Central Coast Watershed Studies

CCoWS

Introduction to Geomorphic Monitoring on Fort Ord BLM Lands: 2001 to 2004

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Preface

Students under the mentorship of Dr. Douglas Smith (Division of Science and Environmental Policy, CSU-Monterey Bay) performed landscape monitoring of gullies, landslides, and other erosional features between 2001 and 2004 on the Fort Ord BLM lands. Some of these studies were completed as class projects for ESSP Geomorphic Systems (ESSP 360) and River Hydrology, Assessment, and Monitoring (ESSP 460). This report provides an introduction to the methods used and examples of early results. The monitoring program will continue to reap future results as the landscape is periodically resurveyed and additional sites and new technology are gradually added.

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These surveys and monitoring efforts have included both funded and unfunded components. Grants from the Fort Ord BLM office and the CSUMB Foundation provided funds to support students and staff and purchase survey equipment. Grants from the BLM included the “watershed and riparian assessment” (Smith et al., 2002a) and the “road and trail resource inventory” (Smith et al., 2002b). The Division of Science and Environmental Policy at CSUMB provided survey gear and supplies to support student learning in the field. We thank the following individuals and agencies for their respective assistance.

- Bob Curry (CSUMB Watershed Institute)
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- Brooks G. Leffler (KAP advisor)
- Amy Thistle (Field assistant)
- Anthony Guerrero (Field assistant)
- Morgan Wilkinson (Field assistant)
- Chad Schmidt (Field assistant)

Table of Contents

1 Executive Summary

Federal Bureau of Land Management (BLM) lands that are part of the re-use of former Fort Ord military base are, in general, very sensitive to erosion from a combination of naturally weak substrate, episodic extreme winter rainfall, and human landscape modification. A multiyear survey program has installed over 150 benchmarks (capped rebar) to monitor changes in the landscape between 2001 and 2004. The survey sites include over 50 cross sections. The monitoring program will continue into the future and will expand in terms of both the number and kinds of monitoring sites and the monitoring technology.

Our monitoring efforts have exposed CSUMB students to the following kinds of monitoring technology: GPS receivers and software, GIS development and interpretation, ground-based photography, high-resolution fixed-wing digital aerial photography, kite-borne aerial photography, dirigible-borne aerial photography, auto-level, rotating laser level, and electronic total station.

Our ongoing studies of landscape change serve five functions.

1. Training CSUMB students to be careful and precise observers of natural and managed environmental systems.
2. Giving CSUMB students experience using modern technology to solve real-world problems.
3. Exploiting existing technology and exploring innovative new technology to derive precise measures of physical and ecological environmental change.
4. Providing data to BLM land managers who must optimize their terrestrial restoration and infrastructure maintenance efforts.
5. Increasing our understanding of the rates of terrestrial environmental change in various geologic and ecological settings of the Monterey Bay area.

The following conclusions can be drawn from our work to date, in no particular order.

1) Gully systems are annually widening and extending through headward erosion.
2) El Nino storms are associated with catastrophic erosion events and large landslides.
3) Subterranean piping is a poorly-understood and under-appreciated mechanism for gully evolution and gully head extension in some geologic settings.
4) Despite normal winter rains and a minor earthquakes, a large landslide has remained relatively stable during 3 years of monitoring.
5) Abandoned jeep roads sometimes undergo a complex spatial distribution of erosion and filling.
6) Two earthen dams are in danger of breaching by gullies.
7) Reproducible land surveys can be achieved by trained students who are motivated to produce excellent, reproducible results. Surveys performed during typical class fieldtrips are commonly useless for precise monitoring purposes, but are invaluable in motivating a certain fraction of the students toward excellence and further field studies.

8) Kite aerial photography can produce very high resolution views of geomorphic features. Orthorectified kite-borne photos can be used for extremely precise monitoring of gullies and other features.

2 Introduction

BLM acquired 7200 acres of former Fort Ord land in 1996 to manage as a natural resource management area (NRMA). The BLM mission is set forth in a Habitat Management Plan (USACE, 1997). The plan requires the BLM to "promote preservation, enhancement, and restoration of habitat and populations of HMP species while allowing development on selected properties that promotes economic recovery after closure of Fort Ord" (USACE, 1997). The terrestrial legacy now managed by the BLM includes a rich and complex ecosystem, a network of abandoned eroding Army jeep trails and foot paths, locally gullied erodible geologic substrate, an evolving web of managed and accidental trails and roads, and a Mediterranean climate, which may foster extreme erosion on disturbed landscapes during sporadic El Nino events (Smith et al., 2002a, and 2002b). There are approximately 50 km of used and abandoned roads and approximately 150 km of managed and unauthorized trails (Smith et al., 2002b).

The natural resources and liabilities of the NRMA have been well documented. The NRMA includes 12 distinct habitat types, with maritime chaparral (64%) annual grassland (17%), and various types of oak woodland (13.3%), dominating the region (Smith et al., 2002a). There is a clear link between geologic substrate and the superposed vegetative habitat type, with maritime chaparral and oak woodlands favoring well-drained soils above relict sand dunes, and grasslands occupying poorer-drained soils and colluvium derived from older Paso Robles Formation. Throughout the NRMA, independent of habitat or substrate, wherever steep slopes have been historically devegetated, or reservoirs have been dug in the valley bottoms, the landscape has eroded into gullies ranging in size from minor ruts to enormous chasms (Smith et al., 2002a).

Smith et al. (2002a) identified over 100 sites with significant erosion problems. Most of the restoration efforts to date have employed a combination of landscape modification to slow erosive overland flow, and native revegetation that both anchors erodible soils and adds habitat value to the NRMA. Smith et al. (2002a) provided a philosophical framework for improving conditions on disturbed parts of the NRMA:

"Restoration should recreate, upon a disturbed landscape, the physical and biological characteristics and processes that produce equilibrium landforms bearing the highest quality habitat, given the constraints of the region. The physical models for specific restoration sites comprise suitable reference sites selected from natural, functioning, undisturbed parts of the nearby landscape. The resulting project should be indistinguishable from the surrounding terrain, given enough time to evolve toward the local climax ecology and equilibrium geomorphology."

That directive applies to proactive restoration of the landscape, which sometimes requires heavy equipment to recontour eroded slopes and labor-intensive native landscaping. An alternative to proactive restoration is "passive" restoration where we let the combination of natural erosive forces and natural plant dispersal processes act over a multi-year period to reduce slopes and revegetate the land. The decision to use passive or proactive restoration should be based upon at least three variables:

1) Is the eroding region too large, complex, or remote to restore using proactive measures?
2) How much environmental harm (on and off BLM property) will be done if erosion is left unchecked?
3) How long will natural processes take to restore equilibrium landscapes and climax habitat?

Answering the first question requires a value judgment based upon a knowledge of BLM resources. The second two, however, can be answered or addressed through a program of landscape monitoring. For example, using a variety of landscape monitoring tools, we can begin to determine whether or not a small gully will tend to grow into a broader network of erosion, eventually leading to highly degraded badlands topography. Likewise, we can eventually determine the time required to naturally regain equilibrium landforms and climax vegetative habitat. Further, we can determine what conditions are required to generate small and massive landslides, and we can tell if landslides are active or dormant.

BLM land managers can use our monitoring data in three ways. First, our data can point to problem areas that are within the available proactive restoration resources of the BLM. Second, given enough monitoring of select erosion sites, we can help the BLM assess the likely outcome of waiting for passive restoration to occur on other sites. Third, monitoring of restored sites can provide feedback on the relative efficacy of restoration techniques. A land management program that employs both passive and proactive restoration strategies on appropriate sites and that monitors restoration sites for success and failure will be able to achieve wider success within the context of finite restoration resources. The success rate of restoration activities should gradually increase as adaptive management is employed, fueled by feedback from restoration monitoring.

This report:

- Describes our monitoring technology
- Presents the general locations of our monitoring efforts, and how the sites are distributed among different geologic substrate and ecology
- Presents specific locations of most of our benchmarks
- Provides a description of the precision we are achieving, and
- Offers examples of some of our early monitoring results

We view this report as an introduction to the program and an early progress report. Although the monitoring program has produced some usable findings, we anticipate requiring many more years of monitoring data to develop answers regarding the time required to passively reach landscape equilibrium and habitat climax.

