MokeWISE Program Draft Technical Memorandum:
Environmental Conditions Overview

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Prepared by:

Balance Hydrologics, Inc. (Anne Senter; Barry Hecht, CEG, CHg and Gregory Pasternack, PhD with UC Davis) and

Hanson Environmental, Inc. (Chuck Hanson, PhD)

in Association with RMC Water and Environment

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1. Introduction

Basin-scale planning is currently underway within the Mokelumne River Watershed under the auspices of the Upper Mokelumne River Watershed Authority (UMRWA) and the Eastern San Joaquin Groundwater Basin Authority (GBA), which represent the Mokelumne-Amador-Calaveras (MAC) and Eastern San Joaquin (ESJ) Integrated Regional Water Management (IRWM) Planning Regions, respectively. Grant funding has been secured from the Proposition 84 Integrated Regional Water Management Program to develop the Mokelumne Watershed Interregional Sustainability Evaluation (MokeWISE) program.

The MokeWISE program has emerged following years of dialogue among a diverse set of stakeholders in the Upper and Lower Mokelumne River watersheds. MokeWISE, when concluded, is expected to yield a scientifically based and broadly supported water resources program that includes sustainable approaches to water resources management in the Mokelumne River watershed. This resources program will foster approaches that are consistent with physical and geomorphic processes that provide enhanced habitat conditions consistent with geomorphically appropriate instream channels, floodplains and riparian corridors for key life stages of resident and migratory fish species and other aquatic and terrestrial species.

As part of the MokeWISE program, members of the Mokelumne Collaborative Group (MCG), the stakeholder group driving development of the MokeWISE program, will explore developing a set of new or newly envisioned water supply alternatives from a variety of water sources, potentially including the Mokelumne River. This report provides a brief overview of current hydrologic, geomorphic, riparian and fishery conditions in the Mokelumne River, and provides an initial framework to help guide the Mokelumne Collaborative Group in developing and selecting alternatives. Gaining a general geomorphic and aquatic habitat understanding of channel- and landscape-forming processes in the Mokelumne River basin is essential for basin-scale planning by and for local stakeholders. It is critically important to retain geomorphic integrity and renewal processes within a watershed to the greatest extent possible. These natural physical processes affect sediment dynamics – which in the river include spawning gravel recruitment and well as instream aquatic habitat diversity important to fishery and other aquatic biota, and on the banks include supporting growth of and occasionally renovating riparian vegetation. The loss of natural stream functions due to extraction of water resources for other societal benefits is no longer an acceptable pathway, and the Integrated Regional Water Management program encourages alternatives that either minimize and mitigate the loss of natural stream functions or offset those losses with strategies that enhance them or provide additional resilience.

This report is broad in geographic scope and necessarily limited by the constraints of the planning structure. It provides an overview of existing conditions, and summarizes the ways in which flows drive geomorphic functions that ultimately provide ecological benefits to the river. In addition, a brief screening of potential challenges and opportunities that fall within the geomorphic and fishery purview is provided, along with general conclusions and suggestions for geomorphic data collection scenarios to enhance understanding of physical processes at the basin-scale and narrow the complexity of the geomorphic and aquatic habitat enhancement questions.

Once the collaborative group identifies potential Mokelumne supply concepts, this report will be expanded to describe qualitative geomorphic processes specific to those concepts that may affect the final selection process. Logically, the geomorphic scenarios will be developed to make fiscal and water-management sense both under normal conditions as well as under future climate change scenarios and episodic conditions which may inevitably affect the watershed in the years to come, such as post-fire, post-flood, post-landslide and during and after drought conditions. The process also identifies potential opportunities and constraints for protecting and enhancing conditions within the watershed for a diverse assemblage of resident and migratory fish and other aquatic and terrestrial species.

2. Current Conditions

2.1 Watershed Scale

The Mokelumne River drains about 627 square miles in the central Sierra Nevada. Mean precipitation in the watershed during 1981-2001 was 48 inches, with a range of 23-65 inches depending on geographic location (Null and others, 2010. In the Mediterranean-montane climate, most precipitation occurs October through May and generally falls as snow above about 3,000 to 5,000 feet in elevation, depending on temperature. As with all other Sierran watersheds, the flow regime of the Mokelumne River is highly dependent on annual snowpack. The California Department of Water Resources (CDM, 2011) projects that the effects of warming due to climate change, if experienced, will significantly alter mean annual runoff, thus affecting the ability of existing facilities to be fully utilized if runoff decreases. Overall, DWR projects that there will be less cold weather and more hot weather, with less light precipitation and more heavy precipitation. Higher temperatures on average could result in more winter precipitation falling as rain rather than snow, resulting in a 20-40 percent decrease in statewide snowpack (CDM, 2011; RMC, 2012). On the other hand, potential increases in water demands for irrigation and other uses as droughts become more common.

