
TABLE OF CONTENTS

	Page
8.0 Geomorphology	8-1
8.1 Sources of Information.....	8-1
8.2 Recent Studies	8-2
8.3 Description of Existing Geomorphology Resource Characterizations by Study Stream	8-4
8.3.1 Geomorphic Channel Classification	8-4
8.3.2 Sediment Supply and Sediment Transport Characteristics	8-8
8.3.3 Stream Channel Sensitivity to Disturbance	8-12
8.3.4 Comparison of Historic and Recent Channel Conditions	8-14
8.4 References	8-16

List of Tables

Table 8-1. Historical Aerial Photographs Obtained for the Middle Fork American River Project.

List of Figures

Figure 8-1. Suspended Sediment Discharge Lower Middle Fork American River (1956-1979).

8.0 GEOMORPHOLOGY

This section summarizes the existing information regarding channel geomorphology and associated fluvial processes in the bypass and peaking reaches (or study streams) associated with the Middle Fork American River Project (MFP or Project). Channel geomorphology is a description of the channel form (morphology) including dimensions, gradient, planform, and pattern. Fluvial processes refer to the flow, sediment supply, and sediment transport characteristics that create and maintain the channel morphology. The Federal Energy Regulatory Commission (FERC or Commission) does not specifically require a chapter on geomorphology; however, this information is integral to understanding channel maintenance processes and the distribution and availability of aquatic and riparian habitat.

The information presented in this report is based on a review of existing information, including published reports, geographic information system (GIS) data, historical and recent aerial photography, and on new information developed by the Placer County Water Agency (PCWA) in 2005 and 2006 as part of a two-phase geomorphology study. The 2005 and 2006 geomorphology studies are documented in PCWA's 2005 Physical Habitat Characterization Study Report (PCWA 2006a) and the 2006 Physical Habitat Characterization Study Report (PCWA 2007), both of which are provided in Supporting Document G (SD-G) for reference.

8.1 SOURCES OF INFORMATION

Existing information regarding the geomorphology of the streams and rivers in the Middle Fork American River Watershed (Watershed) was acquired, reviewed, and evaluated. Specific information that was reviewed and evaluated is summarized in the following.

Previously Published Study Reports

Geomorphic information pertinent to the MFP was found in four previously published reports, as follows:

- Scour and Evaluation at Middle Fork American River below Ralston Afterbay (Watermark Engineering 1999 and 2004). This report describes a 24-year comparison study of changes in channel morphology at the United States Geological Survey (USGS) gaging station Middle Fork American River near Foresthill (USGS No. 11433300).
- American and Sacramento River, California Project - Geomorphic, Sediment Engineering, and Channel Stability Analysis (Ayres and Associates 1997). This report provided geomorphologic and channel sediment data along the lower reaches of the Middle Fork American River and North Fork American River below Oxbow Powerhouse.
- Sediment Study of Ralston Afterbay Reservoir - Final Report (Bechtel Corporation 1997). This report considered issues related to management of sediment deposition

in Ralston Afterbay. This report provided data pertinent to sediment load and sediment transport characteristics of the Rubicon River and the Middle Fork American River.

- Flood Surge on the Rubicon River, California - Hydrology, Hydraulics, and Boulder Transport (Scott and Gravlee 1968). This report was prepared by the USGS and analyzed the geomorphic effects of the failure of the partially completed Hell Hole Dam in 1964.

Aerial Photography

Existing aerial photography was retrieved and evaluated, as follows:

- Historical aerial photography taken in 1961-1962 that pre-dates development of the MFP. These aerial photographs, available as stereo pairs, include scales of 1:6000, 1:12000, and 1:15840. Table 8.1 summarizes the date, location, and streamflow for each of the historical aerial photographs used in this analysis.
- Recent aerial photography taken by AirPhoto USA, Inc in 2002, in a digital geo-referenced format with two-foot pixel size resolution.
- Aerial videography of the bypass and peaking reaches taken in 2005.

8.2 RECENT STUDIES

During 2005 and 2006, PCWA conducted geomorphology field studies along the MFP bypass and peaking reaches, as outlined in the 2005-2006 Existing Environment Study Plan Package (PCWA 2005) and 2006 Geomorphology and Riparian Habitat Characterization Study Plan (PCWA 2006b). These study plans were developed in consultation with the resource agencies and are provided in SD-G for reference.

The studies conducted in 2005 and 2006 focused on characterizing the geomorphic conditions in the bypass and peaking reaches associated with the MFP. The 2005 study methods and results are documented in PCWA's 2005 Physical Habitat Characterization Study Report (PCWA 2006a). The 2006 study methods and results are described in PCWA's 2006 Physical Habitat Characterization Study Report (PCWA 2007). These two reports were used as the primary source of information for the discussions presented in the remainder of this report and are included in SD-G for reference.

In general, the work completed in 2005 and 2006 addressed four main topics: stream channel classification, sediment supply and transport characteristics, relative channel responsiveness and stability, and a comparative assessment of historic and recent geomorphology, as briefly explained in the following.

Stream Channel Classification - Stream reaches were classified based on morphological characteristics following the Rosgen stream channel classification system (Rosgen 1996). The Rosgen classification system utilizes four main geomorphic characteristics to organize and describe similar types of stream channels:

- entrenchment (degree of vertical channel confinement in its valley),
- width to depth ratio (ratio of the maximum width of the flow at bankfull to the maximum depth of the flow at bankfull),
- slope, and
- dominant channel particle size.

The Rosgen classification system is described in detail in the 2005 and 2006 Physical Habitat Characterization Study Reports (PCWA 2006a; PCWA 2007, respectively) contained in SD-G.

