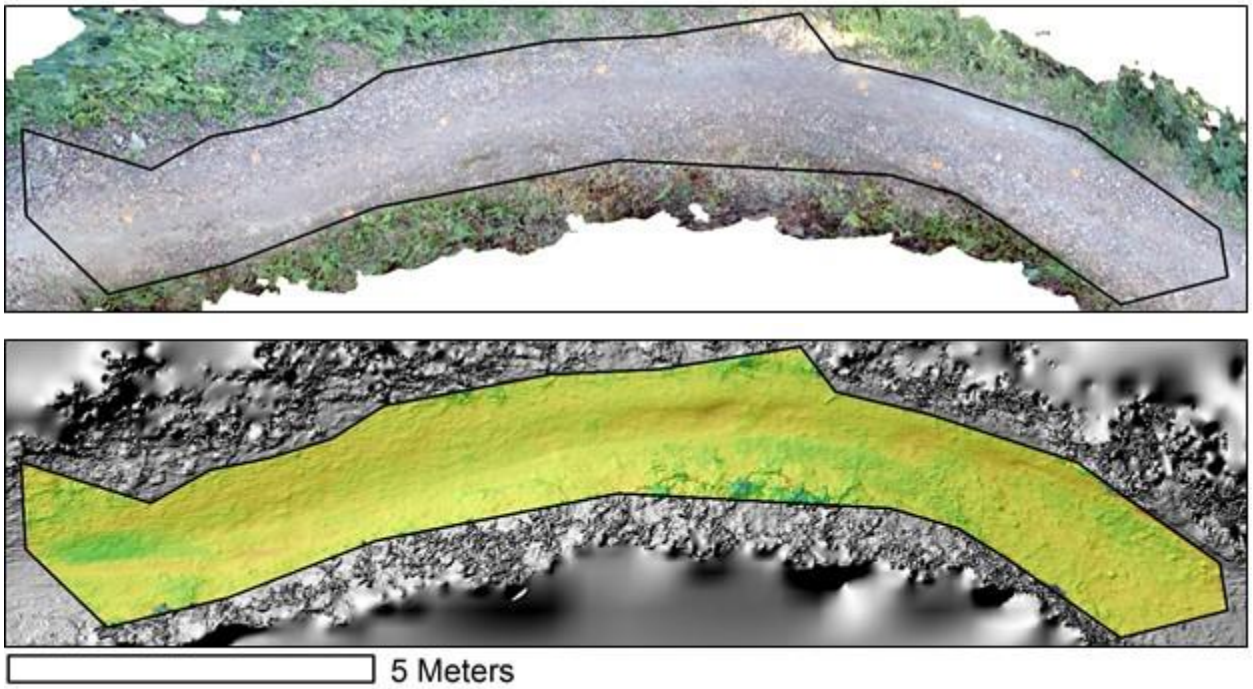
Badger (GAR)



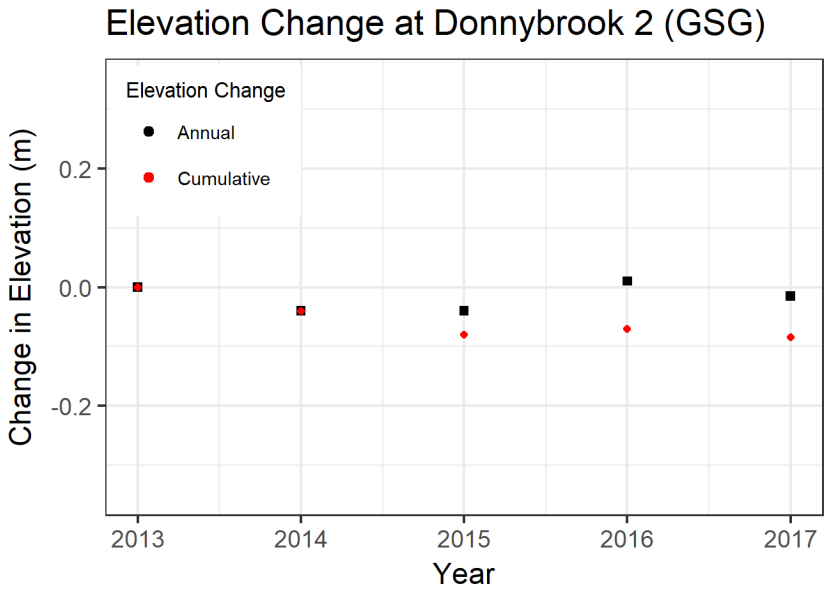
2013-2017 Elelvation Change (m)						Badger (GAR)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.008
-0.254	-0.080	-0.174	-0.064	-0.040	-0.087	
			n=4	n_u=2	n_g=2	