Null et al. (2010) performed an analysis using the WEAP21 rainfall-runoff model to better understand how individual watersheds might be affected with changes in runoff quantity and timing due to climate warming. The Mokelumne River watershed, along with the American

River watershed, was found to be most vulnerable to a combination of the three metrics that were studied: water supply, hydropower generation, and montane ecosystems. This result may indicate that the Mokelumne River watershed is less resilient to climate change than some of the other Sierran watersheds. Within the Mokelumne River watershed, reservoir storage as a ratio of watershed area is relatively large compared to other Sierran watersheds, at 0.70, and the runoff yield of the watershed is also comparatively large at 0.65; both metrics fall within the top 30% of the 15 studied watersheds. Assessment of potential climate warming impacts at the watershed scale provides a valuable planning tool at a local and regional scale that can provide water resources managers with general trends as understood through the spectrum of the WEAP21 model environment.

Natural processes such as fire and consequent loss of vegetative cover in the Mokelumne River watershed will continue to expose soils on hillslopes and in riparian corridors, leading to potential spikes in sediment yield that will gradually diminish as disturbances heal. The variation in yearly rainfall can result in moisture conditions ranging from extreme drought to very large episodic events that deliver a high proportion of sediment and wood into the system, similar to conditions seen in the winter of 2005-2006, where very heavy rains brought sediment and wood into reservoirs across the Sierran watersheds. Climate changes will likely result in warming as well as larger fluctuations in yearly precipitation, leading to more intense individual storms and earlier snowmelt. Each of these potential situations can result in more rain and less snowpack storage that could lead to larger floods, and lower summer or dry-year flows (Null and others, 2010; CDM, 2011).

The natural flow regime for the Mokelumne River has been highly altered by existing projects, including 13 impoundments that each hold greater than one thousand acre-feet of water (Null and others, 2010). The facilities that support this degree of water management have dramatically altered natural flows. On the other hand, the flow schedule for the PG&E project has been designed to mimic the natural hydrograph both in seasonal magnitude and in ramping rates, and to provide hydropower and water to around 1.5 million California residents. Other significant alterations to the natural environment include gold mining, gravel extraction, logging, channelization, and conversion of floodplains and riparian corridors to agricultural fields via shallow floodplain lake infill, channel cutoff and levee building (Kattelmann, 1996).

Although the Mokelumne River and its waters provide for consumptive water use, more water is often desired than is available from surface water alone. Agriculture and other developments have come to depend on groundwater as a reliable supplemental water source. Prior to development, groundwater generally infiltrated into the subsurface and moved from uplands areas to lowland areas further downstream. Below Camanche Dam, the Mokelumne River tends to be a losing stream (i.e., one in which surface water infiltrates into the groundwater system through the channel bed rather than groundwater filtering up into the wetted channel). Recent increases in planted acreage of permanent, irrigated crops with higher water demand such as orchards and vineyards have likely increased the rate of groundwater extraction.

2.2 Watershed above Pardee Dam

PG&E operates a large network of hydropower generation facilities that divert streamflows into over 30 miles of canals and tunnels to produce power (c.f., EDF and CHRC, 2000). Between PG&E and EBMUD, there are seven hydropower facilities that have a maximum 374 megawatts (MW) of total online capacity (Null and others, 2010). Potentially, other than winter floods and spring snowmelt flows that may overwhelm the system, almost all upper watershed flows are subject to flow attenuation as governed by hydropower licensing terms and as predicated by yearly precipitation and snowmelt patterns. Minimum streamflow requirements meant as partial mitigation for hydropower effects are recommended in the 2000 Federal Energy Regulatory Commission license for the PG&E project and a related settlement agreement, which specify flow requirements by month and water year type (FERC, 2000; FERC, 2001). Prescribed requirements are environmentally important, but do not replace natural flow conditions.

