TECHNICAL MEMORANDUM

Sediment Delivery Potential from Failures on the Stanshaw Creek Diversion Ditch
Prepared for: Will Harling, Mid-Klamath Watershed Council and Douglas and Heidi Cole, Marble Mountain Ranch.
Prepared by: Rocco Fiori, Engineering Geologist, PG8066.
May 14, 2016

1.0 Introduction

This memorandum provides my preliminary findings of a survey to assess the sediment delivery potential from failures on the Stanshaw Creek diversion ditch. The Marble Mountain Ranch has a patented water right to divert water from Stanshaw Creek for consumptive and non-consumptive uses. The North Coast Regional Water Quality Control Board (NCRWQCB) and National Marine Fisheries Service (NMFS) are concerned operation of the diversion ditch constitutes a threat to downstream beneficial uses including water quality, and fish and wildlife habitat. This assessment was conducted at the request of Douglas and Heidi Cole, owners of the Marbled Mountain Ranch, and Will Harling, Director of the Mid-Klamath Watershed Council (MKWC).

2.0 Approach

The purpose of the survey was to assess the relative potential for ditch failures to deliver sediment to Stanshaw Creek and other waters of the State of California. The assessment was comprised of the following activities:

1. Review of a recent ditch inspection report prepared by NCRWCB staff (Feiler 2015).
2. Rapid field reconnaissance of the site on April 20, 2016, with Douglas Cole, Will Harling, and Joey Howard (Cascade Stream Solutions).
3. Desktop analysis, including qualitative assessment of site conditions using a 1-meter resolution LiDAR DEM, Digital Ortho-Photographs, and the Regional Geologic Map (Wagner and Saucedo 1987) with ArcGIS.

3.0 Findings

3.1 Ditch Failure Modes

I observed many of the erosion points described in the NCRWCB ditch inspection report and concur with the general characterization of the types of failure modes operating along at the ditch line by Feiler (2015). Based on my observations it appears the failure modes and frequency of occurrence can the ranked in the following order, (with type 1 modes having the greatest likelihood of occurring):

1. Water seepage through the outboard embankment fill material. This failure mode has two likely outcomes: a) slow slump failure of the fill with the potential for ditch flow to overtop the embankment and discharge downslope; or b) rapid slump failure of the fill, leading to the near instantaneous discharge of ditch flow downslope. Type 1b failures are most likely to lead to onsite erosion and possibly contribute to offsite sedimentation.
2. Cutbank failure. The outcome of this failure mode depends on the volume of the failed material. For a) small cutbank failures, the failed material will likely displace some of the ditch flow onto the outboard edge of the embankment and not lead to any onsite erosion; or for b)

larger cutbank failures, the failed material can cause the ditch flow to overtop the embankment. Type 2b failures are the most likely to lead to onsite erosion and possibly contribute to offsite sedimentation.

3. Tree Windthrow. Windthrow from the cutbank or embankment fillslope can lead to either a) slow, or b) rapid failure of the embankment fill, or c) slow and d) rapid displacement of ditch flow on to or over the embankment fill. The magnitude of onsite erosion and possibility of offsite sedimentation is dependant on the size of the tree and duration of uncontrolled ditch flow through the failure.

3.2 Sediment Delivery Potential

Based on my preliminary field observations and desktop analysis it appears the first 1100 feet (starting at the Point of Diversion) of the ditch has the greatest potential to deliver sediment to Stanshaw Creek in the event of a ditch failure. This is primarily because the ditch is located directly above the stream channel, and secondarily because the ditch is partially within the fluvial corridor of Stanshaw Creek (Figure 1). The remaining sections of the ditch have a low to moderate sediment delivery potential (Figure 1 and Table 1). The lower delivery ratings are due to the capacity of large topographic benches and dense vegetation to intercept and store a majority of sediment before it can be delivered to the receiving waters of the State (Figure 1).

Table 1. Relative sediment delivery potential of the Stanshaw Creek Diversion Ditch.

Distance from POD (feet)	Relative Sediment Delivery Potential	Percent of Ditch Length	Receiving Waters	Rationale
0 to 1100	High	24	Stanshaw Creek	Ditch is directly above stream
1100 to 2100	Low	22	Stanshaw Creek	Topographic bench likely to store most sediment and attenuate turbid runoff
2100 to 2800	Moderate	15	Stanshaw Creek	Reduced effect of the topographic bench to store most sediment and attenuate turbid runoff.
2800 to 4600	Low to Moderate	39	Klamath River	Topographic bench likely to store most sediment and attenuate turbid runoff

3.3 Other Sediment Sources

There is approximately 6,400 feet of streambank (2 X 3,200 ft.) on Stanshaw Creek between the Point of Diversion and the Highway 96 Culvert (Figure 1). A preliminary slope stability analysis indicates these slopes are marginally to highly un-stable. Wagner and Saucedo (1987) mapped the landform in this area as Qls (Quaternary Landslide), which also indicates a higher potential for slope instability. Slope failures along the lower reach of Stanshaw Creek are likely a greater source of sediment delivery compared to the features along the ditch described by Feiler (2015), and could create background sedimentation and turbidity levels that would likely overprint inputs emanating from a ditch related failure.

3.4 Recommendations

1. During the field review, Mr. Cole described that his inspection and maintenance efforts target repairs to seepage and other minor failure problems before they evolve into larger or catastrophic failures. Similar inspection and maintenance efforts are recommended moving forward.
2. The use of a pipeline would avoid or minimize the likelihood of sediment delivery related to conveyance of the Cole's water right from the Point of Diversion to the points of consumptive and non-consumptive use.
3. If a pipeline is the selected alternative, consider retaining the existing ditch alignment as an inspection and maintenance travel way. Mild outsloping and appropriately spaced rolling dips along the travel way could be used to effectively improve the stability and drainage of the travel way, and to provide a route for rapid response in the event of a pipeline failure.
4. Slope stability analysis could be used to identify potential areas of concern and develop mitigation strategies.
5. A sediment budget could be used to obtain an accurate assessment of sediment contributions from past ditch failures and other sources.