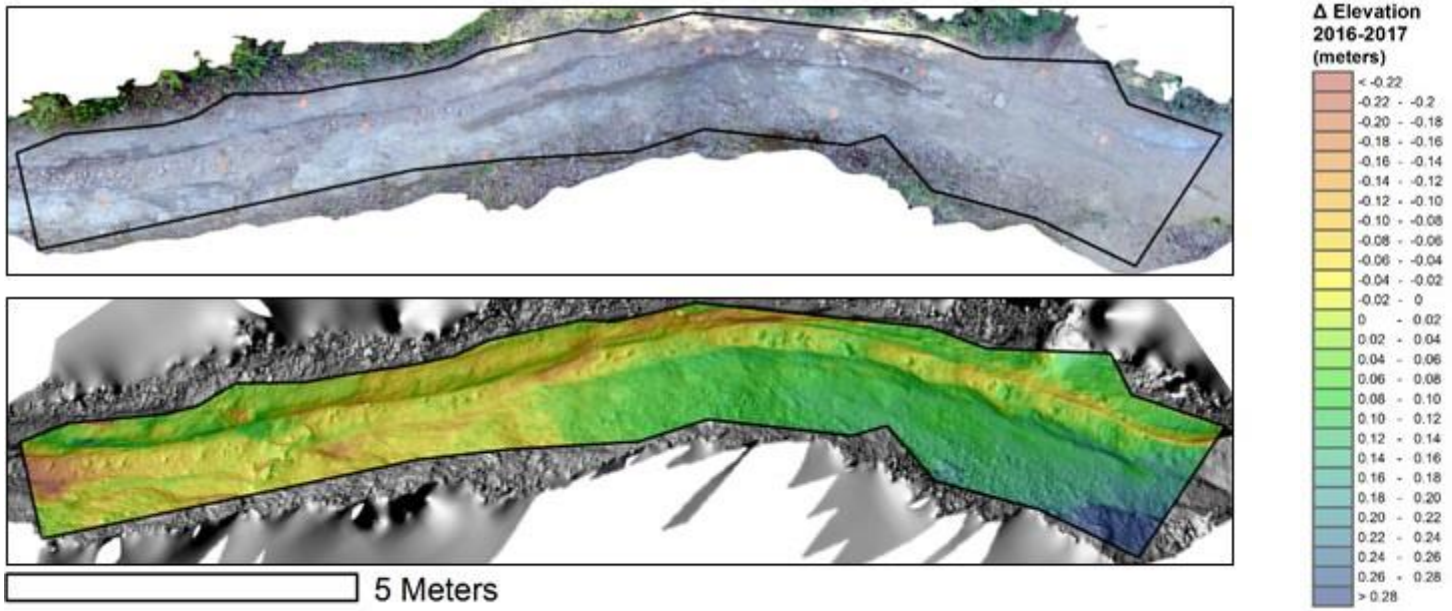
Donnybrook 2 (GSG)