Hydropower development including dams, diversions, canals, forebays, and afterbays can effect channel geometry and channel interactions with local floodplain/riparian corridor habitat, as flows are stored, diverted and released according to prescribed schedules, regardless of specific flow requirements. Below diversion dams, for instance, the loss of sediment supply may lead to a coarsening of bed materials, potential incision and riparian encroachment into the formerly active channel.

The Mokelumne River watershed has a long history of mining operations. Over the past 160 years, mining operations have included placer mining for gold in the mid-1800s, dredge mining for gold, and hard rock mining for copper and zinc (Penn Mine and Poison Lake Mine) and gold (Blazing Star Mill and Mine, Lincoln Mine, Gwin Mine) (CVRWQCB, 2013). Land- and water-use practices over the years have included large, unregulated releases of acidic mine drainage into the Mokelumne River network that has included heavy metals such as mercury. Dissolved metals have been found in fish samples and riverbed sediments, and in reservoir sediments at Pardee and Camanche Reservoirs (Kattelmann, 1996). For instance, the Penn Mine is downstream of Pardee Reservoir and adjacent to Camanche Reservoir. It was mined for copper and zinc from 1861 to the 1950s before being abandoned. In recent years, the mine site including waste rock and runoff was remediated through a joint project by the State of California and the East Bay Municipal Utility District (SVRWQCB, 2010).

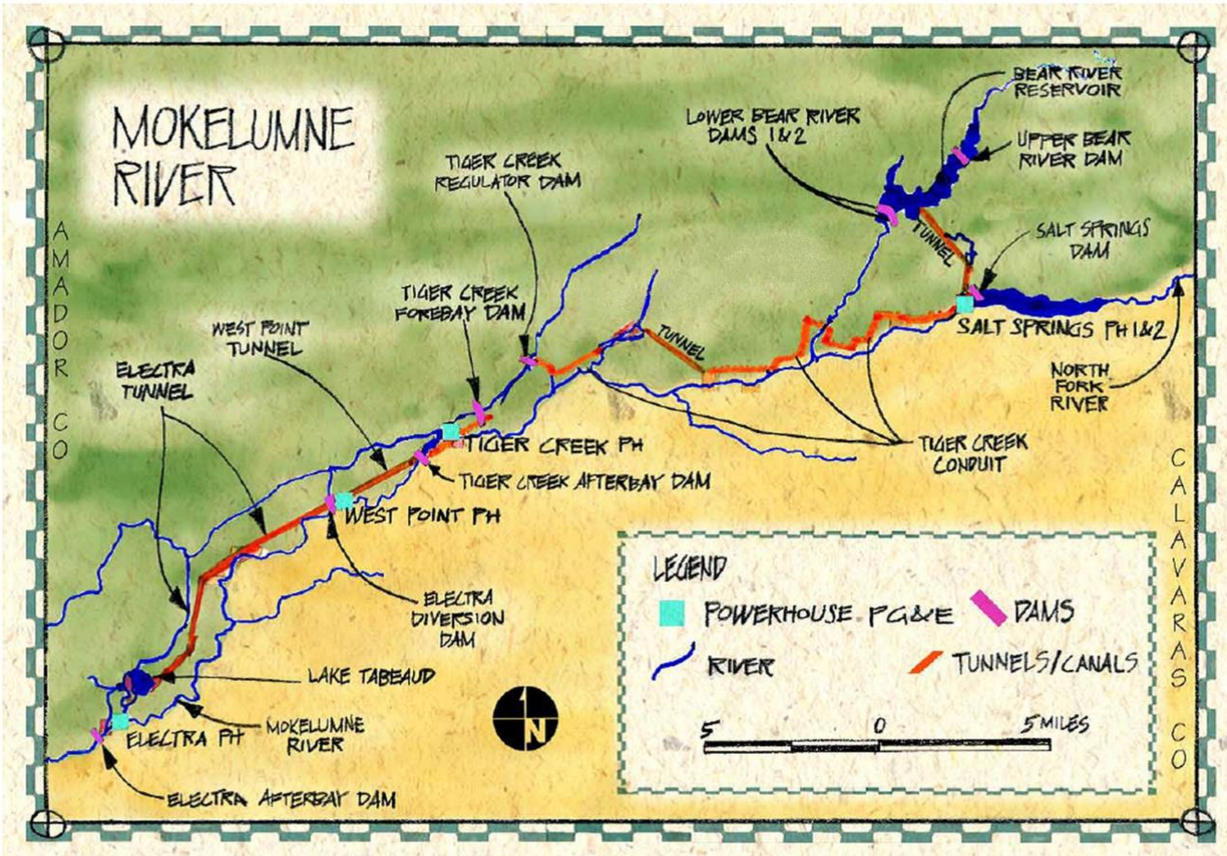

Figure 1. PG&E projects on the Upper Mokelumne River (modified from EDF and CHRC, 2000)