Sediment Supply and Sediment Transport Characteristics - Sediment supply and sediment transport characteristics were determined through ground and aerial surveys. Pertinent information was also derived from previously published reports, including the Scour Evaluation at Middle Fork American River below Ralston Afterbay (Watermark Engineering, Inc 1999 and 2004), Sediment Study of Ralston Afterbay Reservoir (Bechtel 1997), and suspended sediment data from USGS stream gages. The 2005 and 2006 study information, combined with information available from previously published reports, was used to describe the extent and location of sediment contributions to stream channels from hillslope mass wasting and bank erosion, and the relative capacity of study streams to transport and store these sediments.

Stream Channel Sensitivity to Disturbance - Stream reaches were assessed for their potential to respond to changes to the flow or sediment regime. The type and magnitude of channel response to alterations of the flow or sediment regime were described based on a channel classification system developed by Montgomery-Buffington (1997) and on channel characteristics related to the Rosgen Level II and Level III (Rosgen 1996) assessments. The Montgomery-Buffington channel classification is based on the channel bed morphology (e.g., pool-riffle, step-pool, cascade, bedrock, etc). A detailed explanation of the Montgomery-Buffington classification is included in the 2005 Physical Habitat Characterization Study Report (PCWA 2006a) contained in SD-G. The Rosgen Level III methodology is a different approach that uses inventory rating forms to evaluate the stability of the stream bed, bank and valley walls. A description of the Rosgen Level III evaluation is presented in the 2006 Physical Habitat Characterization Study Report (PCWA 2007) contained in SD-G.

Comparison of Historic and Recent Channel Conditions – Geomorphic channel conditions in 1961-1962 and 2002-2005 were compared using aerial photographs and recent videography to identify differences and discernable trends between these two time periods. Large-scale geomorphic features that were easily discernable, such as channel position, planform (sinuosity), width, and sediment storage (bars) were identified and compared. The study results are described in detail in the 2005 Physical Habitat Characterization Study Report (PCWA 2006a). Information was also derived from previously published reports, including the Scour Evaluation at Middle Fork American River below Ralston Afterbay (Watermark Engineering, Inc 1999 and 2004)

and Flood Surge on the Rubicon River, California - Hydrology, Hydraulics, and Boulder Transport (Scott and Gravlee 1968).

8.3 DESCRIPTION OF EXISTING GEOMORPHOLOGY RESOURCE CHARACTERIZATIONS BY STUDY STREAM

The geomorphology of the study streams associated with the MFP is summarized below. More detailed information, including definitions, maps, data tables and representative photographs is available in the 2005 and 2006 Physical Habitat Characterization Study Reports (PCWA 2006a; PCWA 2007) provided in SD-G.

8.3.1 Geomorphic Channel Classification

Geomorphic channel classification was performed using the Rosgen stream channel classification system (Rosgen 1996). Initially, the study streams were classified using Rosgen Level 1 and 2 methods. Specifically, the study streams were visually evaluated from the ground, by helicopter, or using aerial videography to determine general geomorphic characteristics (valley morphology, channel slope, channel shape, and channel pattern).

The Rosgen Levels I and II assessments, completed in 2005, were used to stratify the study streams. Within each of these strata, representative locations along the study streams were selected for detailed ground surveys. Quantitative Rosgen Level II and III classification studies were conducted during 2006 at 25 representative locations along the study streams.

The majority of the study streams are confined within narrow, fluvially dissected V-shaped valleys. However, along the upper reaches, wider U-shaped valleys formed by glaciation dominate the landscape. These wider valleys are present along the upper half of Long Canyon Creek (River Mile (RM) 7.0 - 11.3), the entire lengths of the North Fork and South Fork Long Canyon creeks, and the Rubicon River for approximately five miles downstream from Hell Hole Dam. Stream channel gradients are mostly steep (> 2%), which is typical of mountain systems. More moderate gradients (<2% to 1/2%) occur only on the Middle Fork American River downstream of Ralston Afterbay.

The narrow steep canyons present throughout the Watershed substantially limit the development of a floodplain. Where floodplains are present, they are limited to a very narrow width (less than the width of the bankfull channel). This is indicative of moderately to highly entrenched or confined channels.

Rosgen stream channel classifications are B, F, or a combination B/F channel type for the majority of the study streams. B channel types are described as moderately entrenched or confined with moderately steep to extremely steep side slopes. The channel is relatively narrow and deep, resulting in a moderate width to depth ratio. B channels are typically vertically and laterally stable, and have low bank erosion and sediment supply rates, especially when dominated by coarse materials (bedrock and boulders).

F channels are also confined within steep narrow bedrock canyons, but the channel slope is flatter and the shape of the channel is broader and shallower than B channel types, resulting in a higher width to depth ratio. F channels can be laterally unstable and develop high bank erosion rates (especially when dominated by finer particles), which leads to bar formations (sediment storage) and/or high rates of sediment transport.

In some cases, channel classification of the study streams did not fit clearly into either the B or F channel types. In these cases, the stream reaches were classified as a combination of the two distinct types (B/F). Stream types actually exist along a continuum (Rosgen 1996), rather than having absolutely distinct, clear divisions between types. The range of values for the morphometric parameters that differentiate the different channel types (usually entrenchment ratio, width to depth ratio, and slope) often overlap (Rosgen 1996). Additionally, it was found that the field measured morphometric parameters that define either a B or F channel type were highly variable, changing between both types over very short channel distances (a few hundred feet).

The dominant channel material is also an important component of the Rosgen Level II channel classification. The majority of the study streams are characterized as mixed bedrock-alluvial channels. These types of channels have frequent bedrock and boulder exposures, usually with coarse steps and riffles (boulders) that are interspersed with channel sections where alluvial materials of smaller size (cobble and gravel) collect. Throughout most of the study streams, the dominant channel bed particle sizes included boulders, cobble, and gravel in roughly equal proportions. Sand rarely was observed as a dominant particle size on any of the other study streams. Valley walls typically are comprised of exposed bedrock near the toe of the hillslope/bankfull channel interface.