3 Methods

3.1 Site Selection

Using the erosion study in Smith et al. (2002a) as a guide, a range of landscape disturbances were selected for monitoring. We selected a subset of the many erosion sites based upon scientific interest, benefits for land management, and relatively easy access, and student interest (Table 1). The sites include undisturbed valleys, gullies, landslides, eroding abandoned jeep trails and restoration sites. The sites are chiefly in maritime chaparral and annual grasslands habitat types (Figure 2), in part because those are the most abundant habitats within the NRMA. Most sites are in Paso Robles Formation and poorly-lithified sand dune deposits (Figure 3). Appendix A provides the benchmark coordinates of most of our current monitoring sites (Table 4).

3.2 Benchmarks

We have benchmarked over 50 cross sections (two benchmarks each) and have set approximately 30 other benchmarks various other purposes, including landslide monitoring and longitudinal profile surveys. Our benchmarks consist of approximately 2 feet of steel rebar hammered vertically into the ground. We cap the top of the rebar with an orange, plastic and steel, square "Suprotek" benchmark cap. We started out using the small circular trademark symbol on the cap as the survey mark, but have discovered that the cap sometimes rotates, resulting in a survey mark that might have moved one or two centimeters between surveys. We have corrected most of those surveys, and now we use either the top of the rebar with the cap removed, or a punch mark in the center of the cap. If a cap is missing, we survey the top of the rebar with no corrections. The elevation difference between the top of the cap and the top of the rebar is within the error of our instruments.

After several months or years, the benchmarks commonly become obscured by tall grass, thick thatch, or sediment. We have been able to relocate most of our benchmarks during repeat surveys using a combination of autonomous handheld GPS to get within a few meters, and a metal detector to find the cap and rebar. In the case of total station surveys, we can use previous coordinates to pinpoint the benchmarks with the prism pole.

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Table 1: Monitoring sites as of July 2004. See Figure 1for locations, Figure 2 for habitat, and Figure 3 for geology.

Site	[1]WRAR	Name	Description	Habitat	Geology
1	29	"Owl" landslide	Large rotational landslide	Annual grassland/ Valley needlegrass	Paso Robles
2	33	Skyline gully	Enormous gully and landslide system	Annual grassland	Paso Robles
3	89	Eucalyptus gully	Deep gorge leading up to road	Annual grassland	Alluvium/ Landslide/ Paso Robles
4	na	Eucalyptus reservoir	Earthen dam with gully posing a threat	Annual grassland	Alluvium/ Landslide/ Paso Robles
5	92	Guidotti	Ungullied valley	Annual grassland	Alluvium/Paso Robles
6	44	Pilarcitos gully	Large gully in valley bottom	Annual grassland	Alluvium/Colluvium
7	na	Mid-Pilarcitos	Deeply incised creek	Oak woodland	Paso Robles
8	na	Lower Pilarcitos	Deeply-incised creek	Oak woodland	Paso Robles
9	14	Jack's Road Gully	Small gully system in valley bottom	Oak woodland	Paso Robles
10	28	Healing gully	Gully showing evidence of healing	Annual Grassland	Paso Robles
11	2	Mudhen gully	Large gully system with over 40 checkdams	Maritime chaparral	Aromas Sands
12	3	Mudhen tributary	Small gully connected to mudhen gully	Maritime chaparral	Aromas Sands
13	67	The chasm		Maritime chaparral/ Oak woodland	Aromas Sands
14	63	Parker Flats roads	Rutted jeep roads in chaparral	Maritime Chaparral	Older dunes
15	na	Trail 67	Restored jeep road	Maritime Chaparral	Older dunes
16	na	Trail 26	Restored Jeep road	Maritime Chaparral	Older dunes

1. WRAR erosion site number from Smith et al. (2002a).

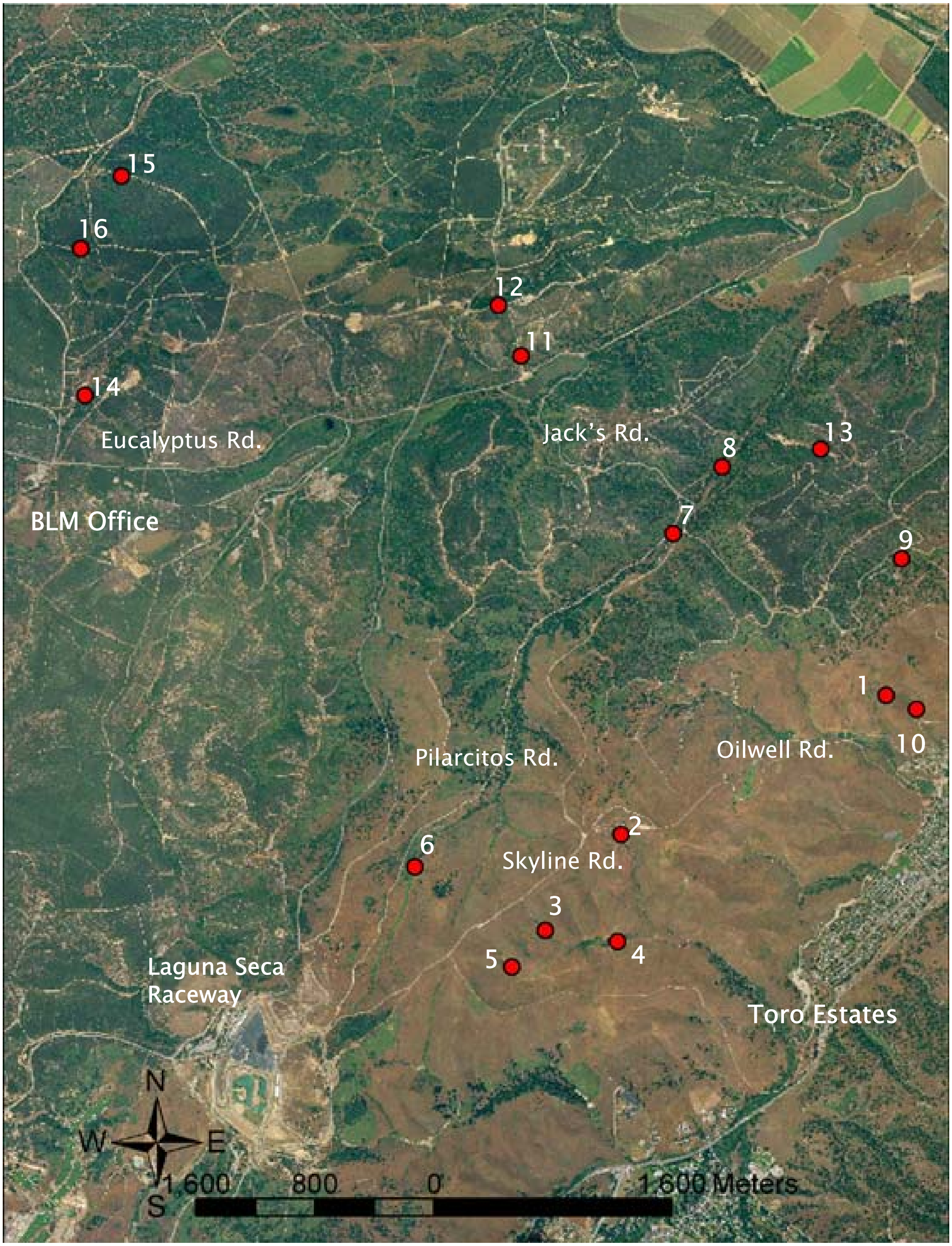


Figure 1: General monitoring site locations on orthorectified digital aerial photograph. See Table 1 for descriptions.