References

Wagner, D.L., and G.J. Saucedo. 1987. Geologic Map of the Weed Quadragle, California, 1:250,000. State of California, Department of Conservation. Regional Geologic Map Series. Weed Quadrangle – Map No, 4A (Geology), Sheet 1 of 4.

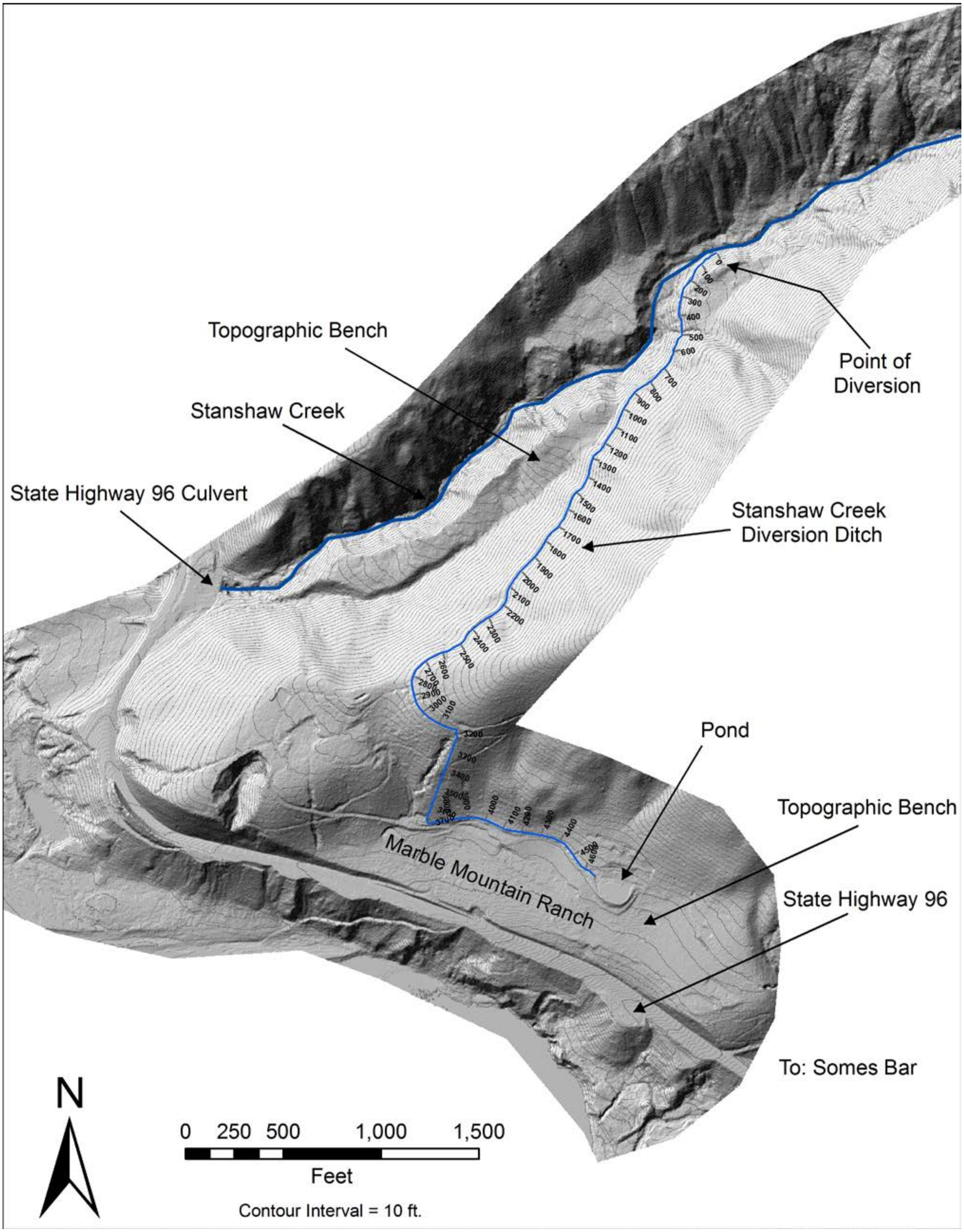
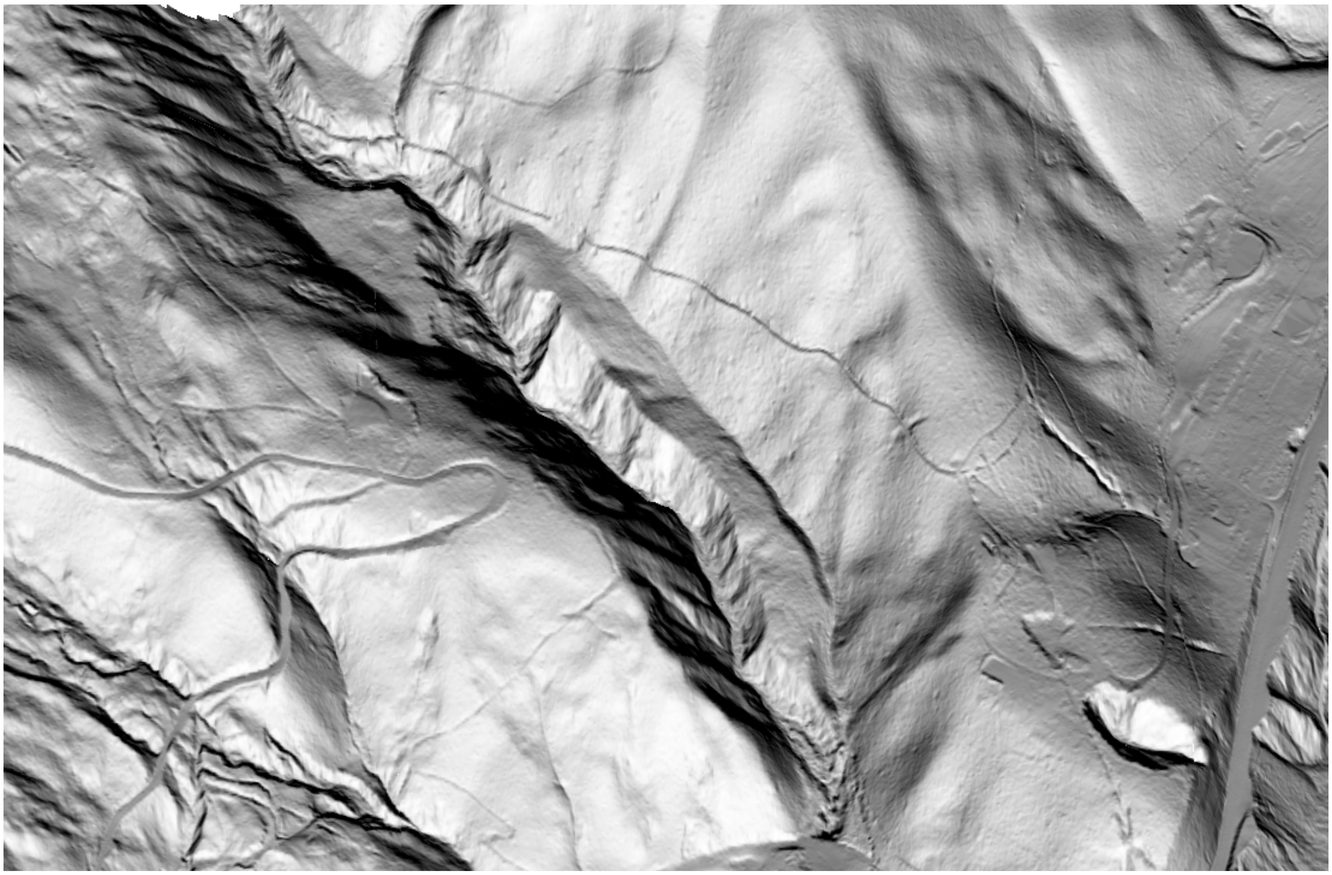