The geomorphic channel classification for each of study streams is summarized below.

Middle Fork American River

The Middle Fork American River between French Meadows Dam and Ralston Reservoir is considered a bypass reach. The Rosgen channel classification for the Middle Fork American River from French Meadows Dam to Ralston Afterbay is a B/F channel type. The overall gradient of the Middle Fork American River between French Meadows Dam and Middle Fork Interbay is approximately 4%, with higher gradients in localized areas. Bedrock sections often alternate with boulder-to-cobble dominated channel sections. Gravels are present in low velocity areas, such as pool tailouts. Between Middle Fork Interbay and Ralston Afterbay, the channel gradient is approximately 2.5%, with localized gradients as high as 5%. The channel between Middle Fork Interbay and Ralston Afterbay is highly to moderately entrenched, with high to moderate width to depth ratios. Valley walls often are comprised of exposed bedrock near the hillslope-toe/bankfull channel interface. Confining valley walls limit the potential for lateral channel migration. Channel bed materials are most frequently comprised of boulders and cobble, with frequent bedrock outcrop exposures. Gravels are plentiful, consistently observed in pool tailouts, often co-dominant with cobbles and boulders.

The Middle Fork American River downstream of Ralston Afterbay is considered a peaking reach. This reach is characteristic of an F channel type. The channel is highly entrenched in a wide canyon with a high width to depth ratio. The overall gradient is approximately 0.5%. Channel sinuosity is moderate to high. High amplitude meanders around large point bars are common, and side bars are also frequent. Lateral shifts in channel planform appear to occur infrequently, as few were observed in a comparison of historic and recent aerial photography. Bed materials include boulders, cobbles, and gravels, with different dominant particle sizes in different sections of the channel, or with mixtures of all three particle sizes in the same reach. Unlike the channel reaches upstream of Ralston Afterbay, no bedrock exposures were visible along the channel bottom. Most of the first 18 miles below Ralston Afterbay are dominated by boulder to cobble sized material. The next downstream seven miles of this reach are dominated by smaller materials, typically cobble and gravel. Previous studies performed by Ayres and Associates (1997) found a similar trend in particle size fining in the downstream direction from Ralston Afterbay. Based on pebble count surveys performed at the head of selected bars, coarse, cobble material was more prevalent in the uppermost 12 miles of the river below Ralston Afterbay, with smaller gravel material dominating in the lower 12 miles, including below the confluence with the North Fork American River.

A small 1.2-mile long section within the peaking reach known as Ruck-A-Chucky Rapids is a B type channel. This reach is characterized by a narrow valley with no bars. The valley narrowing is due to differences in lithology (rock type). The majority of the Middle Fork American River downstream of Ralston Afterbay is comprised of weaker metasedimentary rocks, while the Ruck-A-Chucky Rapids reach is comprised of ultramafic, serpentinite bedrock, which is more resistant to erosion (Ayers Associates 1997). Large boulders within the reach were delivered to the channel by rockfalls. The coarse substrate forms a series of rapids with irregularly-spaced pools, typical for the B channel type.

Sand was the dominant particle size for a short, one mile long reach immediately upstream of Ruck-A-Chucky Rapids. This accumulation of sand is due to the local constriction formed at the rapids, which controls the channel hydraulics at higher flows, causing backwater conditions and the deposition of fine sediment.

Duncan Creek

The one mile reach immediately upstream of the confluence with the Middle Fork American River is a steep (10% gradient), highly entrenched, A type channel. A channel types have the steepest slopes compared to the other Rosgen channel types, and are typically confined in narrow bedrock canyons. These stream types typically exhibit a high energy/sediment transport potential and a relatively low in-channel sediment storage capacity. The coarse materials on the Duncan Creek channel bed and banks provide channel stability and contribute minimal amounts of sediment to the channel.

Upstream of this first mile, the stream gradient flattens; although a wide range of high gradients, from 1.4% to 6%, occurs. The channel is relatively straight, with low sinuosity

values. The remaining 7.6 miles of Duncan Creek up to the diversion dam, is a moderately entrenched B/F type channel. Bedrock, usually in combination with boulders and gravels, was found throughout the channel.

Rubicon River

The 5.6 mile long reach of the Rubicon River immediately downstream from Hell Hole Dam is classified as a C channel type. This section of the Rubicon River is known as the 'Parsley Bar' Reach and is an alluviated valley flat that demarcates the most downstream limits of glaciation. In addition, this reach aggraded by approximately 7 feet (ft) with material derived from the 1964 failure of Hell Hole Dam. Erodible sections of the stream valley within this reach were also widened by the flood (Scott and Gravlee 1968). The dam failure also affected channel geomorphology further downstream, extending to the lower reaches of the North Fork American River near Folsom Reservoir (Scott and Gravlee 1968). The flood surge stripped hillslope colluvium from the base of the steep valley side slopes adjoining the channel. In addition, the flood surge triggered landslides that deposited material into the river, resulting in a net aggradation of the channel (Scott and Gravlee 1968). The channel gradient downstream of Hell Hole Dam is generally 1% to 2%, except for some higher gradients (up to approximately 4%) in localized areas.

The remaining 24.7 river miles of the Rubicon River is similar to most of the Middle Fork American River above Ralston Afterbay, with a highly to moderately entrenched and confined, steep gradient channel. Almost all of the Rubicon River is comprised of rapidly alternating, short sections of either F or B channel types, resulting in a combined B/F Rosgen channel type classification. Boulder and/or cobble are the dominant bed particle size. Similar to the upper Middle Fork American River, bedrock outcrops were observed. Gravels were also plentiful along the Rubicon River, particularly in pool tailouts and velocity shadows created by boulders.