Land management related to timber harvesting, building of roads to provide access to and from the logging sites and redirecting runoff captured by roads can have dramatic effects on sediment and water yield, such as accelerated mass wasting, denudation of soils on steep mountain hillslopes, extension of the channel network, and gullying at channel heads. Potential increased fire incidence is a more natural form of denudation, yet fire suppression practices of the last 100 years have led to hotter-burning fires that burn hillslopes more completely. Landsliding potential may increase after logging or fire; both processes can lead to the deposition of large quantities of sediment into the channel network. Rapid delivery of sediment to the stream network, whether human-induced or naturally occurring, can yield elevated rates of suspended and bedload sediment transport, which affects water quality and can spread widely across downstream habitat. Denuded landscapes also result in increased peak flows, increased flow volume, decreased time to peak, and decreased flow duration (Kattelmann, 1996). There are also potential nonlinear cumulative effects when wildfire, logging, and road building occur in the same basin sequentially (MacDonald, 2000; Constantine and others, 2005). It is important that such cumulative impacts to fish and to other aquatic species, and to stream habitats from damming, water diversions, roads, logging, fire, agriculture, mining, grazing and other human development activities not be overlooked (Euphrat, 1992). A regionally specific study headed by the Sierra Nevada Conservancy, the Mokelumne Avoided Cost Analysis (MACA), is currently in development to address concerns related to increases in fire risks by studying the differences in cost between investing in active forest treatments and fuels reduction and post-fire costs, such as reducing the risk of large damaging fire in the upper watershed, restoring ecological functions and identification of specific areas that may be most important to restore for water quality and habitat (SNC, 2013).

2.3 Watershed at Pardee and Camanche Dams

The storage volume, landscape position and dam operations at Pardee and Camanche Dams are highly disruptive to the geomorphic continuity of the Mokelumne River watershed, as these two dams form an impenetrable boundary between the upper and lower watershed. Functions that are disrupted include flow magnitude, frequency, duration, timing and rate of change, which as a group are defined as flow attenuation features that can alter ecological and geomorphic processes (Poff and others, 1997).

Pardee Dam was completed in 1929. The East Bay Municipal Utility District (EBMUD) has the right to divert 325 million gallons of water per day (mgd) from this facility to Alameda and Contra Costa Counties (EBMUD, 2013). Camanche Dam was completed in 1964 to provide flood control and to help meet downstream water demands. A large proportion of the available water is stored and later released to the Mokelumne River, while larger organic materials (biological sediments) and inorganic sediments are mostly captured within the reservoirs. Dissolved organics and inorganics may pass through the dam, but not at a natural rate. These, too, can settle through the water column, changing concentrations and affecting water quality. Inorganic sediments entrained in the water column settle onto the reservoir bed except for very small particle sizes; thus, turbidity can increase but bedload transport ceases. Both Camanche and Pardee Reservoirs show signs of increasing rates of sediment accumulation (Kattelmann, 1996) in concert with a dramatic decrease in flow velocity due to containment. This watershed-scale discontinuity prevents the natural flow regime from maintaining the geomorphic and ecological integrity of the watershed. In many cases, not all geomorphic functions were considered in evaluating and mitigating effects when the dams were built; awareness of the environmental consequences of dams has grown in recent decades.

2.4 Watershed below Camanche Dam

Water regulation from a fluvial geomorphic perspective has had negative effects on the lower Mokelumne River environment, with positive effects for development such as flood control and water supply benefits. Pardee and Camanche Dams have fundamentally altered the ability of the river to perform geomorphic work downstream of these dams by capturing sediment and attenuating flows. Peak flows associated with winter floods and snowmelt hydrographs are significantly lower than pre-dam peak flows. Hydrologic analysis of pre-Camanche Dam flows over the period 1904-1963 showed that annual peaks exceeded 7,000 cubic feet per second (cfs) in about one-third of the years, while in post-dam years 1964-1999, annual peaks never exceeded 7,000 cfs (Pasternack and others, 2004). Median monthly flows for the geomorphically critical snowmelt month of May decreased on average by a factor of approximately six, from 3355 cfs before Pardee to 565 cfs after Camanche (flow records 1905–1929 and 1964–2003, respectively) (Escobar-Arias and Pasternack, 2011). Water storage in the reservoirs and maintenance of instream flows downstream of Camanche Dam throughout the year provide suitable habitat to support adult migration, spawning and egg incubation, juvenile rearing, and juvenile downstream migration by both fall-run Chinook salmon and steelhead.