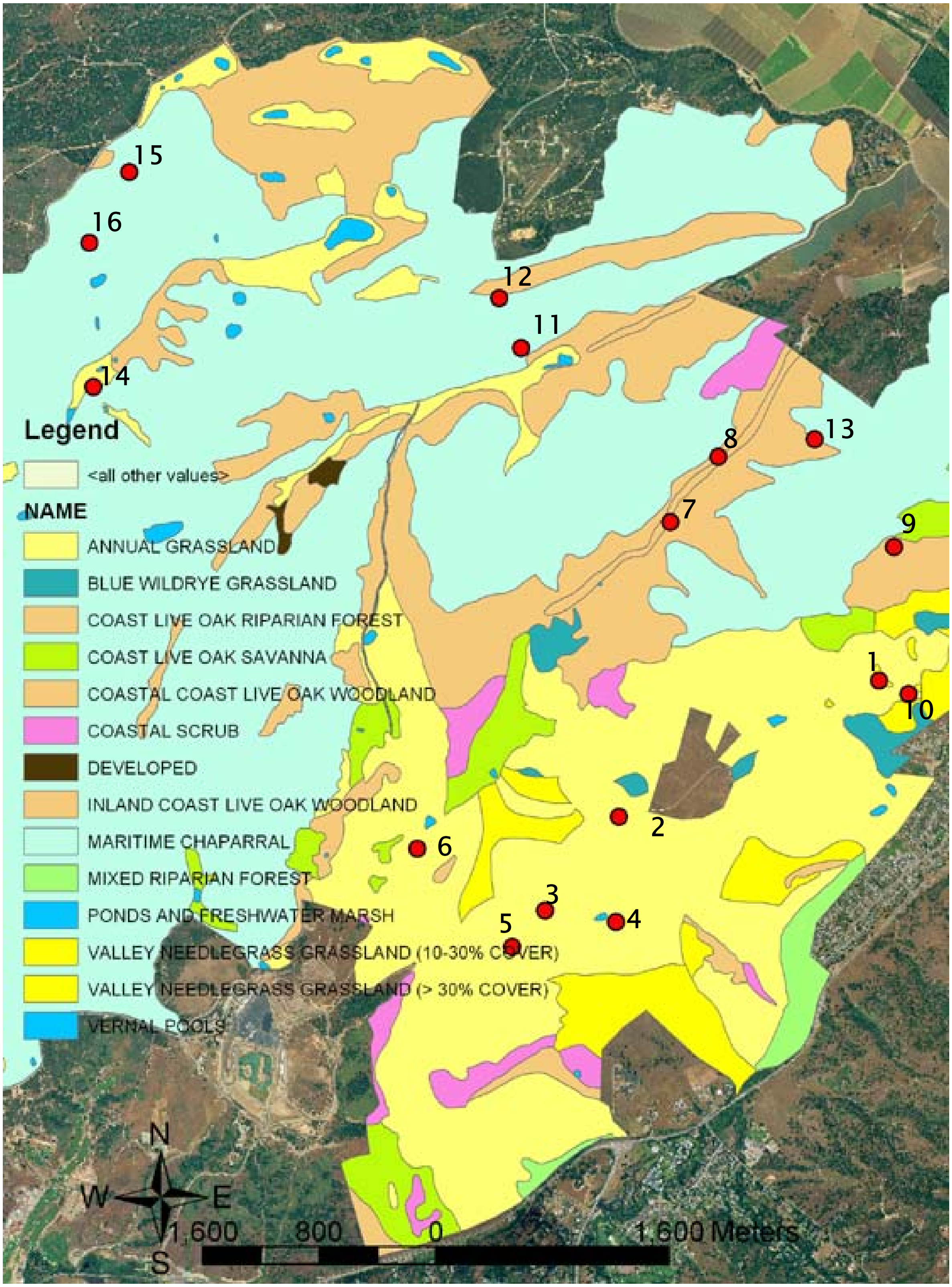


Figure 2: Vegetative habitat types associated with monitoring sites. See Table 1 for descriptions.

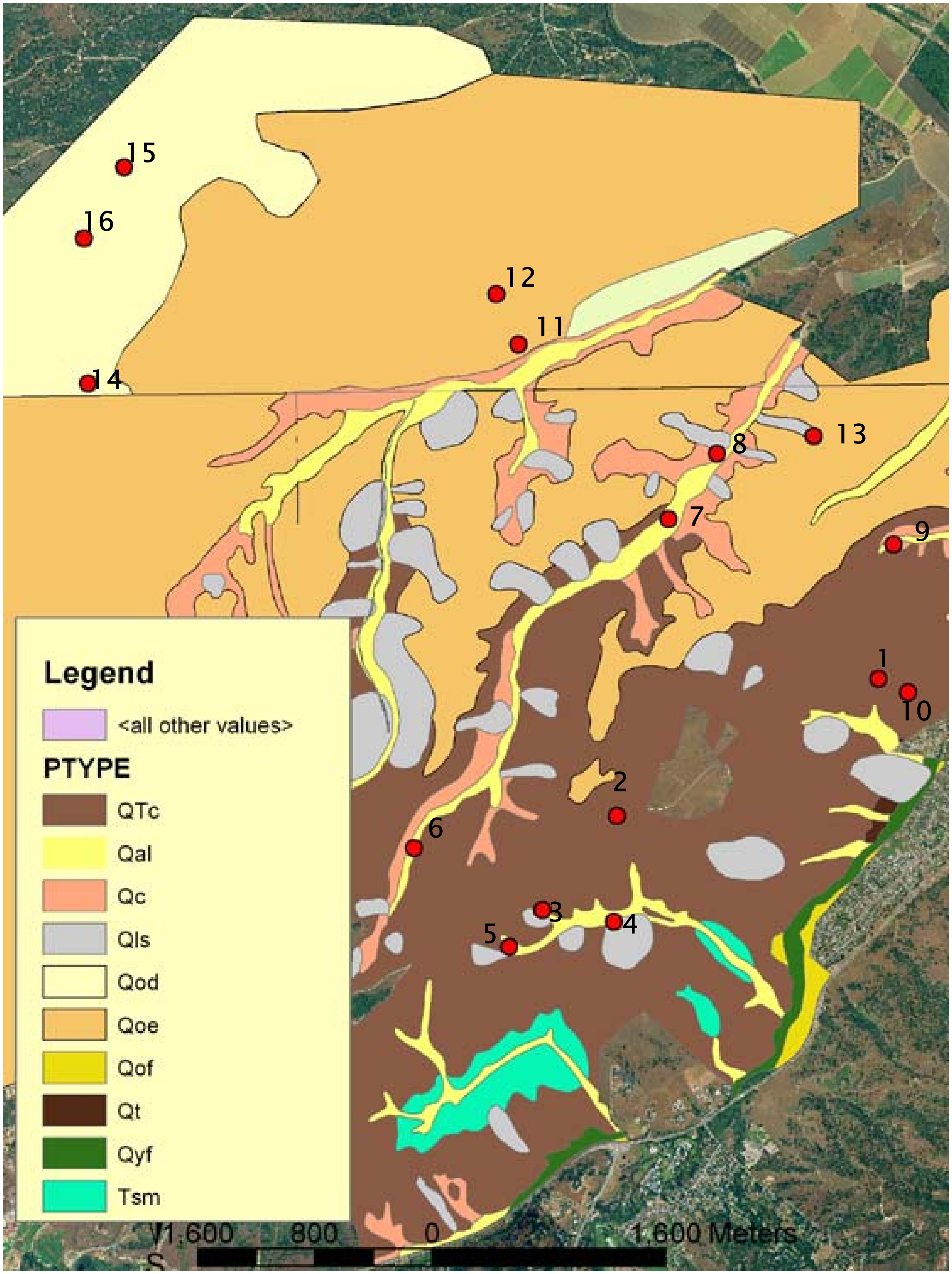


Figure 3: Geology associated with monitoring sites. See Table 1 for descriptions.

3.3 Monitoring Techniques

Landscape monitoring, including precise surveys, qualitative photographic analyses, and field descriptions, provides data to fuel ideas about the nature of landscape evolution. Monitoring is an essential part of the observational field science of geomorphology. The objective of monitoring is to obtain accurate and precise estimates of the style , magnitudes, and rates of local landform change.

On each site visit, data are collected in designated field books, or on specially-printed data sheets. In the case where one person is observing and another is recording data, the data recorder will repeat the numbers back to the observer as verification. It is common for this technique to eliminate at least one error during a survey, especially when walkie-talkies are used for communication. If leveling surveys are performed, the survey is closed at the end of the survey and a within-survey precision is calculated. At the office, the data are typed into a spreadsheet and plots of the survey are created. If the survey is a repeat visit to a site, the new data are plotted with the older data to visually assess landscape change. Differences in elevations of benchmarks are then compared in order to quantify the between-survey precision.

Reproducibility of scientific data is the currency of sound field science. Ultimately, we strive for reproducibility in all aspects of our work. We view our records as the beginning of a long-term study, a study that may outlive our careers. We understand the value of decades long (or longer) monitoring in terms of understanding slow earth processes and landscapes and the human interactions that lead to their degradation and restoration. Lucky field researchers that stumble upon historic land surveys whose benchmarks are recoverable will find a wealth of environmental understanding in a simple resurvey of those sites. We would like to leave a legacy of reproducible surveys to future researchers.

Table 2 details the monitoring techniques we have applied to each site. Specific techniques are detailed in the sections following Table 2.