Figure 1. Project Location Map. Marble Mountain Ranch and the Stanshaw Creek Diversion Ditch. Base image is a 2010 1-meter LiDAR DEM Hillshade, provided by the Mid-Klamath Watershed Council.

Stanshaw Creek Diversion Ditch
Sediment Source Assessment



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April 4, 2017

Stanshaw Creek Diversion Ditch Sediment Source Assessment

1.0 Introduction

This report summarizes the approach and findings for a sediment source assessment of the Stanshaw Creek diversion ditch prepared by Fiori GeoSciences (FGS). The Marble Mountain Ranch (MMR) has a patented water right to divert water from Stanshaw Creek for consumptive and non-consumptive uses. The California State Water Resources Control Board (SWRCB) and National Marine Fisheries Service (NMFS) are concerned the operation and maintenance of the diversion ditch constitutes a threat to downstream beneficial uses including water quality, and fish and wildlife habitat.

2.0 Approach

The potential for ditch related sediment and turbidity to impact the waters of California was assessed through a combination of field assessments and desktop analysis. Ditch related sediment sources and delivery paths were inventoried and mapped in the field. Storm water runoff was monitored for sediment and turbidity outputs at several key locations in the study area. Visual inspection and photographic monitoring was conducted at springs, un-channelized flow paths, stream courses, and at a five-gallon bucket that was part of a domestic water system located downslope from the ditch. The 19 sites identified by Feiler et al. (2015) were located and assessed as part of this study. Douglas Cole was interviewed in the field and by email regarding ditch infrastructure, implementation of ditch operation and maintenance Best Management Practices (BMPs), and the timing of storm driven erosion events.

Field activities were conducted by FGS on April 20, 2016, December 15 and 16, 2016, February 24, 2017 and March 22, 2017. Field dates in December, February and March were conducted during leaf-off conditions and while overland flow conditions were present. A timeline of key data collection activities associated with this study is summarized in Table 1.

Desktop analysis included assessment of watershed scale and site level conditions using a 1-meter resolution LiDAR DEM, Digital Ortho-Photographs, and the Regional Geologic Map (Wagner and Saucedo 1987) with ArcGIS. LiDAR data was acquired in December 2014 and January 2015 by Quantum Spatial, Inc. (QSI 2015) under contract with the Mid-Klamath Watershed Council and provided to FGS in 2016. Rainfall statistics for the nearby gage at Orleans, California (Station ID 046508), were used to characterize water year types and to identify potential hydrometerologic drivers of slope stability and sediment delivery for recent and historic management periods of the Stanshaw Creek Ditch. Rainfall data was obtained from websites operated by the California Data Exchange Center (CDEC) and the US Geologic Survey (USGS).