Construction of Camanche provided Lodi, Woodbridge and surrounding areas with significant flood protection, particularly for floods of high recurrence intervals. Such 50- or 100-year events may occur only several times per century, yet they may alter habitat conditions perhaps almost as much as human habitations and infrastructure. Floods of moderate recurrence – the 5-, 10- and 20-year events that renew habitat, move and clean the large bed-material that 'armors' the channel, and promote fresh and renewed riparian vegetative growth – are disproportionately modulated and muted by Camanche, as they are by most mid-sized reservoirs. The dams provide some flood-protection benefits downstream during events of moderate recurrence, but to only a limited degree and at fairly specific locations. Such events also have little regulatory implications, and do not meaningfully affect flood-insurance premiums or availability. There may be 20 or 30 such events per century, a frequency which appreciably affects habitat and geomorphic configuration of the channel but which is lost due to the muted hydrograph created by dam effects. In summary, geomorphic conditions affecting natural values tend to benefit from control at the very highest of flows, those of the magnitude likely to induce massive flooding. The much more frequent lower-magnitude floods, though, have important geomorphic functions which can be provided without impairing conventional flood-protection benefits.

The term "bankfull" flow is defined as the flow that just fills a channel up to the bank tops (Williams, 1978), and begins spilling over onto the active geomorphic floodplain. It is widely thought that near-bankfull flow is needed to maintain and renew the geomorphic integrity of a channel. Hydrologic analysis has found that it is the natural flow rate that returns to a particular location in a stream at approximately a 1.5 to 2-year return interval (Knighton, 1998). Prior to Pardee Dam, the estimated 2-year flow was almost 9,000 cfs. Post-Pardee Dam, a 2-yr flow was reduced to about 3,400 cfs due to diversion and flow regulation. Camanche Dam further reduced the 2-year return flow to about 2,000 cfs. Statistically this means that the historic 9,000 cfs 2-year flow may now occur only once every 50 years (Edwards, 2004). Note that Camanche Dam cannot release more than 5,000 cfs through its facilities, so any amount above that goes over the emergency spillway that bypasses the Day Use Area. In the 49 years since Camanche came online, the maximum mean daily flow at the dam was only 5,750 cfs. Loss of sediment continuity in a watershed can create an effect termed 'hungry water' (c.f., Kondolf, 1997). This change in geomorphic functionality can result from gravel mining of floodplain alluvium and from discontinuities related to dams. All flows, regardless of how small, carry dissolved particles and suspended particles. As flows increase in volume, flows become capable of moving coarser sediment along the channel bed (i.e., bedload transport). If these coarser sediments are not present in transport or are greatly reduced in supply, channel banks, beds and floodplains become more prone to erosion. This hungry water effect can result in channel incision, bank widening, and bed armoring, particularly at, and downstream of, a dam. Channel incision and bed armoring have occurred below Camanche Dam, while bank widening has not occurred for two reasons that are discussed next.

First, significant flow reductions enabled vegetation to encroach into the active river corridor and stabilize the ground with its roots. Today, the channel is approximately 30 to 50 percent narrower than it was prior to construction of the dams (Edwards, 2004). Riparian vegetation found along both banks of the lower Mokelumne corridor provides some shading and large woody debris/cover habitat beneficial to juvenile salmonids and other fish, although not to the extent of years prior to dam building and introduction of levees and gradual expansion of fields into the vegetated margin along the riverbanks. Overstory species that are currently along the channel margin include cottonwoods, valley oaks, and black walnuts in mixed stands. Box elder, willow, alder and Oregon ash are also present in a second canopy layer. This transition from extensive riparian forests covering the floodplains to what could be termed as a sparse riparian corridor on an "inset floodplain" inside the levees, suggests a geomorphic adjustment of sorts to the post-dam bankfull flow regime. In other words, a markedly sparser riparian corridor exists close to the channel banks where possible, in many cases between the levee and the channel edge. These areas do provide important habitat areas for wildfowl and other species that currently inhabit the area.