Table 2: Monitoring techniques applied to each site

Site	Name	Monitoring	Direct observation	Ground photography	Aerial Photography	Kite Photography	Autolevel	Rotating laser	Total station	Bank pins	Scour chains
1	"Owl" landslide		X	X	X	X			X		
2	Skyline gully		X	X	X	X			X		
3	Eucalyptus gully		X	X	X						
4	Eucalyptus reservoir		X	X							
5	Guidotti		X	X							
6	Pilarcitos gully		X	X		X	X	X			
7	Mid-Pilarcitos		X	X				X			
8	Lower Pilarcitos		X	X				X			
9	Jack's Road Gully		X	X				X			
10	Healing gully		X	X				X	X		
11	Mudhen gully		X	X	X		X	X		X	
12	Mudhen tributary		X	X				X			
13	The chasm		X	X				X	X	X	X
14	Parker Flats roads		X	X				X			
15	Trail 67		X	X				X			
16	Trail 26		X	X				X			

3.3.1 Un-aided direct observation

Each time we visit a monitoring site we visually note whether the site shows evidence of recent new erosion or deposition, or has evidence of dormancy and stability. This process helps us determine whether we need to modify our more specific monitoring methods at a site, and adds a "common-sense" check on the precise measurements we obtain there. Considering how memories fade with time, this very traditional method of field observation must be augmented with very clear note taking and field sketches to be useful as a long-term aid to monitoring.

3.3.2 Ground-based photography

A hand-held digital still camera is perhaps the most cost-effective way to sustain crude long-term monitoring. The photos can range from broad vistas that place the monitoring site in context, or close-up details that illustrate very specific erosion processes. The benefit of photos will be enhanced if they are cataloged by site and date and if there are recognizable landmarks that offer a reference point for scale and orientation. We have documented dozens of erosion sites with informal hand-held photographs. Sites that have been monitored solely by ground-based photography do not appear as a separate site in Table 1. Quantitative comparisons of landforms through time can be obtained through methods outlined in Hall (2001), where the camera is always

1) relocated on the same point (perhaps atop a stake driven into the ground),
2) aimed in the same direction
3) aimed to include a permanent scale, such as a meter stick in the view,
4) set at the same focal length, and
5) used with the same lighting conditions

We have not used the methods of Hall (2001) at this time.

3.3.3 Fixed-wing oblique aerial photography

Reconnaissance flights from a small maneuverable aircraft are invaluable for locating significant erosion sites and for developing an appreciation of regional context for specific erosion sites. Some sites have causes that are not immediately obvious from the ground, and some erosion sites may pose hazards to roads and homes located far downstream. A handheld digital camera can capture some of those views for a permanent record and for transect planning purposes (Figure 4).

Figure 4: Oblique aerial photograph of Skyline Gully from a fixed-wing aircraft (2004). Eastward view.

3.3.4 Fixed-wing aerial photography

The view from above a landscape is an in valuable tool in geomorphic analysis. An industry standard for many years has been photography taken from standard aircraft flying a rectangular pattern over the ground. Once an aerial photograph is undistorted through orthorectification on a computer, the image can be used in a number of ways, including as a base map for plotting spatial data (Figure 5). Serial aerial images separated by a year or more can be compared to qualitatively describe, or quantitatively measure landscape changes.

In the course of our work on BLM projects we have obtained a 1 m resolution, color, digital aerial photograph that has been orthorectified and georeferenced for use in a GIS context. The aerial photograph covered all of BLM Fort Ord lands in the spring of 2001 (Figure 6). Using that image, we have been able to plot our site locations and compare historic photos in order to date the occurrence of gullies and landslides. Historic photos are available on the internet and through other library sources.

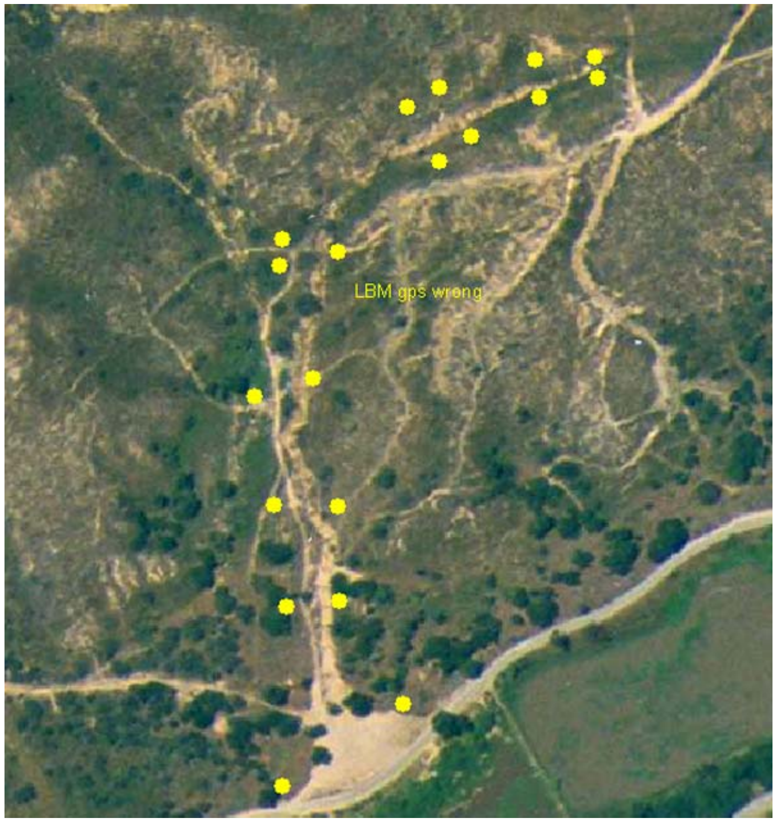


Figure 5: Cross section survey benchmark locations plotted on orthorectified digital aerial photograph of Mudhen Gully (2001). Image is approximately 400 m wide. North toward top.

Figure 6: Othorectified, 1-m resolution, digital aerial photograph of Pilarcitos (2001) Gully. North toward top. Box is approximately 60 m wide. Box shows position of Figure 12.

3.3.5 Dirgible (blimp) aerial photography

Small, radio-controlled, lighter-than-air craft can carry a small payload that includes a camera. Low altitude photography results in very clear images with extraordinary resolution, far exceeding that obtainable from a fixed-wing aircraft. In the first months of 1995, early staff of the then nascent CSUMB Watershed Institute hired a consultant to take a dirigible-borne aerial photography at a number of their concurrent restoration sites. We have access to several of these images (Figure 7) for comparison with our more recent photographs.

Figure 7: Blimp-borne aerial photograph of Skyline Gully (ca. January1995). Compare with Figure 1 for detail. Note cars for scale. Westward view.

3.3.6 Kite aerial photography

Strong winds acting on a large kite can generate enough lift to suspend a light camera and cameral platform from the kite string (Figure 8). The resulting photographs have the same high-resolution quality as the blimp-borne photos, but do not usually have as high of a vista or as much spatial freedom.

We have a 30 square foot soft Sutton Flowform kite, custom camera platform (Figure 9; Brooks Leffler, http://homepage.mac.com/kyteman/), radio control gear, 150 m of strong line, and a wireless digital camera (Figure 10). The radio control gear is used to aim the camera once the camera platform is aloft. We are still learning the best techniques for aiming the camera, and anticipate rapidly improving our success.

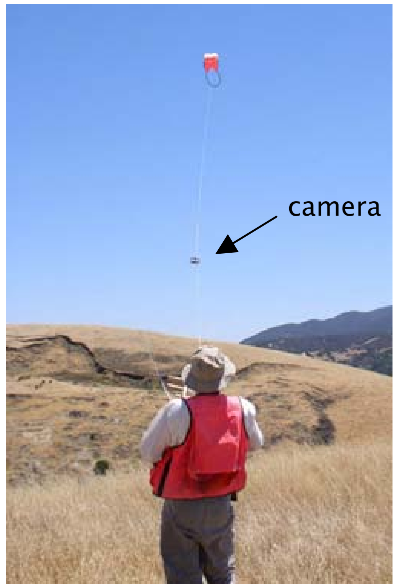


Figure 8: 30 ft^2 area Sutton Flowform kite with camera rig attached. Note antenna from radio controller for camera platform. The head and wing of the "Owl" landslide are visible in background.

Figure 9: Camera rig is suspended from kite line by a picovet suspension system that utilizes tiny pulleys and line to keep the camera platform level at a wide range of kite-string angles.

The use of kite aerial photography (KAP) is growing as a tool for illustrating architecture and landscapes. A few research groups are using it for geology and environmental monitoring (e.g., http://activetectonics.la.asu.edu/kites/index.html). Two innovative improvements we are developing for KAP are:

1) orthorectifying and georeferencing vertical images for high resolution monitoring, and
2) incorporating wireless technology to improve success rate. Although we have not achieved the level of success we hope to, in the near future we will have the camera beam a live image to a laptop or tablet computer as a web cam. Then we can aim the camera more precisely and can trigger the camera when we have the optimum view in the viewfinder.