Long Canyon Creek

The lower half of Long Canyon Creek from the confluence with the Middle Fork American River (RM 0.0) to RM 7.0, is characteristic of an A channel type. The channel has a steep gradient (approximately 5%), low sinuosity, low width to depth ratio, and is highly entrenched. This lower seven mile-long reach is a confined, V-shaped channel structurally controlled by bedrock exposures. Boulders, cobbles, and gravels are commonly present.

The upper third of Long Canyon Creek, from RM 7.0 to RM 11.3 (confluence with North Fork and South Fork Long Canyon creeks), lies within a wider, U-shaped valley section that is slightly less entrenched compared to the lower half of Long Canyon Creek, and has a moderate width to depth ratio F channel type. The overall channel gradient is less than the downstream reach (approximately 2%), with steeper gradients in localized areas. Short sections of bedrock exposures (500 ft or less) were frequently observed in this upper reach. Boulders and cobbles usually were the co-dominant bed material

size, although gravels also were equally co-dominant with boulder and cobble on occasion.

North Fork Long Canyon Creek

North Fork Long Canyon Creek, from the diversion (RM 3.1) downstream to the confluence with South Fork Long Canyon Creek is a B channel type. Stream gradients range from approximately 2% to 5%. The channel is characterized by low sinuosity. Bedrock exposures were frequently observed throughout the reach. Boulders, cobble, and gravel were found in approximately equal proportions on the channel bed.

South Fork Long Canyon Creek

South Fork Long Canyon Creek from the diversion (RM 3.3) downstream to the confluence with the North Fork Long Canyon Creek is also identified as a B channel type. Channel gradients range from approximately 2% to 5%, and channel sinuosity is low. Bedrock exposures frequently were observed throughout the reach. Cobble and gravel were usually measured in approximately equal proportions on the channel bed.

8.3.2 Sediment Supply and Sediment Transport Characteristics

All of the bypass reaches were characterized as mixed bedrock-alluvial channels. The mixed bedrock-alluvial channels have frequent bedrock/boulder exposures, usually with coarse steps and riffles (boulders), that are either interspersed with channel sections where alluvial materials of smaller sizes (cobble and gravel) collect, or there is a shallow mantling of alluvial material. The gradient and morphology of the steeper gradient mountain channels, indicative of most of the bypass reaches associated with the MFP, are highly variable, and are prone to forcing by external influences, such as bedrock exposures, faulting, and large bed particle sizes recruited to the channel from mass-wasting along steep canyon walls (Montgomery and Buffington, 1997). In addition, high gradient mountain streams typically are considered to be supply limited. Supply limited channels are able to transport considerably more material than is delivered to them by the Watershed, resulting in either bedrock, or mixed bedrock-alluvial channels.

The Middle Fork American River below Ralston Afterbay continuing downstream to the North Fork American River is considered to be transitional between supply limited and transport limited. This channel segment is entirely alluvial. The pool-riffle bedform and large sediment storage features (bars) are characteristic of the alluvial channel type. Alluvial channels adjust over long periods of time so that the sediment supplied to them is transported under the prevailing flow regime. The channel is neither aggrading nor degrading and the dimensions of the channel are stable.

Most of the study streams have limited amounts of alluvium stored in the river channel (i.e., as bars) or on the valley bottom (i.e., terraces). The main sediment sources along the study streams are shallow slope failures and erosion of stored alluvium (e.g., banks and terraces). Other sediment sources are likely associated with debris flows from steep tributary channels. Boulders are also present throughout the study streams, which were likely derived in part from mass-wasting processes, such as rockfalls, along

the inner gorge sections. Areas of glacial deposits, which are poorly consolidated to unconsolidated sediments, (primarily till) are also recognized as significant sources of sediments. Exposed deposits were observed on side slopes and banks along the North Fork Long Canyon Creek, South Fork Long Canyon Creek, and upstream portions of the Rubicon River.

The sediment supply and transport characteristics associated with each of the study streams are discussed in more detail below.

Middle Fork American River

Sediment contributions to the Middle Fork American River between French Meadows Dam and Ralston Afterbay occur from debris slides, rock falls, and debris torrents. Each sediment delivery mechanism occurs in roughly equal proportions. All of these mass-wasting sediment production processes tend to occur on an infrequent, episodic basis (PCWA 2006a; Bechtel 1997). Debris flows originating from steep-gradient tributaries are also likely sediment contributors.

Rockfalls occur frequently along the inner gorge canyon of the Middle Fork American River above Ralston Afterbay. Rockfalls may deliver significant amounts of very coarse material (boulders) to the stream channel. As such, much of the boulder material delivered to the channel by rockfalls is not movable by the more frequently occurring flows. These coarse bed elements result in a channel that is relatively less adjustable compared with more alluvial, self-formed channels.

Two-thirds of the debris torrents located along this section of the Middle Fork American River were found within the boundaries of the Star Fire, which burned through the area in August-September 2001. The higher frequency of debris torrents in this area is likely related to the loss of forest vegetation, although increased visibility of the hillslopes due to the open vegetative canopy after the fire may have enhanced the identification of debris torrents in this area compared to other areas that were not burned. Sediment load transported by the Middle Fork American River downstream from French Meadow Dam is captured in Middle Fork Interbay.