Field and desktop analysis followed standard methods including methods described in Kondolf and Piegay (2003), Reid and Dunne (1996), Dunne and Leopold (1978), Sigafoos (1964), and techniques of the USGS. Key infrastructure and erosion feature attributes were recorded in the field and include feature type, location, dimensions (e.g. length, width, and average thickness), sediment delivery ratio (if applicable), age estimate, and descriptive notes. Sediment volumes for the two largest features (the stream crossing at the unnamed tributary and the gully at Irving Creek outfall) were estimated using dimensions obtained

from the 1-meter LiDAR DEM and calibrated with field measurements. For all other erosion features, sediment production and delivery volumes were estimated by pacing the dimension of at least one side of the feature (typically the width) and then visually estimating its thickness and length. Sediment delivery volumes were defined as the quantity of earth materials that reached a watercourse and/or stored on floodprone surfaces. The sediment delivery ratio was estimated as the ratio of the volume delivered to the volume of sediment stored on the hillslope or road bench. Sediment production and delivery volumes using these methods are assumed to have an approximate +/- 20 percent margin of error, unless noted otherwise. The threat of future sediment delivery was assessed through a combination of field and desktop analysis.

The work presented herein builds on the field reconnaissance and findings from Fiori (2016), Feiler (2015), and Anderson et al. (no date).

Table 1. Data collection activity timeline.

DATE	Activity
December 2014 & January 2015	LiDAR data acquisition by Quantum Spatial, Inc (QSI).
December 17, 2014	SWRCB staff field inspection and meeting with stakeholders.
February 12, 2015	SWRCB staff field inspections, reports by Feiler (2015) and Anderson et al. (no date).
April 20, 2016	FGS Field Reconnaissance, report by FGS (2016).
December 15 and 16, 2016	FGS Field Assessment and Storm Water Quality Monitoring, this study.
February 24, 2017	FGS Field Assessment and Storm Water Quality Monitoring, this study.
March 22, 2017	FGS Storm Water Quality Monitoring, this study.

3.0 Findings

Rainfall is a principle driver of erosion and sedimentation. The likelihood of hillslope derived sediment to deliver to a water course is increased through a combination of saturated soil conditions and storm related triggering events.

Rainfall records for the gage at Orleans California indicate the 2017 water year wet season rank as the 9th wettest for the 112-year period of record (Table 2). Rainfall statistics for this gage also show the WY2017 wet season had a rainfall total of 53.26 inches, a 12.6-year recurrence interval (RI), and characterized as an "Extremely Wet" water year type (Table 2 and Figure 1). In comparison, the Orleans rainfall data show the WY2016 and WY2006 wet seasons rank as the 30th and 6th wettest for the past 112 years of record (Table 2).

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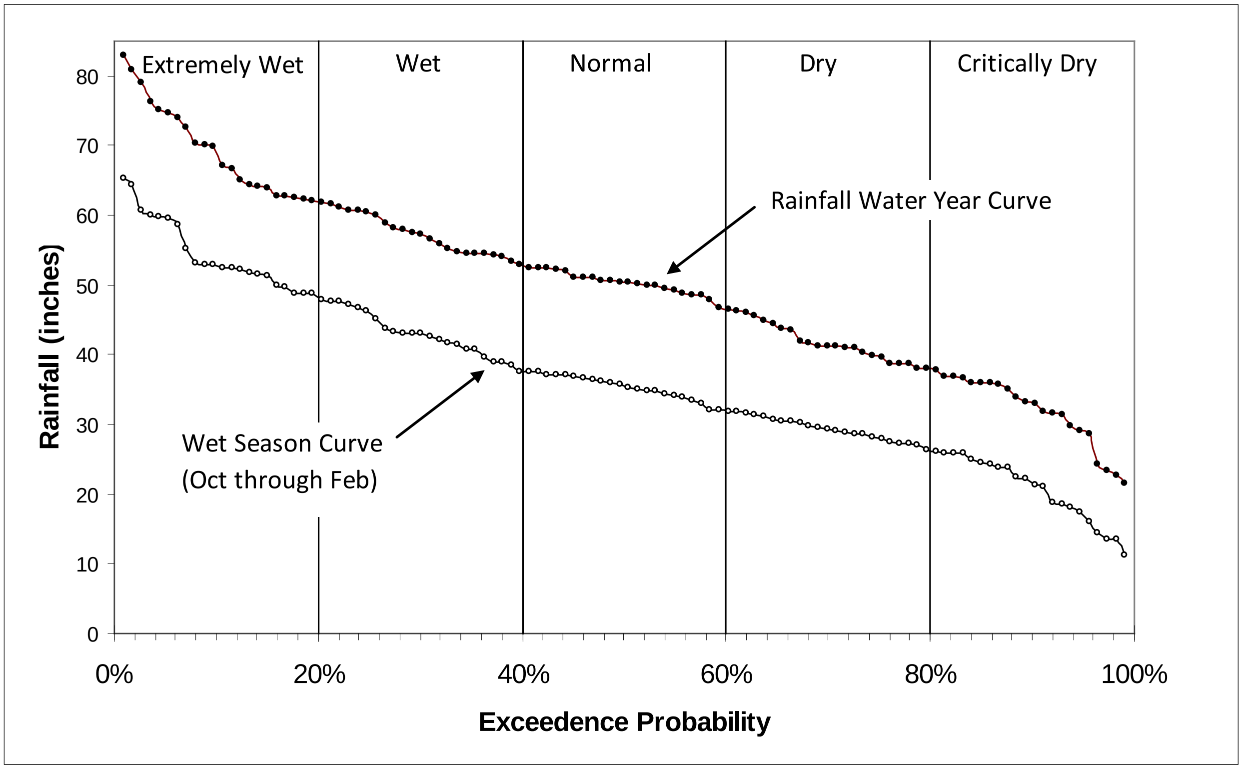

Figure 1. Rainfall exceedence probability and water year type for Orleans, California (NOAA Gage ID: 046508).