Figure 10: Detail of wireless camera mounted in camera platform. The yellow wand supports the antenna wire. Picovet rig is wound around the top bracket.

At present, we are aiming the camera using radio-control gear while we see the orientation of the camera from the ground (Figure 11). We have the camera set to automatically take a photo every 30 seconds. We also have the technology to raise the camera platform on large helium-filled balloons on very calm days.

Figure 11: On days with marginally enough wind, the kite operator is busy avoiding camera damage while an assistant operates the radio controlled camera.

Digital, fixed-wing aerial photography with a resolution of one meter (e.g., Figure 6) is readily available on the internet, and is considered standard for analyzing landscapes. KAP photos offer a much higher resolution image over a smaller area (e.g., Figure 12).

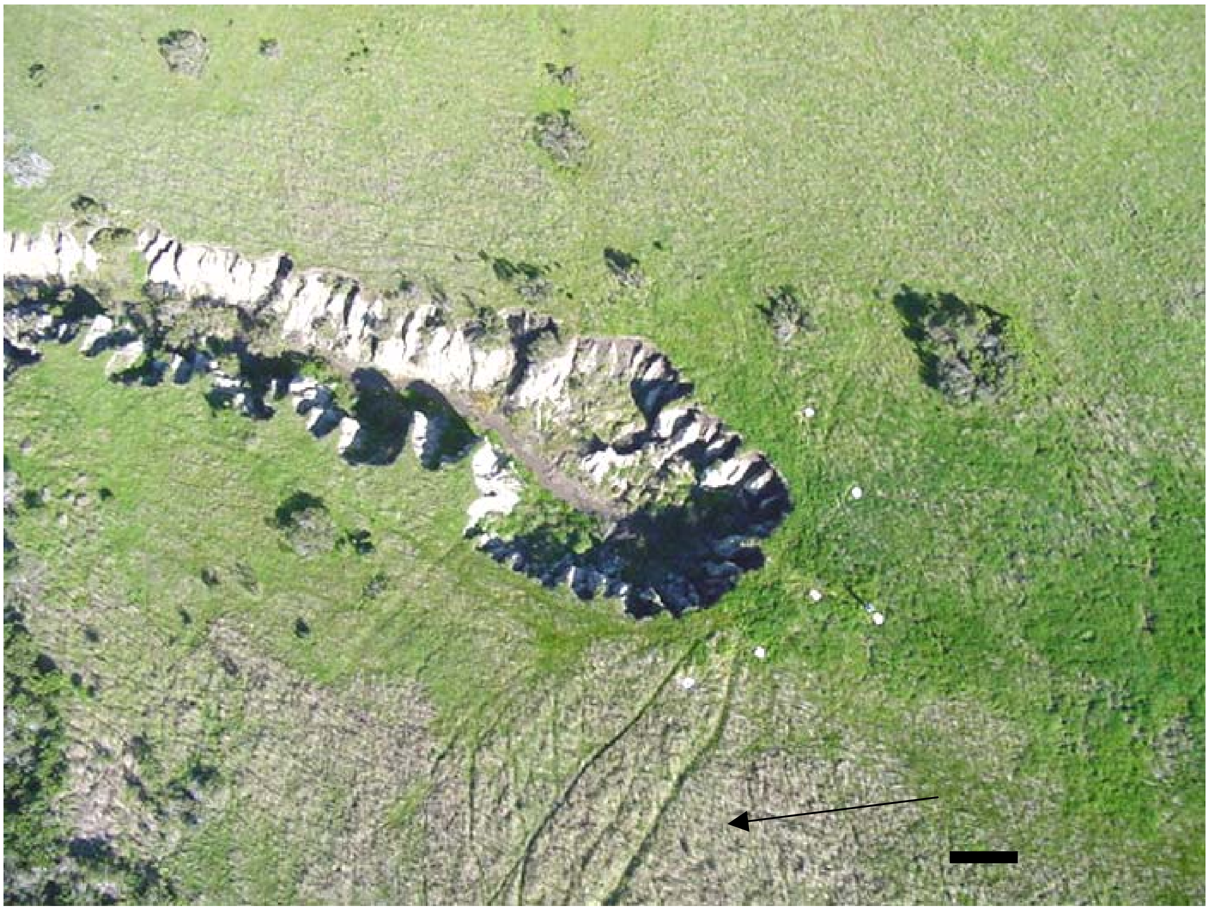


Figure 12: Kite-borne aerial photography with white markers laid out to test accuracy and precision (Hall, 2003). Arrow is approximately north. Bar is 5 m long. Compare with boxed region of Figure 6 showing same feature in a 1-m resolution aerial photograph.

3.3.7 Autolevel and rod survey

Autolevel-and-leveling-rod is a standard survey technology that we rarely use for longitudinal profiles or cross sections. These surveys are performed between benchmarks so that

1) each successive survey utilizes points from the same distance along the tape (plus any new significant breaks in slope), and
2) vertical precision can be determined.

We use the level in combination with a tightly-drawn 50-m or 100-m tape. The level provides high-precision elevations, while the tape is used for precise distance measurements. The tape is pulled between to benchmarks and the rod is placed at the same places as in previous surveys, plus an new significant breaks in slope. The distances are determined to the nearest centimeter where high precision is required, otherwise we measure to the nearest decimeter. The surveys are closed, and between-survey precision is determined. To determine leveling precision we find the difference in elevation between the right and left benchmarks, and compare that value between successive survey trips. Our between-survey vertical precision determined in this way is typically better than 0.01 m. In other words we are able to tell if the landscape has changed by more than 0.01 m vertically.

3.3.8 Rotating laser level and rod survey

The rotating laser is our workhorse for longitudinal profiles and cross section surveys. We use the rotating level to obtain precise elevations, and we use a tightly-drawn 50-m or 100-m tape to obtain distances along the transect.

These surveys are performed between benchmarks so that

3) each successive survey utilizes points from the same distance along the tape (plus any new significant breaks in slope), and
4) vertical precision can be determined.

We use the level in combination with a tightly-drawn 50-m or 100-m tape. We obtain high-quality elevation data from the rotating laser, and we obtain high quality distances using the meter tape (Figure 13). The tape is pulled between to benchmarks and the rod is placed at the same places as in previous surveys, plus an new significant breaks in slope. The distances are determined to the nearest centimeter where high precision is required, otherwise we measure to the nearest decimeter. The surveys are closed, and both within-survey and between- survey vertical precision is calculated. To determine leveling precision we find the difference in elevation between the right and left benchmarks, and compare that value between successive survey trips. Our between-survey precision determined in this way is typically better than 0.01 m. In other words we are able to tell if the landscape has changed by more than 0.01 m vertically. The successive years of data are superimposed to evaluate landscape change (e.g., Figure 14).

3.3.9 Electronic "total station" survey

The Topcon 210 electronic total station is used to precisely monitor the three-dimensional position of benchmarks, using a laser pulse and a reflective prism. Based upon our experience, the instrument commonly achieves sub-centimeter precision over many hundreds of meters distance, so we are confident in being able to discriminate very small landscape changes using this instrument. It has been most effectively used so far in monitoring a grid of benchmarks set across the “owl” landslide (Table 1).

Figure 13: Rotating laser level with 50-m tape drawn between benchmarks at a Parker Flats survey site.

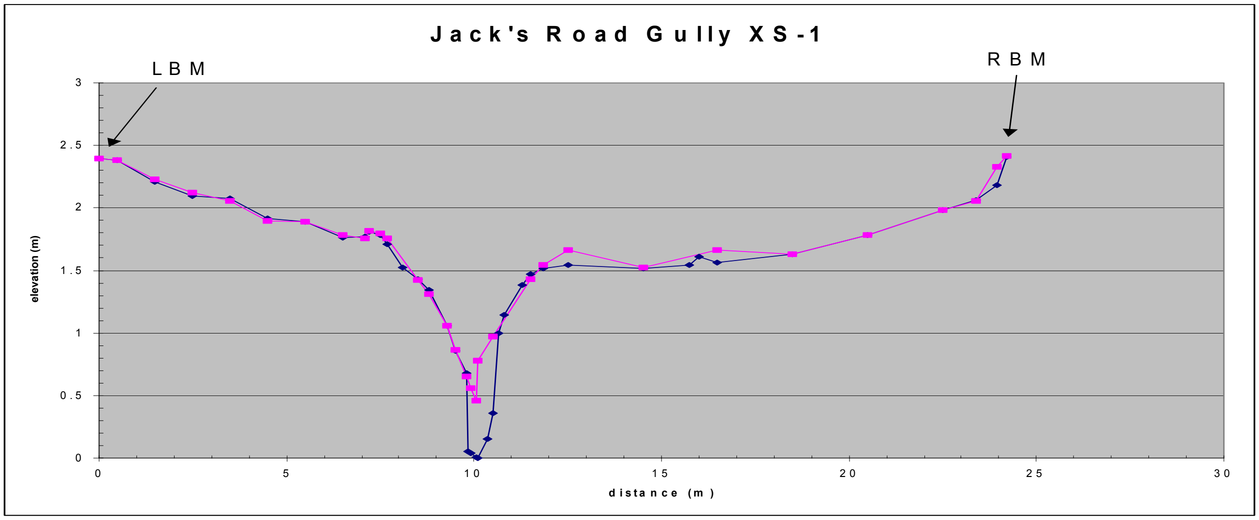


Figure 14: Plot of successive rotating laser cross section of Jack's Road. Note that the benchmarks lie at the same position, indicating high level of reproducibility. The gully cross section has eroded downward 0.5 m between 2002 (pink) and 2004 (blue).