Fine sediment in pools was measured at selected locations along the Middle Fork American River above Ralston Afterbay, the lowermost portion of the Rubicon River above Ralston Afterbay, and the North Fork of the Middle Fork American River following the 2006 Ralston Ridge Fire. The fire occurred in late August/early September 2006 and was located primarily along the Middle Fork American River between Middle Fork Interbay and Ralston Afterbay. Sediment studies were conducted in October 2006 on each of the streams to identify existing sediment conditions in pools prior to the 2006-2007 rainfall and high flow seasons. A commonly used quantitative method for measuring the presence of fine sediments in pools, known as V^* (Lisle and Hilton 1991), was performed in selected areas of the river potentially affected by the Ralston Ridge Fire. V^* measurements are used to evaluate and monitor the supply of mobile sediment in the channel and to detect fine sediment inputs to the stream over time. The results of the V^* baseline study on the Middle Fork American River, the Rubicon River, and the

North Fork of the Middle Fork American River indicated that all of the pools sampled (12 pools) contained low amounts (<0.1) of fine sediment. The V^* data in these reaches suggested that there is adequate flow to transport fine sediments, and prevent channel sedimentation under the current flow regime. More detailed information about the V^* measurements, including methods and results, is included in the 2006 Physical Habitat Study Report (PCWA 2007) contained in SD-G.

In general, sediment transport capacity decreases in the downstream sequence of channel morphologies in mountainous terrain, as the relative valley wall confinement and channel slope decrease downstream. In conjunction with reduced transport capacity, total sediment supply generally increases in a downstream direction. Along the Middle Fork American River, the peaking reach can be described as transitional between supply limited and transport limited, compared to the bypass reach upstream which is supply limited. The greatest number of mass wasting events (sediment contributions) to the channel was identified within this reach compared to the other study streams. Sediment contributions to the peaking reach primarily occur from debris slides, with a total of 32 debris slides identified along the reach during 2006. Additional sediment sources were occasionally observed included debris torrents, rock falls, and bank erosion on the outside of meander bends. Throughout the peaking reach, large channel bar deposits were observed. Based on the channel slope, small particle size, significant amount of bar storage and pool-riffle channel morphology, and the peaking reach has a relatively lower transport capacity compared with the MFAR and Rubicon River bypass reaches.

Suspended sediment has periodically been collected by the USGS at two gaging stations within the peaking reach. The two gaging stations are Middle Fork American River near Foresthill (USGS No. 11433300), which is just below Oxbow Powerhouse, and Middle Fork American River near Auburn (USGS No. 11433500), which is between Mammoth Bar and the confluence with the North Fork American River. The suspended sediment sampling performed by the USGS consisted of grab samples that were used to calculate tons per day (tpd) of suspended sediment discharge (SSD). Most of the data were collected after PCWA hydroelectric facilities became operational. The grab samples at the Middle Fork American River near Foresthill gage were collected in March, July, and October 1979. At the Middle Fork American River near Auburn gage, suspended sediment was collected periodically from October 1956 through September 1967, with an average of eight samples per year, and three times in 1979 during the same months as the upstream gage. The SSD data is displayed on Figure 8-1. In general, higher suspended sediment loads occur during high flow events, while lower flow events transport relatively low suspended sediment loads. Typical for suspended sediment load measurements and SSD calculations, there is a fairly large amount of scatter in the data on the Middle Fork American River. For example, over 18,000 tpd of sediment was measured for a flow of 9,000 cubic feet per second (cfs) (1.5-year unregulated flow event,) on March 7, 1960, while on March 7, 1967 33,500 tpd was measured for a flow of 9,200 cfs. The highest SSD measured was on December 23, 1964, following the Hell Hole Dam failure and flood surge, with an estimated 273,000 tpd, which occurred prior to the completion of the MFP facilities. In 1979, similar suspended sediment loads were measured at both stream gages for similar flows.

Since the data set from the SSD sampling at these two gages is small, the conclusions that can be drawn from the data are limited. The boundaries at which the lowest discharge will mobilize and transport suspended sediment or the highest suspended sediment load carried in this reach can not be determined. However, the data record does indicate that there is a suspended sediment load, and that there is some sediment transport which is occurring under the present-day flow regime.

Duncan Creek

A combined total of 11 sediment contribution sites were observed along Duncan Creek. These sites consisted of debris slides, rock falls, and eroding banks. The predominant bedrock, step-pool, and cascade channel bedforms are considered indicative of a supply-limited channel condition.

Rubicon River

Sediment contributions from 24 sites were identified with debris slides being the most common mass-wasting process. Nearly all sediment contribution occurs within the 23-mile reach downstream of the South Fork Rubicon River confluence (PCWA 2006a; Bechtel 1997). However, no tributaries to the Rubicon River, except for Long Canyon Creek, were examined as part of the PCWA 2005 or 2006 geomorphology studies.

As a result of the Hell Hole Dam failure and related flood surge in 1964, Scott and Gravlee (1968) found that over 70 landslides along the steep-sided canyon walls of the Rubicon River were triggered, either during or shortly after the flood wave. These landslides contributed significant amounts of coarse sediment to the channel. The upper reaches of the Rubicon River may be coarser today than prior to the flood surge as finer sediments were transported downstream and lag deposits of boulders from the landslides were left behind. Boulder deposits along the channel margins and on top of bars were recognized during recent field studies (PCWA 2006a; PCWA 2007). These coarse deposits from the flood surge were also observed in the comparison of the historic and recent aerial photography. The Rubicon River has been identified as the principal source of sediment to Ralston Afterbay Reservoir (Bechtel Corporation 1997). The proportion of sediment load contributed from Long Canyon Creek, the Middle Fork American River, and the Rubicon River is currently unknown.

Long Canyon Creek

A total of 18 mass wasting sites were identified along Long Canyon Creek in 2005. Rock falls were the most common type (17) of sediment contribution observed along Long Canyon Creek. One debris slide was mapped, located at RM 10.5. Channel characteristics indicate Long Canyon Creek is supply limited and is able to transport considerably more material than is delivered to the Watershed, resulting in either a bedrock, or mixed bedrock-alluvial channel.

North Fork Long Canyon Creek

Three debris slides were observed along North Fork Long Canyon Creek in 2005. In addition, several areas that exhibited bank-cutting and bank erosion were observed.