Table 2. Rainfall statistics for the top 10 ranked and selected wet season water years for Orleans, California (NOAA Gage ID: 046508). For this study the water year wet season is defined as the period from October 1st to February 28th.

Rank	Water Year	Rain (inches)	Recurrence Interval (years)	Water Year Type
1	1956	65.2	113.0	Extremely Wet
2	1974	64.5	56.5	Extremely Wet
3	1958	60.6	37.7	Extremely Wet
4	1927	59.9	28.3	Extremely Wet
5	1982	59.8	22.6	Extremely Wet
6	2006	59.6	18.8	Extremely Wet
7	1983	58.7	16.1	Extremely Wet
8	1965	55.2	14.1	Extremely Wet
9	2017	53.3	12.6	Extremely Wet

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10	1999	53.0	11.3	Extremely Wet
30	2016	43.8	3.8	Wet
76	2015	30.3	1.5	Dry

3.1 Sediment Sources

Field assessments conducted by FGS identified a total of 33 erosion features and characterized sediment production and delivery for 13 features that occurred during WY2017 and 11 older features (Table 3 and Figure 2. Based on dendrogeomorphic evidence, storm history, and landowner information, the older features were most likely triggered by storms during WY2006 and previous years with wetter than normal water year types (Figure 1 and Table 2).

Cutslope Failures

Data in Table 3 show that compared to other feature types cutslope failures had the greatest frequency of occurrence (14/22), produced approximately 96 yds^3 of sediment, and did not deliver sediment to the waters of California during the study period. Volume estimates for pre-WY2017 cutslope failures were not prepared for this study, but could be extrapolated from existing data. Ditch segments with pre-2017 fillslope and cutslope erosion are delineated by solid yellow and red lines, respectively on Figure 2.

Fillslope Surface Erosion

Fillslope surface erosion (FSE) had the second greatest frequency of occurrence (5/22), produced approximately 3 yds^3 of sediment, and delivered approximately 1.6 yds^3 of sediment to the waters of California during study period (Table 3). Of the total 1.6 yds^3 of sediment delivered, approximately 70% of that volume (1.1 yds^3) was delivered directly to the bed and banks of the unnamed tributary to Stanshaw Creek from two small features at Stations 470 and 513 (Figure 2). Approximately 50 percent, of the 1.1 yds^3 delivered sediment, was stored along the channel margin. Based on field observations of MMR BMPs and rates of natural regeneration, vegetation will likely stabilize the deposition remaining along the channel margin. The third site of fillslope surface erosion related delivery occurred at Station 148 where less than 0.5 yds^3 of sediment was delivered directly to Stanshaw Creek. Sediment delivery from features located at Stations 148 and 513 were associated with grading efforts to relocate sediment produced from nearby cutslope failures. Grading associated sediment delivery could be avoided or minimized if the ditch travel way was larger and capable of using equipment to export sediment spoils off-site. Two of the five FSE features did not deliver sediment.

Shotgun Culvert

Sediment production and delivery volumes were estimated for the shotgun culvert located at Station 474. During WY2017 study period, erosion related to the outfall from the shotgun culvert was estimated to produce and deliver 1 yds^3 and 0.7 yds^3 of sediment, respectively. The long-term sediment production and delivery volumes were estimated to be 6.3 yds^3 (Table 3). According to Douglas Cole, the culvert was installed in 1996. By assuming the plunge pool volume represents erosion over a 21-year period an erosion rate of ~0.3 yds^3/yr and incision rate of ~ 4"/yr was estimated. Field inspection of the feature indicates the plunge pool has become quasi-stable in the consolidated paleo-landslide deposits that underlie the site. The difference in the short- and long-term of sediment delivery rates, 0.7 yds^3 versus

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~0.3 yds^3/yr, was likely due to the accounting of the sedimentation related to a scarp that formed along the contact between the unconsolidated colluvium and fill, and the underlying paleo-landslide deposits (Figure 3). The cylindrical shape and flat base of the plunge pool, and the stair-stepped topography suggests this feature has eroded into more resistant material and the current incision rate may be an order of magnitude lower than the rate calculated above.