Second, an extensive levee system was emplaced in the lower watershed. Over 60 percent of channel banks are leveed in the approximately 33 miles of the Lower Mokelumne River channel between Camanche Dam and its confluence with the Sacramento-San Joaquin Delta (Merz and Setka, 2004). Many fields are located on the historic floodplain, as these overbank areas were where finely sized sediments settled out from the water column as floods recede, creating very rich soils well suited to supporting riparian forests and myriad terrestrial species. Levees were built mostly to protect agricultural fields from flooding and have led to channelization of the river corridor. Levees confine flow to a narrower channel by design, tending to promote incision, so geomorphic functions including gravel deposition and bar formation, channel movement across the floodplain, and creation of side channels are no longer possible in leveed areas. Recently, the Three Rivers Levee Improvement Authority has implemented plans to create levee setbacks along the Feather, Yuba, and Bear Rivers to the north. Levee setbacks are designed to help regain lateral distance next to the channel to promote geomorphic function and increase high quality habitat area, while concurrently providing flood protection to the 200-year recurrence interval level (TRLIA, 2014)..

The conversion of topographically complex floodplains to level fields leads to woodland fragmentation and loss of continuity, complexity, and width of the vegetated corridor, generally due to tree removal during levee building or during plowing and planting of available acreage. Following such practices, there often remains only a narrow band of trees one canopy diameter wide in places where once the riparian forests were up to one-mile wide. Along the Mokelumne River, over 70 percent of forested floodplains have been cleared and over 80 percent of seasonal lakes have been converted to agricultural land use (Edwards, 2004).

Gravel mining in previous decades occurred adjacent to and in the river channel, resulting in a series of pits that in some cases remain connected to the river channel. These pits alter water quality, leading to warmer water, and act as sediment traps for what little sediment might be transported; they also provide habitat for predatory fish such as bass. Current gravel mining operations have moved away from the wetted channel, but still remain within the river's floodplain extent in areas where channel-related effects such as avulsion or meandering deposited gravels in those locations.

A riverine habitat characterization study was conducted on the lower Mokelumne River by Merz and Setka (2004). The study found that riffles (fast, shallow flow across gravels, high degrees of turbulence, higher slopes), which are associated with cobble- and gravel-bedded reaches and are necessary to salmonid species' reproductive success, comprise less than 1 percent of the total habitat; riffles constitute 10 percent to 25 percent of the length of many unregulated rivers. Gravels are found in limited quantities for up to about 10 miles downstream of Camanche Dam—mostly in the rehabilitated reaches where gravel augmentation by EBMUD over the past decade has taken place or where gravels have been transported during high flow events. This 10 mile reach corresponds with the highest river gradient below Camanche Dam. The channel bed becomes sand-dominated at Elliot Road located about 10 miles downstream of Camanche Dam, then transitions to mud-dominated downstream to Woodbridge Dam. In the lowest reaches, the channel bed is muddy-sand and aquatic-plant dominated. Glide habitat (moderately shallow water, smooth surface, low velocity) comprised over 95 percent of the wetted channel habitat within the lower Mokelumne River. These geomorphic variations in channel bed substrate influence the array of possible aquatic functions.

There is one impoundment facility below Camanche Dam. Woodbridge Dam is an adjustable weir dam that provides the Woodbridge Irrigation District with a small reservoir about 470 acres in size. The facility has a fish ladder and fish observation facilities used by EBMUD to monitor upstream fish passage. In addition, there is a bypass pipeline that conveys fish moving downstream from the fish screen at Woodbridge Irrigation Canal. A smolt trap is located at the end of the bypass pipeline and captures fish migrating downstream when the trap door is in place.

2.5 Aquatic Habitat Conditions

The Mokelumne River supports a diverse assemblage of resident and migratory fish species. Resident rainbow trout and other native fish inhabit the upper basin watershed. Impoundments, including Camanche and Pardee reservoirs, provide habitat for a number of native and introduced fish species, including largemouth bass that support recreational fisheries. The Mokelumne River downstream of Camanche Dam supports a diverse assemblage of resident and migratory fish species including fall-run Chinook salmon and steelhead, which prior to construction of the river's dams continued where they spawned upstream in the upper watershed. Historically, aquatic habitat conditions within the Mokelumne River watershed have been influenced by a number of factors including, but not limited to the following.