South Fork Long Canyon Creek

Large scale mass wasting events were not identified along the bypass reach in 2005. However, eroding channel banks were noted throughout the reach during the field surveys.

8.3.3 Stream Channel Sensitivity to Disturbance

Stream channel sensitivity, or the responsiveness of the stream channel to change, is based on several factors that depend upon the channel type, as well as the nature, magnitude, and persistence of the disturbance. The physical setting of the channel including confinement, bank materials, vegetation, fires, or other historical disturbances is also important in predicting channel response. Some channel types are more responsive to alterations of the flow and sediment regime than other channel types. In general, bedrock or mixed bedrock-alluvial channel types are less responsive to alterations than entirely alluvial channels. Several different approaches were used to characterize the stability of study streams and identify reaches more susceptible to alterations in flow or sediment regime.

The combined results indicate that most study stream channels, including the larger Middle Fork American and Rubicon rivers, are relatively stable and have a relatively low channel responsiveness potential. This is due in part to the periodic exposures of bedrock and boulders in the channel and valley walls throughout most of the study streams, and to the highly to moderately entrenched channel morphology. Shorter sections of river that have fair or poor channel stability are interspersed between longer stable sections along Duncan Creek, the Middle Fork American River between French Meadows Dam and Ralston Afterbay, and the Rubicon River.

The Middle Fork American River below Ralston Afterbay, and the North Fork and South Fork Long Canyon creeks exhibit relatively greater potential for adjustment and channel responsiveness. These stream reaches have lower gradients, are dominated by finer, more erodible material, and have bedforms indicative of more responsive channel types. This does not mean that adjustments cannot occur in other channel reaches, only that the types and magnitude of potential adjustments are relatively less. For all of the study streams, the most likely channel response to change in flow and sediment regime, even in the steeper gradient, entrenched channels, is a coarsening of the bed particle size if there are high flows that are adequate to transport bed sediments. Based on the channel types present, other types of adjustments that could occur on the more responsive Middle Fork American River below Ralston Afterbay and North Fork and South Fork Long Canyon creeks, include changes in sediment storage (channel bars), depth, width, and slope.

A summary of the channel responsiveness along each of the study streams is presented below.

Middle Fork American River

Most of the Middle Fork American River between French Meadows Dam and Ralston Afterbay was rated as having 'low' response potential due to the extensive length of transport channel types including, bedrock, step-pool, and cascade bed-forms. A small fraction of this reach was rated as having 'high' response potential because the various channel reaches exhibited an intermediate type plane-bed/forced pool-riffle morphology. The Rosgen Level III evaluations performed at representative locations within this reach supported these findings. Segments with predominately 'good' channel stability ratings were common with infrequent segments rated as 'poor', indicating a higher potential for bank erosion.

The 24-mile long pool-riffle section of the Middle Fork American River downstream of Ralston Afterbay is potentially one of the most responsive MFP study reaches. With the exception of the Ruck-A-Chucky Rapids, morphological characteristics such as channel geometry (width and depth), sediment storage (channel bars), and particle size are potentially subject to adjustment in response to changes in the flow and sediment regime. Based on the results of the Rosgen Level III assessments conducted at representative locations, this reach was rated to have 'good' or 'fair' bed and bank channel stability.

Duncan Creek

More than half (approximately 65%) of the surveyed Duncan Creek was designated as having a 'low' response potential or sensitivity to disturbance. The remaining locations (approximately 45%), which are interspersed between the stable reaches, were rated as having 'moderate' or 'high' response potentials. The reaches with a 'low' responsiveness rating have a high prevalence of bedrock and steep gradient step-pool and cascade channel types. Conversely, the 'moderate' or 'high' ratings occur in reaches with finer channel bed material compared to the other reaches and have a plane-bed channel morphology. Based on the Rosgen Level III assessments at representative locations, a similar proportion of 'low' bank erosion potential to 'moderate' or 'high' bank erosion potential was observed.

Rubicon River

Most of the Rubicon River is designated as having a 'low' response potential and 'good' channel stability. Locations with 'high' response potential or 'poor' channel stability are located in a five mile long reach downstream of Hell Hole Dam. This reach of stream is located in a wider, less confined valley bottom than other sections of the river, and was subject to aggradation and alteration by the Hell Hole Dam failure in 1964. Downstream of the confluence with the South Fork Rubicon River, 'poor' channel stability ratings are interspersed within the 'good' channel stability ratings. Segments with 'poor' channel stability tend to occur in areas where large mass wasting sites were observed.

Long Canyon Creek

Long Canyon Creek predominantly consists of areas designated with 'low' response potential and 'good' or 'fair' channel stability. Smaller, infrequent areas were also identified as having 'moderate' response potential or 'poor' bank erosion. *North Fork and South Fork Long Canyon Creeks*

North Fork and South Fork Long Canyon creeks are considered to have 'high' and 'moderate' response potentials, respectively. The findings from the Rosgen Level III assessments were similar. Both the North Fork and South Fork Long Canyon creeks have 'fair' to 'poor' channel stability ratings. The lower stability ratings as compared to the other bypass reaches are due to the predominately finer gravel and cobble bed material present in these streams and interspersed locations of bank erosion and/or channel bank undercutting.

8.3.4 Comparison of Historic and Recent Channel Conditions

Historic aerial photographs (1961-1962) were compared with low-altitude videography (2002-2005) to document any changes in pre- and post-Project channel conditions. This effort focused on the Middle Fork American River and the Rubicon River. Geomorphic features of the smaller study streams could not be distinguished in the historical aerial photographs, and thus were not suitable for comparison. The results of the channel comparisons indicated that little change in sediment storage (bar formations) or channel position or planform has occurred on either the Middle Fork American River or the Rubicon River. In addition, results of other studies on channel conditions and stability in the Middle Fork American River and Rubicon River, including Scott and Gravlee (1968) and Watermark Engineering (1999 and 2004), were reviewed. Results from these studies indicated that in certain locations on these rivers, changes in channel dimensions have occurred over time.