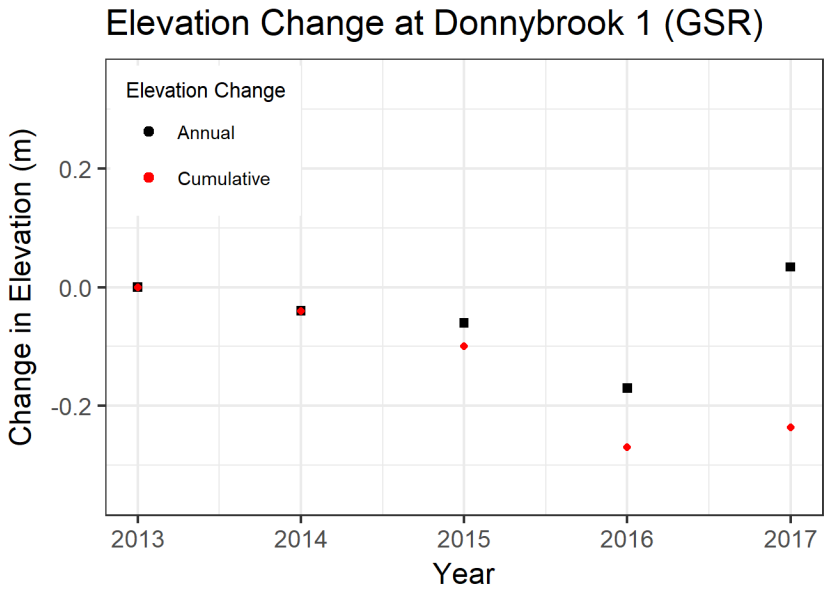
2013-2017 Elelvation Change (m)						Donnybrook 2 (GSG)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.008
-0.085	-0.085	NA	-0.021	-0.021	NA	
			n=4	n_u=4	n_g=0	

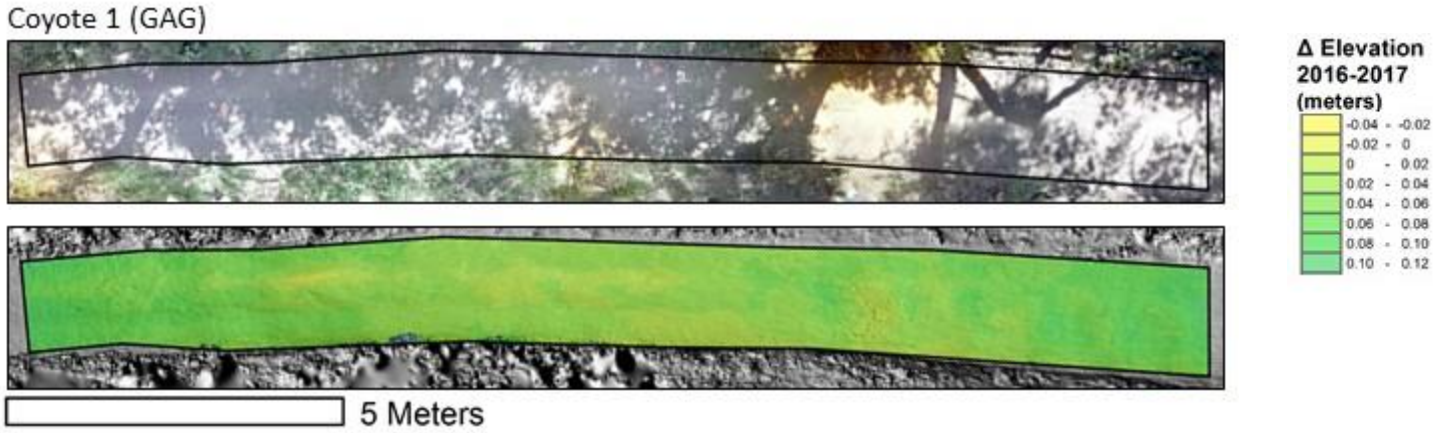


Donnybrook 1 (GSR)