3.3.10 Bank pins

Bank pins are used to measure stream bank erosion rate (Harrelson et al., 1994). Bank pins are pieces of metal rod driven perpendicular into the bank of a gully or stream. The rod is driven flush. If subsequent visits to the site discover a section of rod exposed, the length of exposed rod is recorded. The exposed rod is a record of the magnitude of bank erosion that has occurred since the rod was installed. We drive the rod flush once again following each measurement. If several such measurements are performed, and the dates are recorded, a rate bank erosion can be developed. For our bank pins we use 2 ft or 3 ft sections of rebar. The pins are relocated in the field through GPS, field sketches, location descriptions, and colored survey tape.

3.3.11 Scour Chains

Scour chains are used to measure erosion and deposition in the bottom of a gully or stream (Harrelson et al., 1994). Scour chains are lengths of metal chain driven vertically downward into the alluvium of a gully or stream bottom. The chain is driven down until the last link is flush with the local surface of the gully bottom. During a subsequent flow event where bottom scour occurs, the chain will take on a new geometry. The chain will commonly be shaped like an inverted "L" with the top portion buried. The length of the bent portion of the "L" is a measure of how much scour occurred, and the depth of burial is amount of subsequent deposition during the waning portion of the flow. The scour chains are relocated in the field using GPS, field sketches, location descriptions, colored survey tape, and a metal detector.

4 Results

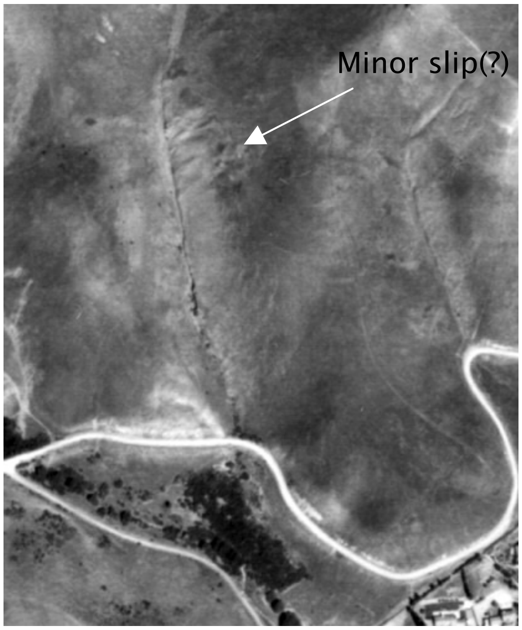
We have established over 50 benchmarked cross sections. Our survey data are contained in fieldbooks, data forms, and in electronic spreadsheets (available from Douglas_Smith@csumb.edu). Although we have not repeated all of our original surveys, we have been able to repeat the majority of them at least once. This section of the report provides a sample of our results. More detailed reporting of survey results will be presented in a subsequent report.

4.1 The Owl Landslide

The Owl landslide (Figure 15) is located in a narrow, "v" shaped valley intersecting Oil Well Rd. (point 1; Figure 1). It is the largest potentially active landslide we have identified in the NRMA. Aerial photographic evidence (Figure 16) shows that the landslide was not present on 9/20/1997, in the months immediately preceding the major storms of the 1997-1998 El Nino event. An image taken on 8/22/98, in the summer following the El Nino rains, clearly shows the geometry of the headwall scarp and "owl" wing. Although the earlier photo shows some hummocky topography typical of colluvial creep, the headwall scarp and wing are absent. This comparison strongly implicates the winter storms, which brought an annual total of 47.19 inches of rain, 230% of the normal.

We have used a total station set at benchmark OC-1 (Table 4) to monitor the relative motions of 36 benchmarks we set in a rectangular grid across the landslide. There are benchmarks set outside the slipped region as well for reference. Three surveys of the benchmarks have been performed November 2002, October 2003, and July 2004. The October 2003 survey suggested an average of 3 cm of slip on the benchmarks toward the southwest (downhill). The 2004 data have not yet been compared to previous surveys. During the time of our survey there have been relatively normal winters and one significant earthquake (Paso Robles December 2003).

Figure 15: Panoramic view of The “Owl” landslide taken with kite aerial photography (See Figure 8). Photo taken July 26, 2004. The image is a composite of two images that were “stitched” together into one image. View is to the west.



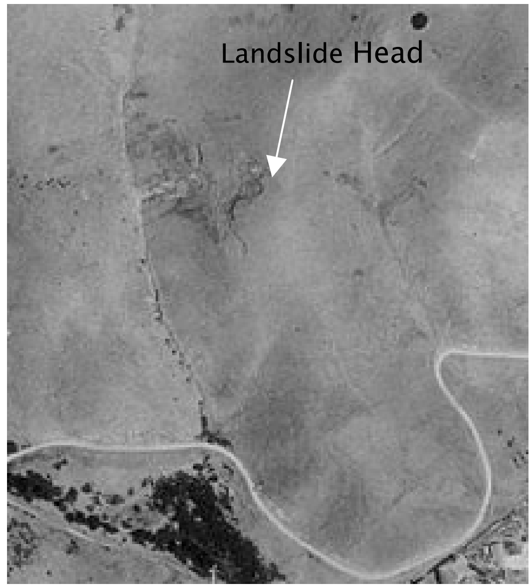


Figure 16: Comparable aerial photographs of the “Owl” landslide. Left image was taken 9/20/1997. Right image was taken 8/22/98. North is to the top in both images.

4.2 Skyline Gully

The Skyline gully system (Figure 4 & Figure 7) is located near the intersection of Oil Well and Skyline Roads (point 2; Figure 1). It is one of the largest gully systems in the NRMA. The gully system was greatly enlarged during the 1997-1998 El Nino winter rains. Large subterranean soil pipes formed in numerous locations, fostering the development and growth of gullies. A large headwall scarp is now present that was not present in early 1995 when blimp-borne photos were taken (Figure 17). This landslide likely developed during the same El Nino winter as the Owl landslide (Figure 15).

Figure 17: Skyline gully. Left photo is a blimp-borne aerial photograph (early 1995). Right Photograph is ground photograph (2004). Note the new large headwall scarp present in the 2004 image. Point A is approximately the same landform in both images. Left photograph is closer view than right photograph. There are many more mature willow trees in the 2004 image. View is to the west in both images.

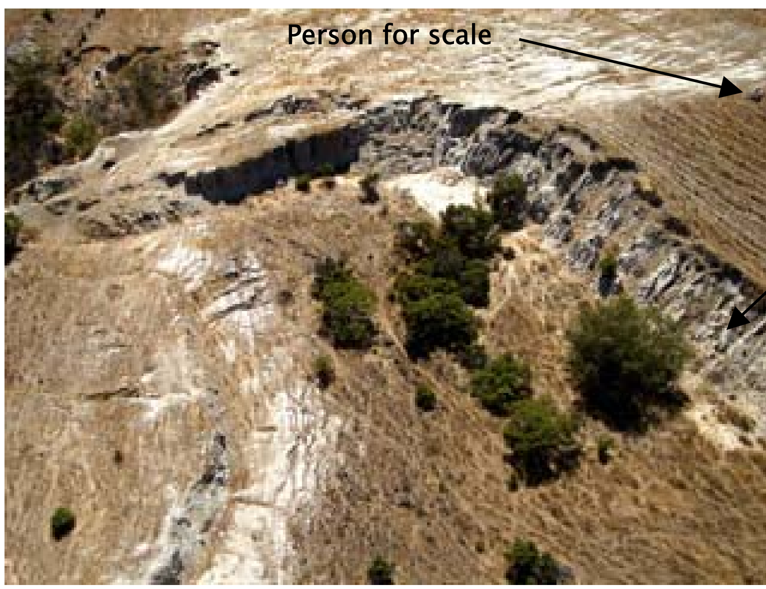


Figure 18: Kite aerial photograph (2004) shows close up of the new headwall scarp shown in Figure 17. Westward view.