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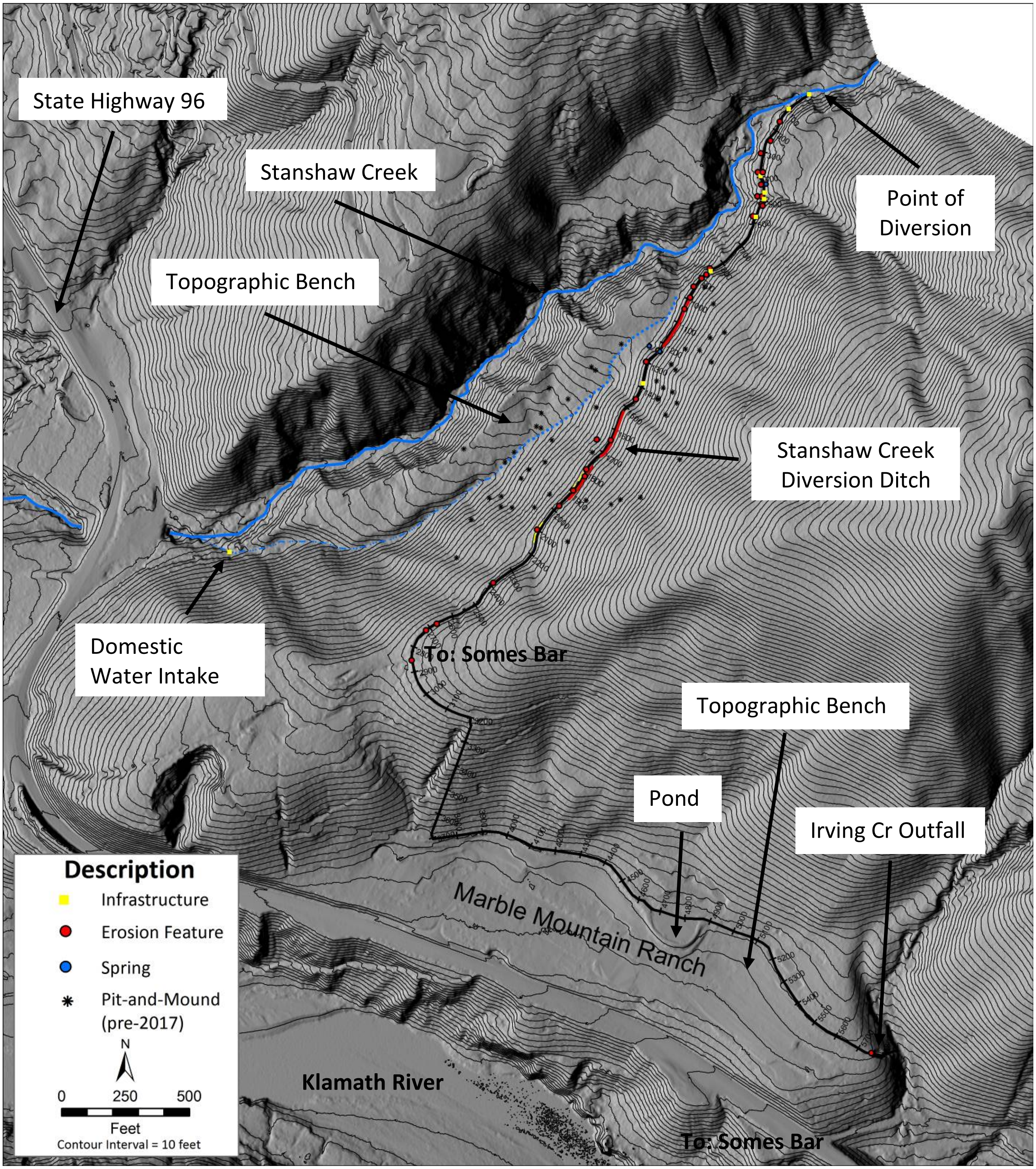

Figure 2. Study Area Map. Marble Mountain Ranch and the Stanshaw Creek Diversion Ditch. Base image is a portion of the 2014/15 1-meter LiDAR DEM Hillshade, provided by the Mid-Klamath Watershed Council.

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Ditch segments with pre-2017 fillslope and cutslope erosion are delineated with solid yellow and red lines, respectively. Map prepared by FGS.

Table 3. Sediment production and delivery estimates for features associated with the operation and maintenance of the Stanshaw Creek Diversion Ditch. Notes: 1) numbers in parenthesis show the total number of features observed and numbers without parenthesis indicate data for features that delivered sediment. 2) The shotgun culvert was installed in 1996 by the Cole's. 3) Pre-WY2017 features were most likely triggered by storms during WY2006 and previous water years. 4) Sediment production and delivery volumes present in this table are assumed to have an approximate +/- 20 percent margin of error.

Feature Type	Frequency[1]	Sediment Production (yds^3)				Sediment Delivery (yds^3)			
		Min	Max	Avg	Total	Min	Max	Avg	Total
WY2017 Features									
Fillslope Surface Erosion	3 (5)	1	2	1.6	3	0.3	0.8	0.5	1.6
Fillslope Failures	1 (2)	-	-	-	56	0	0	0	0
Cutslope Failures	7 (14)	1	65	13.7	96	0	0	0	0
Culvert Erosion[2]	1	-	-	-	0.5	-	-	-	0.5
Headcut Erosion	1	-	-	-	17	-	-	-	10
WY 2017 Total:	**13 (22)**	**2**	**67**	**15.3**	**173.0**	**0.3**	**1**	**0.6**	**12.5**
Pre-WY2017 Features[3]									
Fillslope Failures	6	35	156	89	534	0	133	46	273
Gully	2	23	93	-	116	0	93	-	93
Hillslope Failures	1	-	-	-	278	-	-	-	167
Culvert Erosion[2]	1	-	-	-	6.3	-	-	-	6.3
Headcut Erosion	1	-	-	-	775	-	-	-	775
Pre-WY2017 Total:	**11**	**58**	**249**	**89**	**1709**	**0**	**226**	**45.5**	**1314**

Ditch-Stream Crossing

The ditch-stream crossing located at the unnamed tributary of Stanshaw Creek (Station 488) was identified as an area of concern by Feiler (2015) and evaluated as part of this study. This evaluation, included an on-site interview with Douglas Cole on February 24, 2017. According to Mr. Cole, he constructed the crossing in 1996 to replace a failing wooden flume that he believes was part of the original ditch infrastructure. The crossing was constructed with human powered equipment, consists of a 4-foot diameter plastic culvert placed on a "bedrock ledge", and native earth materials used for backfill. Mr. Cole stated the crossing has not failed since he constructed it. Using this information, in combination with standard methods, the crossing fill volume was estimated to be approximately 160 yds^3 +/- 35 yds^3. There was no field evidence to indicate this feature has failed either catastrophically or partially during the past 21 years.

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A likely failure scenario would be related to debris blocking the culvert that would force stream flow to overtop and erode the fill. In this scenario, it would be reasonable to assume that the culvert and 50 percent of the fill volume would wash-out which would result in the potential delivery of approximately 80 yds^3 of sediment (assume a 20 percent plus or minus margin of error). The estimate of potential delivery from this study is less than the 150 to 300 yds^3 estimated by Feiler (2015).