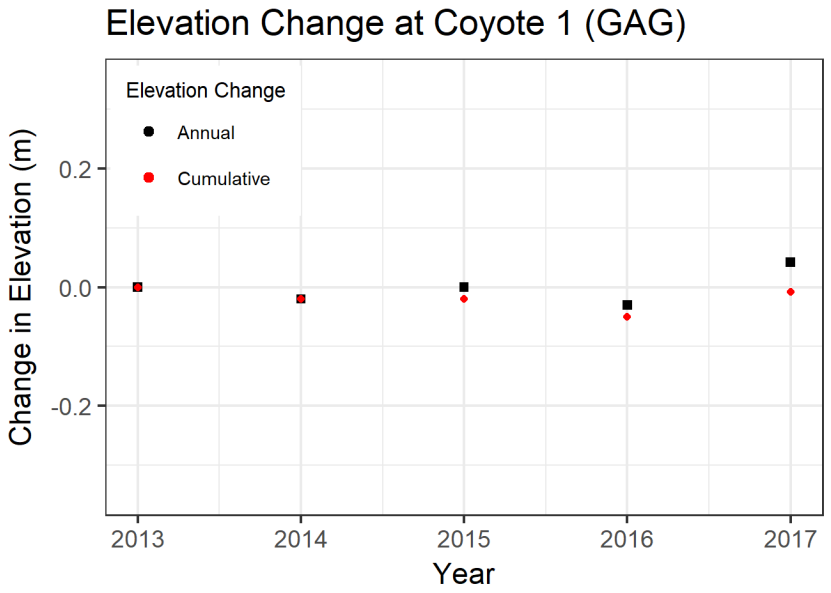


2013-2017 Elelvation Change (m)						Donnybrook 1 (GSR)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.009
-0.236	-0.236	NA	-0.059	-0.059	NA	
			n=4	n_u=4	n_g=0	