A summary of findings comparing the historic and recent channel condition along the Middle Fork American River and Rubicon River is presented below. More detailed information is available in PCWA's 2005 Physical Habitat Characterization Report contained in SD-G.

Middle Fork American River

The Middle Fork American River between French Meadows Dam and Middle Fork Interbay is comprised of large boulders with exposed bedrock. Boulders appear to be the dominant particle size, with scattered indefinable smaller sized sediment also present. Few to no depositional features were identified in either the historic or the 2005 low-altitude video. At a few selected locations, bar deposits comprised of coarse material, presumably boulders, were discernable in both the historical aerial photographs and in the 2005 low-altitude video, indicating little change in particle size at these locations.

The Middle Fork American River between Middle Fork Interbay and Ralston Afterbay is entrenched in a narrow canyon with a dense canopy cover. Geomorphic features are

also similar in this reach between the historic and recent aerial photographs along sections where the channel was clearly visible. Significant differences in sediment storage characteristics were not observed between the two time periods. Visual comparisons between the photographs augmented by the low-altitude video suggest that current channel width is similar to the width of the 1960's channel. Channel sinuosity and planform also appear similar between the historical and recent aerial photographs.

Recent sediment storage and channel geomorphic characteristics below Ralston Afterbay were found to be similar to historic characteristics. In both sets of the aerial photographs, bar-pool-riffle bedforms are common and a significant amount of sediment is stored in point bars and alternate (side) bars. Approximately 75% of the channel bars observed in the recent aerial photographs are similar in frequency, size, and particle size composition to that observed in the historical aerial photographs. At a few locations (approximately 5% of the channel), bars that were present in historical aerial photographs were not observed in the recent aerial photographs. Approximately 8% of channel bars appear to be longer and/or to be of a larger particle size composition in the recent aerial photographs compared to the historical aerial photographs.

Channel planform and sinuosity also appear similar between the historic and recent aerial photographs along the MFAR below Ralston Afterbay. One relatively small change in the channel planform was observed just downstream of Ralston Afterbay where a cutbank has migrated in a southern direction. Shifts in channel bar position were identified along 12% of the stream segment, resulting in a change in the thalweg position.

Overall increases or decreases in sediment storage at these locations were not observed between the historic and recent aerial photographs. Although changes in the channel were not evident in the aerial photography, results of recent studies by Scott and Gravlee (1968) and Watermark Engineering (1999 and 2004) suggested that changes in channel dimensions have occurred at certain locations. Changes in thalweg elevation (0.2 feet of aggradation) were measured following the Hell Hole Dam failure as measured at the Middle Fork American River near Auburn stream gage (USGS No. 11433500) (Scott and Gravlee 1968). At the Middle Fork American River near Foresthill stream gage (USGS gaging station No. 11433300), the channel dimensions changed from a wide shallow channel to a narrow, incised channel as a result of bed scour and incision over a 24-year period extending from 1980 to 2004 (Watermark Engineering 1999 and 2004). This report also states that the greatest changes in channel dimensions occurred following high flow events (February 1983 and early 1997). The authors did not provide an explanation for the channel down-cutting and the causes are not known at this time. In addition, the study was only conducted at one location, and the extent to which conditions at this location represents conditions at other locations downstream of Ralston Afterbay is not known. This incision at this location may be a response of the flow down-cutting through the sediment that had been deposited following the Hell Hole Dam failure in 1964 that was documented by Scott and Gravlee (1968). Conversely, the down-cutting could be a response to sediment capture by the reservoirs upstream. Down-cutting and/or coarsening of the channel bed (finer

sediments are transported out of the reach, leaving a coarser lag behind) may occur when sediment supply is reduced, particularly due to removal or capture of larger particle sizes associated with bedload sediments, and flows capable of transporting sediments are present..

Rubicon River

Since the 1960's, the Rubicon River has changed dramatically in channel morphology immediately downstream from Hell Hole Dam. Aggradation, channel widening, and increased sediment storage, with an increase in the size and frequency of bars, are evident in the aerial photography. Scott and Gravlee (1968) concluded that these changes were caused by the 1964 failure of Hell Hole Dam and the resulting flood surge. The most dramatic changes to the channel occurred within the approximately five mile reach downstream of Hell Hole Dam. Scott and Gravlee (1968) estimated that material from the dam failure was deposited immediately downstream resulting in an increase in the thalweg elevation of 7 ft or more. Channel width increased from approximately 100 ft to over 300 ft.

Effects that are likely associated with the flood surge were also identified much further downstream of the dam. Comparison of historic and recent aerial photography indicate that the frequency and size of bars increased. Furthermore, the channel thalweg position has adjusted up to 2 to 3 miles upstream of Ralston Afterbay. The appearance of new bars and adjustments of the channel planform along the thalweg are evidence of increased sediment deposition.

8.4 REFERENCES

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TABLE

Table 8-1. Historical Aerial Photographs Obtained for the Middle Fork American River Project.