Figure 3. Upstream view of the shotgun culvert located at an unnamed tributary to Stanshaw Creek, Station 474.

Irving Creek Headcut

The Irving Creek headcut is located at Station 5755 near the terminus of the Stanshaw Creek ditch. This feature most likely formed as the result of draining Stanshaw Creek ditch flow over a natural slope and into Irving Creek. Feiler (2015) identified this feature as an area of concern.

Aerial photographs (available at the Mid-Klamath Watershed Council office) indicate this portion of the ditch has been in use since the mid-1940's. Which suggests this feature is at least 72 years old (2017-1945). Profile and volume estimates derived from the 2014/15 1m LiDAR DEM indicate that approximately 775 yds^3 (+/- 100 yds^3) of sediment has been delivered to Irving Creek over the assumed 72 year period and has had an average long-term delivery rate of ~11 yds^3/yr.

Short-term minimum sediment production and delivery rates of 17 yds^3/yr and 10 yds^3/yr were estimated for the actively eroding portion of the gully. These estimates compare favorably to the long-term delivery rate.

The short-term estimates were based on the following observations and assumptions: volumes and rates were estimate by summing: 1) the length of the actively retreating gully head (115 feet), 2) the features average depth (16 feet), and 3) an average retreat rate (0.25 feet/year). The sediment delivery rate was calculated by multiplying the production rate by a sediment delivery ratio of 60 percent. Field observations indicate the lower portions of the gully are currently storing at least 40 percent of sediment produced by the actively eroding headwall portions of the gully. Vegetated deposits are accumulating along the gully sidewalls and the relatively stable bed elevations indicates the feature is evolving toward an equilibrium condition and the feature may stabilize naturally or respond positively to simple stabilization measures.

3.2 Sediment Delivery Paths and Storm Water Quality Monitoring

FGS field assessments identified five features that delivered sediment to the waters of California during WY2017. These features were characterized and described in Section 3.2 and include three small fillslope surface erosion features at Stations 148, 470, and 513, the culvert outfall at Station 474, and the headcut at Station 5755. With the exception of the Irving Creek headcut, these features were located within the first 1000 feet of the ditch.

Field assessments including storm water quality monitoring conducted on the topographic bench located downslope of Stations 1000 to 2850 found no clear evidence that ditch related sedimentation or turbidity has affected or has the potential to affect the waters of California, barring natural and catastrophic events. Instead, FGS observed clear water consistently draining from the topographic bench during storm water runoff periods, a high degree of surface roughness from vegetation and irregular topography capable of trapping and storing fine sediments proximal to sediment producing features, and soils with a significant fraction of coarse angular particles that appear to resist surface erosion. Additionally, a sediment trap (in the form of a five-gallon bucket) connected to a domestic water intake system contained negligible amounts of fine sediment and organic materials during two field surveys (Figure 2 and 4).

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The quantities and material types observed in the sediment trap were consistent with and supportive of the observations described herein. Moreover, it should be considered that the domestic water system and sediment trap would provide the water user an alert system and mechanism to document the occurrence of nuisance level water quality impacts associated with disturbances within the watercourse.

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Figure 4. Photographs of downstream receiving waters of the Stanshaw Creek Ditch (Stations 1000 to 2880) and the domestic water supply intake system. Note the five-gallon bucket used as a sediment trap. Survey dates: Upper photographs - December 16, 2016, lower photographs - March 22, 2017.

3.3 Future Sediment Delivery Potential

The first 1000 feet of the ditch has the greatest potential to deliver ditch related sediment to Stanshaw Creek. The greater delivery potential of this ditch segment is due to it is location directly above the stream channel (Figure 2). Based on the findings from this study the remaining two segments of the ditch are considered to have low to moderate sediment delivery potential (Figure 2 and Table 4). The lower delivery ratings are due to the capacity of large topographic benches and dense vegetation to intercept and store a majority of sediment before it can be delivered to the receiving waters of the State.
These findings are consistent and generally unchanged from what was reported by Fiori (2016)

Table 4. Relative sediment delivery potential of the Stanshaw Creek Diversion Ditch.

Distance from POD (feet)	Relative Sediment Delivery Potential	Percent of Ditch Length	Receiving Waters	Rationale
0 to 1100	Moderate to High	18	Stanshaw Creek	Ditch is directly above stream
1100 to 2850	Low	31	Stanshaw Creek	Topographic bench likely to store most sediment and attenuate turbid runoff
2850 to 5880	Low to Moderate	51	Klamath River And Irving Creek	Topographic bench likely to store most sediment and attenuate turbid runoff

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3.4 Background Sediment Sources

Landslides and Gullies

There is approximately 6,400 feet of streambank (2 X 3,200 ft.) on Stanshaw Creek between the Point of Diversion and the Highway 96 Culvert (Figure 2). Review of the LiDAR DEM and Aerial Imagery reveals a significant number of landslides, gullies, roads, and timber harvest units on the lands surrounding the study area and managed by the US Forest Service. These features are capable of contributing acute and chronic sediment to the mainstem of Stanshaw Creek (KNF 1998). Wagner and Saucedo (1987) mapped the landform underlying the study area and lower Stanshaw Creek as Qls (Quaternary Landslide), this indicates there is a high potential for slope instability. Sediment delivery from slope failures and gullies located along the lower reach of Stanshaw Creek pose a significantly greater sediment delivery potential compared to the ditch related features described in this study. Sediment delivery from one of the moderate to large landslides located along lower Stanshaw Creek have the capacity to produce background sedimentation and turbidity levels that would overprint inputs from ditch related failures.