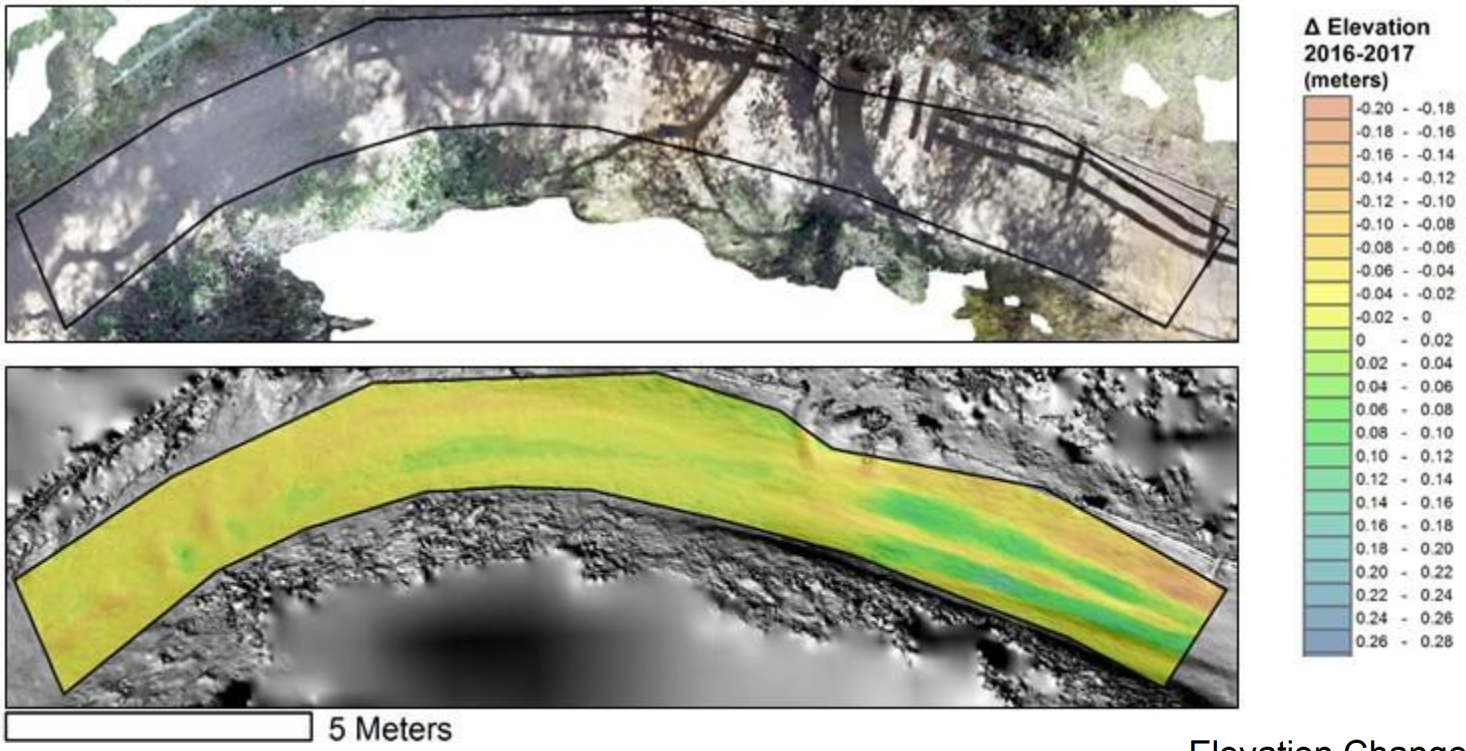




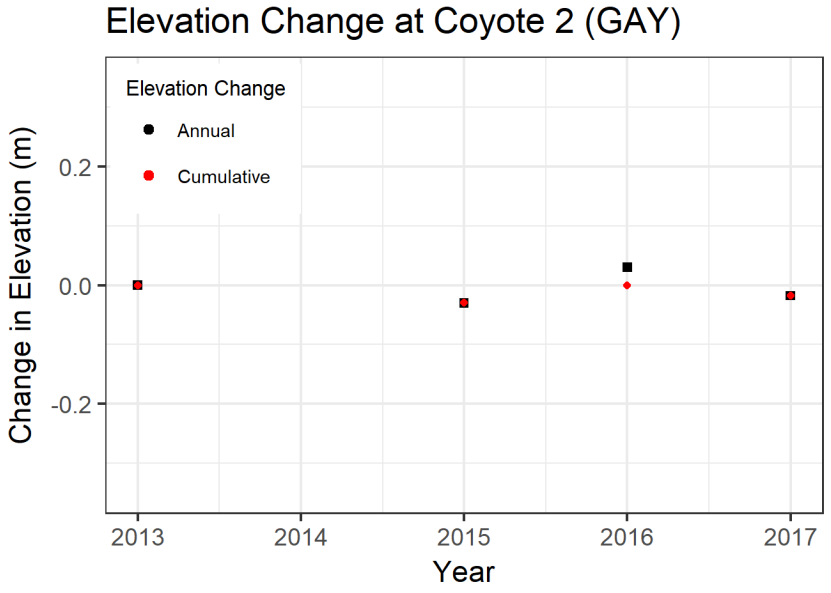
2013-2017 Elelvation Change (m)						Coyote 1 (GAG)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.006
-0.008	-0.050	0.042	-0.002	-0.017	0.042	
			n=4	n_u=3	n_g=1	



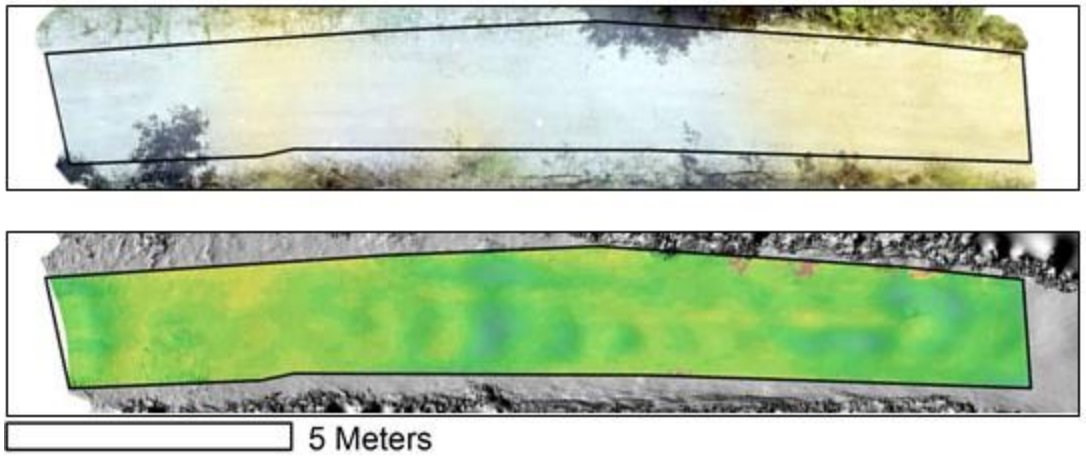
Coyote 2 (GAY)

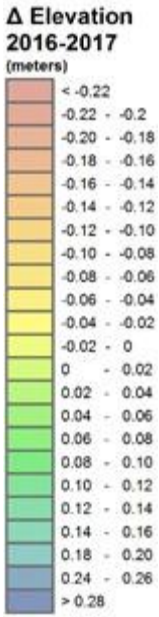


2013-2017 Elelvation Change (m)						Coyote 2 (GAY)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.003
-0.018	0.000	-0.018	-0.006	0.000	-0.018	
			n=3	n_u=2	n_g=1	