Scale	River Mile		Date of Photo	Photo Numbers	USGS Discharge (cfs)	
	Start	End			Middle Fork American River Near Auburn CA (RM 1.0)	Middle Fork American River at French Meadows, CA (RM 45)
Middle Fork American River						
1:6000	16.5	20.3	7/7/1961	MK-UAB 1-1 to 1-19	181	12
1:6000	34.1	38.8	7/7/1961	MK-UAB 1-26 to 1-35	181	12
1:6000	46.5	47.1	7/7/1961	MK-UAB 2-9 to 2-16	181	12
1:12000	15.6	29.2	7/7/1961	MK-UAB 2-57 to 2-72	172	11
1:12000	22.1	30.8	8/30/1961	MKE-TL 1-63 to 1-71	49	0.9
1:12000	25	31.2	8/30/1961	MKE-TL 1-56 to 1-62	49	0.9
1:12000	27.9	31.2	8/30/1961	MKE-TL 1-51 to 1-55	49	0.9
1:12000	33.8	37.5	8/16/1961	MKE-TL 1-16 to 1-21	56	1.4
1:12000	33.8	37.5	8/30/1961	MKE-TL 1-47 to 1-50	49	0.9
1:12000	35.8	39.7	8/16/1961	MKE-TL 1-22 to 1-35	56	1.4
1:12000	44.8	French Meadows Res.	7/7/1961	MK-UAB 2-46 to 2-57	181	12
1:12000	47.2	53	8/15/1961	MK-UAB 3-34 to 3-40	54	1.4
1:15840	0	1.3	8/2/1962	PLA 5-19 to 5-18	90	-
1:15840	0.1	4.1	7/28/1962	PLA 2-30 to 2-32	105	-
1:15840	3	8.4	11/29/1962	PLA- 12-3 to 12-2		
1:15840	5.3	10.4	8/1/1962	PLA 4-209 to 4-211	93	6.1
1:15840	9.5	12.5	8/2/1962	PLA 5-120 to 5-121	90	5.9
1:15840	11.8	17.2	8/2/1962	PLA 5-124 to 5-125	90	5.9
1:15840	15.5	21	8/2/1962	PLA 5-191 to 5-193	90	5.9
1:15840	29	33.5	8/11/1962	PLA 6-53 to 6-55	86	4.3
1:15840	32.1	35.8	8/11/1962	PLA 6-39 to 6-40	86	4.3
1:15840	38	41.9	8/1/1962	PLA 4.58 to 4-62	93	6.1
1:15840	41.6	45.3	8/1/1962	PLA 4-32 to 4-35	93	6.1

Table 8-1. Historical Aerial Photographs Obtained for the Middle Fork American River Project (continued).

Scale	River Mile		Date of Photo	Photo Numbers	USGS Discharge (cfs)
	Start	End			South Fork Rubicon at Georgetown (Enters Rubicon at RM 22.5)
Rubicon River					
1:6000	0	2.1	7/7/1961	MK-UAB 1-20 to 1-25	11
1:6000	Hell Hole Dam		7/7/1961	MK-UAB 2-1 to 2-8	11
1:6000	Hell Hole Dam		7/7/1961	MK-UAB 1-36 to 1-44	11
1:12000	0	4.7	7/8/1961	MK-UAB 2-73 to 2-82	11
1:12000	25.8	Upper Water- shed	7/7/1961	MK-UAB 2-22 to 2-45	11
1:12000	29.3	Hell Hole Dam	8/16/1961	MKE-TL 1-36 to 1-46	
1:15840	2	7.2	8/14/1962	PLA 7-129 to 7-131	5.2
1:15840	5.6	11.5	8/11/1962	PLA 6-46 to 6-49	6
1:15840	9.8	14	8/1/1962	PLA 4-205 to 4-206	6.6
1:15840	11.8	16.7	8/1/1962	PLA 4-152 to 4-154	6.6
1:15840	14.3	18.1	8/1/1962	PLA 4-48 to 4-49	6.6
1:15840	15.3	20.4	8/1/1962	PLA 4-45 to 4-46	6.6
1:15840	17.8	23	8/14/1962	PLA 7-174 to 7-176	5.2
1:15840	20.8	27.7	11/3/1962	PLA 11-151 to 11-154	No data

Scale	River Mile		Date of Photo	Photo Numbers	USGS Discharge (cfs)
	Start	End			Duncan Canyon Creek near French Meadows CA (RM 6)
Duncan Creek					
1:12000	6.5	8.6	8/16/1961	MKE-TL 1-1 to 1-10	0.5
1:12000	8.6	Upper Water- shed	8/16/1961	MKE-TL 1-11 to 1-15	0.5
1:15840	0	4.7	8/1/1962	PLA 4-58 to 4-62	1.6
1:15840	0.5	7.4	8/1/1962	PLA 4-32 to 4-36	1.6

Table 8-1. Historical Aerial Photographs Obtained for the Middle Fork American River Project (continued).

Scale	River Mile		Date of Photo	Photo Numbers	USGS Discharge (cfs)
	Start	End			Long Canyon Creek near French Meadows, CA (RM 11.3)
Long Canyon Creek					
1:15840	0	3+	8/14/1962	PLA 7-129 to 7-131	0.4
1:15840	0.3	3.8	8/11/1962	PLA 6-50 to 6-51	0.4
1:15840	2.6	5.8	8/11/1962	PLA 6-43 to 6-44	0.4
1:15840	4	7.4	8/1/1962	PLA 4-200 to 4-202	1.1
1:15840	5.7	8.6	8/1/1962	PLA 4-146 to 4-148	1.1
1:15840	7.4	11.2	8/1/1962	PLA 4-55 to 4-57	1.1
1:15840	9	11.2	8/1/1962	PLA 4-37 to 4-39	1.1
North Fork Long Canyon Creek					
1:6000	2.55	Upper Watershed	7/7/1961	MK-UAB 1-45 to 1-56	No data
1:12000	0.3	Upper Watershed	8/16/1961	MKE-TL 1-36 to 1-46	No data
1:15840	0	2	8/1/1962	PLA 4-37 to 4-39	No data
South Fork Long Canyon Creek					
1:12000	2.8	Upper Watershed	8/16/1961	MKE-TL 1-36 to 1-46	No data
1:15840	0	1.5	8/1/1962	PLA 4-37 to 4-39	No data

FIGURE

Figure 8-1. Suspended Sediment Discharge Lower Middle Fork American River (1956-1979).