Windthrow and Snowdown Trees

FGS field assessments and desktop analysis identified naturally toppled trees as a likely background contributor of coarse and fine sediments to watercourses within the study area. Close examination of the LiDAR DEM reveals pit-and-mound topographic features distributed across the landforms underlying the study area. Pit-and-mound topography is a characteristic signature of soil disturbance resulting from toppled trees. Tree topple is also referred to as tree uprooting, windthrow, snow-down, floralturbation, arboturbation, among other terms. Schaetzl et al. (1988) provides an excellent review of this phenomenon, and work by Swanson et al. 1982, Gabet et al. 2010, Roering et al. 2010, and Phillips et al. 2017 provide information from regional and global studies.

Several toppled trees were identified and mapped during fieldwork conducted on December 16, 2017. Some of these toppled trees were located within 1200 feet of the domestic water intake and overland flow was observed to connect these sediment sources to the ephemeral channel and domestic water supply intake (Figures 4 and 5a). However, field observations conducted during overland flow conditions indicate sediment transport and/or turbidity originating from these sources would likely occur only during the most extreme, short duration, high intensity rainfall events.

During the field assessment on February 24, 2017, FGS observed the initial aftermath of a significant snow-down event that occurred in relation to a winter storm that delivered several feet of wet snow to the Mid-Klamath region on January 2nd and 3rd, 2017. This snow-down event resulted in toppling a significant number of trees across the study area, including trees in close proximity to the domestic water system intake. Overland flow was observed to connect to the ephemeral watercourse upstream of the domestic water system, yet no sediment transport nor turbid waters were noted (Figure 5b).

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Figure 5. Photographic examples of uprooted trees and overland flow in the study area. These natural sediment sources are located on the topographic bench upstream of the domestic water supply that is shown in Figures 2 and 4. Survey dates: Left photograph (5a) - December 16, 2016, Right photograph (5b) - February 24, 2017.

3.5 Discussion

Feiler (2015) described 19 sites on the Stanshaw Creek Diversion Ditch as areas of concern for past and/or future sediment delivery. During this study, FGS located and walked the slopes below each of these sites with the purpose of identifying past and potential sediment delivery. Of these 19 sites, FGS found five sites had delivered sediment to the waters of California. Four of these sites were located within the first 1000 feet of the Point of Diversion (Stations 0 to 1000) and the fifth site at the Irving Creek Headcut (Station 5755) (Figure 2). FGS found no evidence of past sediment delivery from the 14 sites located between Stations 1000 and 2850. Specifically, FGS found no evidence of chronic rilling or gullying on the hillslope below Stations 1000 and 2850. One hillslope gully was located approximately 50 feet downslope of Station 1677. However, no clear evidence linked the formation of this gully with past ditch failures and its genesis may be related to natural hillslope erosion processes. The limited number of fluvial erosion features (rills and gullies) on the hillslope below Stations 1000 and 2850 provides strong evidence that ditch-overtopping events are rare or unlikely. This is most likely due to MMR BMPs and/or that overtopping events result in dispersed flow that lack the tractive force needed to initiate the formation of rills or gullies.

The recent snow-down event, decay state of the pre-WY2017 toppled trees, and the pit-and-mound topography indicate floralturbation is a commonly occurring soil displacement mechanism within the study area. Discussions between FGS and the owner of the domestic water system included statements by the owner that water quality impacts have occurred at this location in the past. Based on the available evidence it appears the water quality impacts described by the adjacent landowner were most likely related to floratubation rather than erosion related to the operation and maintenance of the Stanshaw Creek Diversion Ditch.

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3.6 Recommendations

1. Field evidence and desktop analysis reported herein indicates the Best Management Practices employed by the MMR avoids, minimizes or mitigates sediment delivery related to operation and maintenance of the Stanshaw Creek Diversion Ditch. Mr. Cole described that his inspection and maintenance efforts target repairs to seepage and other minor failure problems before they evolve into larger or catastrophic failures. Similar inspection and maintenance efforts are recommended moving forward.
2. Field evidence and desktop analysis reported herein indicates the Best Management Practices employed by the MMR to shut-off ditch flow prior to winter storm events avoids, minimizes or mitigates sediment delivery related to potential overtopping events. Similar pre-emptive efforts are recommended moving forward.
3. Reconstruct the ditch prism to establish a smooth and continuous gradient (i.e. remove low and high spots) would improve ditch flow efficiency and reduce seepage losses.
4. Reconstruct the ditch prism so the outboard travel way is at least 12 feet wide. This will reduce the potential for uprooted trees from damaging ditch infrastructure, limit overtopping events, avoid or reduce delivery from cutslope failures, and allow larger equipment to be used for routine and emergency maintenance. The use of larger equipment will reduce or avoid grading related sediment delivery and make it possible to export and store sediment spoils off-site. Mild outsloping and appropriately spaced rolling dips along the travel way could be used to effectively improve the stability and drainage of the travel way.

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5. Conduct a cost-benefit analysis to determine whether lining or piping the ditch will result in the water savings and reduce sediment delivery threats. This analysis may indicate that a combination of unlined, lined, and piped ditch flow will provide a win-win solution for the MMR and environment.
6. The gully at the Irving Creek Outfall the feature is evolving toward an equilibrium condition and this feature may stabilize naturally or respond positively to simple stabilization measures. Low cost erosion control solutions should be considered to address sediment delivery from this site.

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Cover Image: 3D oblique view of lower Stanshaw Creek and the Stanshaw Creek Diversion Ditch Derived from the 1-meter 2014/15 LiDAR DEM. Image by FGS.

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