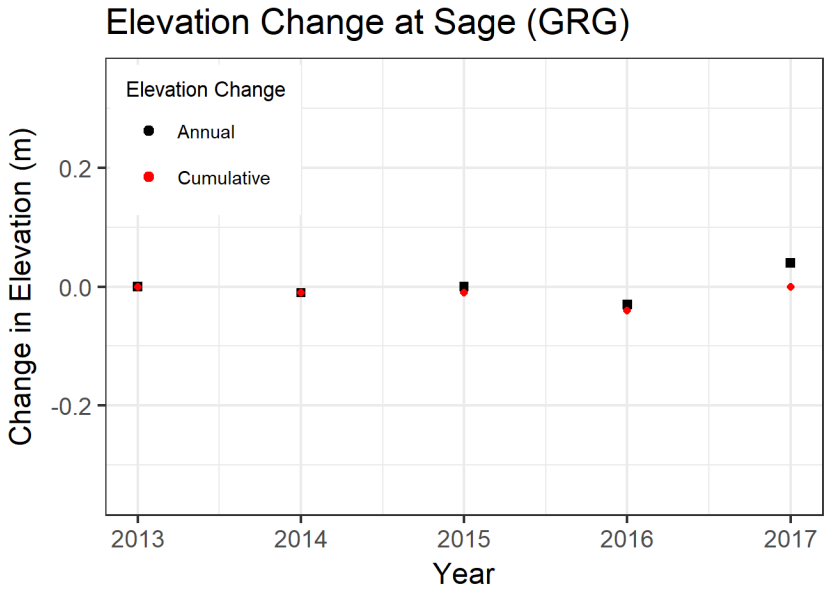


Sage (GRG)

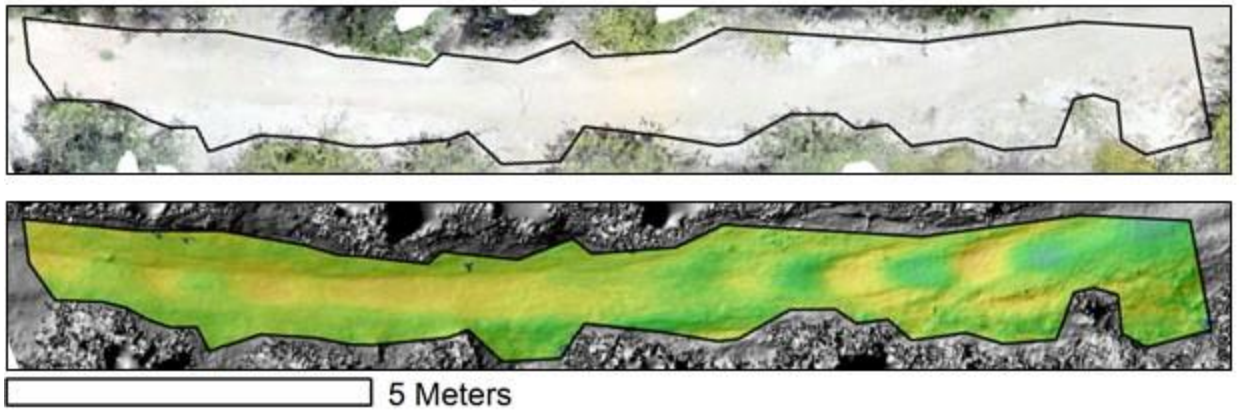


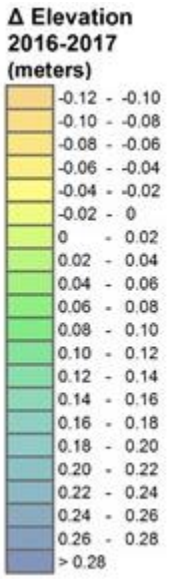


2013-2017 Elelvation Change (m)						Sage (GRG)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.007
0.000	-0.040	0.040	0.000	-0.013	0.040	
			n=4	n_u=3	n_g=1	