4.3 Pilarcitos Gully

Pilarcitos gully (Figure 12) is located up valley from a small reservoir and earthen dam along Pilarcitos Road (point 6; Figure 1). Smith et al. (2002a) suggested that the large gully is the result of water level fluctuation (base-level drop) in a reservoir located at the toe of the gully. We do not know when this gully formed. We have established 15 benchmarked cross sections across the gully system (Table 4) to monitor its gradual changes at many places along its length (e.g., Figure 19). The gully has incised through colluvial and alluvial valley fill (Table 1, Figure 3).

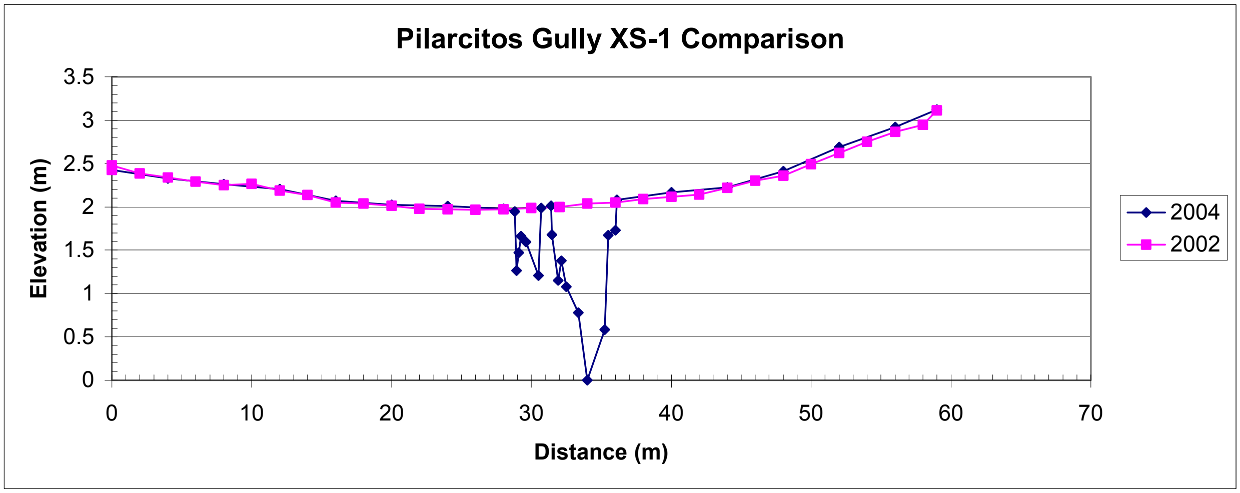


Figure 19: The un-gullied valley bottom of Pilarcitos Canyon present in 2002 was incised in 2004 by the steady headward migration of the large Pilarcitos gully.

Ground-based photography shows the gully head and non-gullied valley bottom up gradient (Figure 20). Figure 21 shows the longitudinal gradient of Pilarcitos gully surveyed in July 2002. The head has migrated approximately 0.5 m up valley since 2002.

A test of georeferenced orthorectified kite-borne aerial photography precision was performed by Elvie Hall (Hall, 2003). A feature on the ground that is 7.93 m long was measured as 7.92 m and 7.98 m respectively in a GIS environment using two independently created kite aerial photographs (Hall, 2003). That level of horizontal precision, 1 cm to 5 cm, is comparable to the horizontal precision of our ground based cross section surveys using a taut 50-m tape.

A subsequent test of kite photography produced the image of Pilarcitos in Figure 12. The six white squares are targets placed 5 m from the gully head (Figure 12). Subsequent GIS measurements of two independently-derived orthorectified images of the gully and targets indicated an average accuracy of between 0.08 m and 0.09 m (e.g., Table 3). Orthorectification was based upon several differentially-corrected GPS points using a GeoExplorer II handheld receiver.

Table 3: Summary of results of kite aerial photography precision (Hall, 2003).

Points	On the ground measurement (headcut to target) (m)	ArcGIS measurement (m)
1	5	4.91
2	5	4.90
3	5	4.40
4	5	5.09
5	5	4.96
6	5	5.23
Average	5	4.915 (Difference =0.085)

Figure 20: Ground-based photograph of Pilarcitos gully (June 2004). View is to southwest, up valley past steep gully head. Gully head scarp is 6.5 m tall (Figure 21).

The Pilarcitos cross sections have been measured on several occasions by both trained student technicians and general class field trips. The results of the class field trip surveys are typically low quality, not accurate enough for monitoring purposes. Trained student technicians have repeatedly demonstrated that they can reproduce surveys with very high precision. The cross sections performed with taut 50-m tape and rotating laser usually close below 1 cm. Between survey precision is commonly below 1 cm as well. This precision is determined by comparing left and right benchmark elevations on successive surveys (e.g., Figure 14).

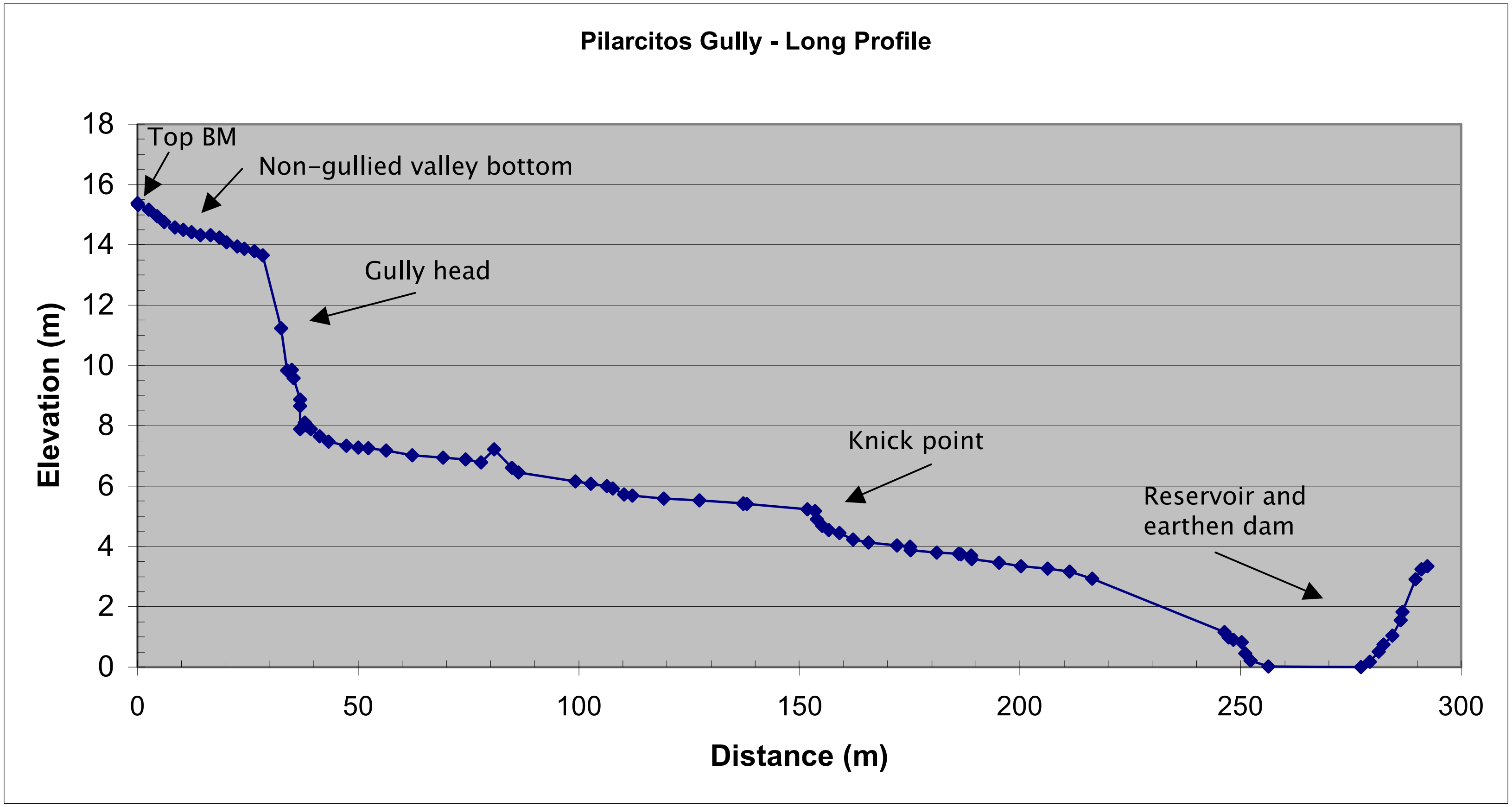


Figure 21: Longitudinal profile of Pilarcitos gully (July, 2002).

5 Discussion

Fort Ord BLM lands offer a wide range of opportunities to train students and to understand landscape evolution under both natural and managed conditions. There are opportunities to develop experiments where, for example, geology, ecosystem, or slope are controlled variables and erosion rates are measured through time. As more data are collected, we will may begin to understand how variables, such as grazing, native plant restoration, mountain bike trails, boars, and culverts play a role in modifying erosion rates on the NRMA.

Future reports will provide a more exhaustive list of benchmarks and examples of analysis.

6 References

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7 Appendix A: Benchmarks

Table 4: A subset of benchmark coordinates for monitoring sites.

GPS coordinates					average absolute difference 2004-2002		
Not differentially corrected						easting	northing
Garmin Trek receiver						3 m	3 m
UTM WGS-84							
	2002			2004			
Site#	Pilarcitos	easting	northing	easting	northing	difference	
6	PIL-1-LBM	612432	4050889	612431	4050888	1	1
6	PIL-1-RBM	612490	4050866	612484	4050863	6	3
6	PIL-2-LBM	612381	4050774	612380	4050774	1	0
6	PIL-2-RBM	612439	4050740	612439	4050741	0	1
6	PIL-3-LBM	612445	4050905				
6	PIL-3-RBM	612490	4050870				
6	PIL-4-LBM	612467	4050933	612467	4050933	0	0
6	PIL-4-RBM	612495	4050917	612494	4050917	1	0
6	PIL-5-LBM	612491	4050983	612507	4050979	16	4
6	PIL-5-RBM	612513	4050966	612515	4050973	2	7
6	PIL-6-LBM	612501	4051041	612501	4051041	0	0
6	PIL-6-RBM	612553	4051011	612548	4051013	5	2
6	PIL-7-LBM	612538	4051100				
6	PIL-7-RBM	612575	4051074				
6	PIL-8-LBM	612554	4051134				
6	PIL-8-RBM	612599	4051087	612598	4051085	1	2
6	PIL-9-LBM	612650	4051154	612650	4051154	0	0
6	PIL-9-RBM	612661	4051136	612659	4051130	2	6
6	PIL-10-LBM	612424	4050877	612422	4050874	2	3
6	PIL-10-RBM	612468	4050859	612470	4050856	2	3
6	PIL-11-topBM	612447	4050851				
6	PIL-12-LBM	614389	4053450	614393	4053446	4	4
6	PIL-12-RBM	614426	4053440	614423	4053437	3	3
6	PIL-13-LBM	615094	4054330				
6	PIL-13-RBM	615122	4054021				
6	PIL-14-LBM	614233	4053131	614226	4053134	7	3
6	PIL-14-RBM	614247	4053118	614244	4053118	3	0
6	PIL-15-LBM	614828	4053887				
6	PIL-15-RBM	614842	4053840				

	Jacks Road Gully #1						
9	JR1-1-LBM	615725	4053001	615729	4052989	4	12
9	JR1-1-RBM	615739	4052978	615739	4052970	0	8
9	JR1-2-LBM	615744	4053003	615740	4053000	4	3
9	JR1-2-RBM	615746	4052984	615751	4052976	5	8
9	JR1-3-LBM	615755	4053007	615753	4053001	2	6
9	JR1-3-RBM	615757	4052988	615761	4052974	4	14
9	JR1-4-LBM	615787	4052998	615790	4052998	3	0
9	JR1-4-RBM	615788	4052988				
9	JR1-5-TBM	615712	4052975				
9	JR1-5-BBM	615820	4052996	615820	4052987	0	9
9	JR1-6-TBM	615718	4052975				
9	JR1-6-BBM	615822	4052985	615820	4052983	2	2
	Parker Flat Roads						
14	PF-1-LBM	610307	4054023	610304	4054024	3	1
14	PF-1-RBM	610314	4054029	610307	4054033	7	4
14	PF-2-LBM	610253	4054047	610248	4054045	5	2
14	PF-2-RBM	610256	4054060	610256	4054058	0	2
14	PF-3-LBM	610276	4054040	610280	4054045	4	5
14	PF-3-RBM	610280	4054047	610277	4054046	3	1
14	PF-4-LBM	610470	4054134	610465	4054135	5	1
14	PF-4-RBM	610463	4054143	610459	4054145	4	2
14	PF-5-LBM	610455	4054162	610454	4054161	1	1
14	PF-5-RBM	610460	4054170	610459	4054167	1	3
14	PF-6-LBM	610487	4054154	610485	4054152	2	2
14	PF-6-RBM	610479	4054160	610479	4054157	0	3
14	PF-7-LBM	610435	4054098	610437	4054099	2	1
14	PF-7-RBM	610417	4054123	610414	4054120	3	3
14	PF-8-LBM	610493	4054164				
14	PF-8-RBM	610486	4054171				
14	PF-9-LBM						
14	PF-9-RBM	610529	4054220				
	Trail 67 restoration						
15	TR67-1-LBM	610522	4055539				
15	TR67-1-RBM	610535	4055560				
15	TR67-2-LBM	610505	4055541				
15	TR67-2-RBM	610506	4055559				

	Trail 26 restoration								
16	TR26-1-LBM	610206	4055033						
16	TR26-1-RBM	610215	4055051						
16	TR26-2-LBM	610148	4055049						
16	TR-26-2-LBM	610154	4055060						

	Gully 28 (healing gully)								
10	28-1-LBM	615801	4052068						
10	28-1-RBM	615776	4052060						
10	28-2-LBM	615813	4052020						
10	28-2-RBM	615782	4051999						
10	28-3-LBM	not in spreadsheet							
10	28-3-RBM	look in field book							
10	28-4-LBM	ditto							
10	28-4-RBM	ditto							
10	28-5-LBM	615846	4051879						
10	28-5-RBM	615875	4051894						
10	28-5a-LBM	1 m downvalley from 5							
10	28-5a-RBM	2 m downvalley from 5							
10	28-6-LBM-1	615812	4052020						
10	28-6-LBM-2	615819	4052026						
10	28-6-LBM-3	615847	4052045						
10	28-6-RBM	615795	4052004						
10	28-7-LBM	not in spreadsheet							
10	28-7-RBM	look in field book							
10	28-LP-1	ditto							
	Mudhen Gully								
11	CS-1-LBM	613240	4054231						
11	CS-1-RBM	613165	4054180						
11	CS-2-LBM	613199	4054296						
11	CS-2-RBM	613168	4054293						
11	CS-3-LBM	613200	4054355						
11	CS-3-RBM	613159	4054356						
11	CS-4-LBM	613184	4054436						
11	CS-4-RBM	613148	4054425						
11	CS-5-LBM	613196	4054496						
11	CS-5-RBM	613163	4054506						
11	CS-6-LBM	613200	4054515						
11	CS-6-RBM	613165	4054522						
11	CS-7-LBM	613263	4054572						
11	CS-7-RBM	613243	4054606						

11	CS-8-LBM	613283	4054587						
11	CS-8-RBM	613263	4054618						
11	CS-9-LBM	613326	4054612						
11	CS-9-RBM	613320	4054635						
11	CS-10-LBM	613362	4054624						
11	CS-10-RBM	613361	4054637						
	Owl Landslide								
1	OC-1	615510	4052049						
1	OS-2	615510	4052058						
1	LS-13	615565	4052109						
1	LS-14	615568	4052076						
1	LS-15	615572	4052039						
1	LS-16	615578	4051999						
1	LS-17	615581	4051970						
1	LS-18	615585	4051937						
1	LS-19	615610	4051943						
1	LS-20	615606	4051975						
1	LS-21	615603	4052005						
1	LS-22	615599	4052042						
1	LS-23	615596	4052077						
1	LS-24	615594	4052107						
1	LS-25	615623	4052104						
1	LS-26	615624	4052075						
1	LS-27	615627	4052043						
1	LS-28	615629	4052010						
1	LS-29	615632	4051979						
1	LS-30	615634	4051949						
1	LS-31	615661	4051953						
1	LS-32	615660	4051983						
1	LS-33	615658	4052013						
1	LS-34	615656	4052043						
1	LS-35	615654	4052073						
1	LS-36	615651	4052102						