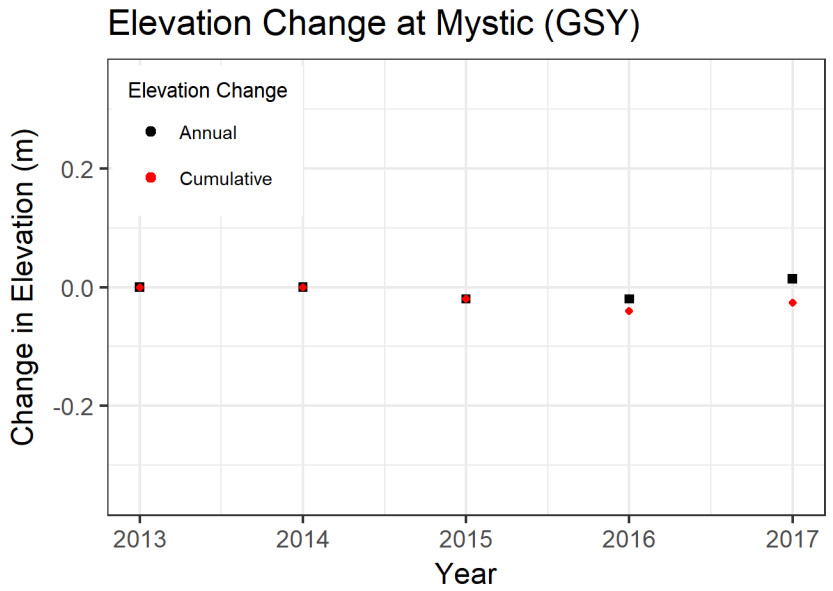


Mystic (GSY)

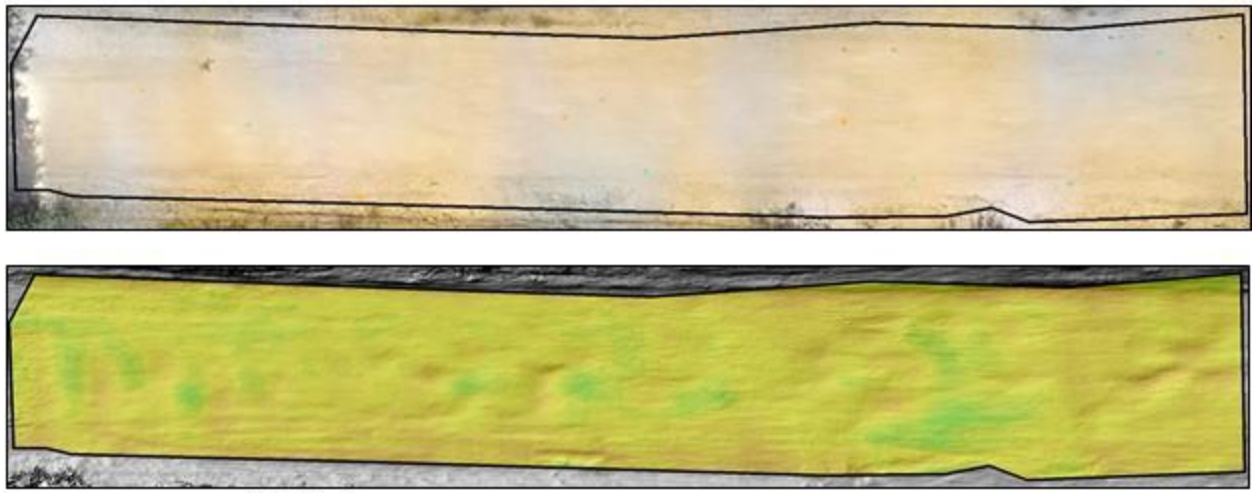




2013-2017 Elelvation Change (m)						Mystic (GSY)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.006
-0.026	-0.026	NA	-0.007	-0.007	NA	
			n=4	n_u=4	n_g=0	



North Canyon (GRY)



2013-2017 Elelvation Change (m)						North Canyon (GRY)
Cumulative			Annual Average			2017 GCP Z Error (m)
all years	non-graded	graded	all years	non-graded	graded	0.005
0.035	0.000	0.035	0.009	0.000	0.035	
			n=4	n_u=3	n_g=1