- Mining activity following the discovery of gold in 1848 and copper in 1861 resulted in the disposal of mining waste and tailing piles, which generated lethal heavy metal concentrations and associated fish kills in the Mokelumne River. In addition to gold and copper mining, sand and gravel mining also adversely affected habitat conditions for spawning and juvenile rearing by Chinook salmon and other fish species.
- Winery and cannery operations historically degraded water quality due to the discharge of organic waste into the lower Mokelumne River. The discharge of organic waste into the river resulted in increased biological oxygen demand and associated depressed levels of dissolved oxygen, which created stressful or unsuitable habitat conditions for fish and other aquatic resources. In recent years, no releases of winery or cannery waste to the river have been reported.
- Dams and water diversions have resulted in changes to the quantity and seasonal timing of instream flows occurring within various portions of the watershed. These changes have included water storage and releases associated with hydroelectric power generation, historic water diversions associated with mining activity, and water storage and diversions for municipal, industrial, and agricultural uses. Construction of Pardee and Camanche dams created impassable barriers to upstream migration by anadromous fish species including Chinook salmon and steelhead. Reservoir releases and water diversions largely regulate instream flows currently supporting fishery habitat within the Mokelumne River system.
- Levee construction has resulted in changes to the hydraulic and geomorphic characteristics of the Mokelumne River watershed by constraining the river channel, in many areas reducing riparian vegetation, and restricting or eliminating seasonally inundated floodplain habitat within the lower portions of the Mokelumne River.

Reservoir storage operations, in addition to levee construction, have altered many of the dynamic processes and degraded the quantity and quality of habitat for fish and other aquatic resources.

- Land-use changes within the Mokelumne River watershed, particularly adjacent to the lower reaches of the river, have resulted in changes to the native riparian vegetation, which in many areas has been replaced by agricultural operations, sediment and erosion, reductions in instream habitat diversity and complexity through channelization, levee construction, and reclamation, as well as point and nonpoint discharges from urban and agricultural areas.
- As part of fishery mitigation for the loss of spawning and juvenile rearing habitat associated with construction of Camanche Dam, the Mokelumne River Fish Hatchery was constructed in 1964 by EBMUD and is operated by the California Department of Fish and Wildlife (CDFW). Production of fall-run Chinook salmon and steelhead within the Mokelumne River hatchery has altered the dynamics of salmonid populations inhabiting the lower reaches of the Mokelumne River.

Other factors have also influenced the population dynamics and habitat conditions within the Mokelumne River watershed, including recreational angling, illegal harvest, and the introduction of a number of non-native fish and other aquatic species including striped bass and largemouth bass.

Instream flows within the lower Mokelumne River are a key element in determining the quality and availability of suitable habitat for salmon and steelhead spawning and juvenile rearing, as well as habitat for other resident and migratory fish and aquatic species. In 1961, EBMUD entered into an agreement with CDFW regarding releases of water from Camanche Reservoir storage to support fishery habitat within the lower river. The 1961 agreement required reservoir releases for minimum instream flows totaling 13,000 AFY. The 1961 agreement was subsequently superseded in 1998 by the Joint Settlement Agreement (JSA), which included an increase in minimum instream flows, a more comprehensive linkage between water allocations for fishery habitat and hydrologic conditions within the Mokelumne River watershed, cold-water pool and temperature management, and funding for habitat restoration and maintenance activities within the lower watershed. The JSA, which has become a part of the State Water Resources Control Board (SWRCB) water right permits as well as the Federal Energy Regulatory Commission (FERC) license for EBMUD operations, includes provisions for seasonal management of instream flow releases within the lower Mokelumne River for salmonid adult migration, spawning and egg incubation, juvenile rearing, and juvenile downstream migration. While the 1961 minimum instream flow agreement provided an allocation of 13,000 AFY, the JSA provides minimum water allocations ranging from 22,500 acre-feet (AF) in critically dry years up to 165,900 AF in wet years depending on water storage levels in Pardee and Camanche reservoirs. The JSA includes provisions for seasonal releases from Camanche Reservoir with the greatest releases occurring during the late fall, winter, and early spring months associated with salmonid spawning, egg incubation, and juvenile rearing, although baseflows are provided year round to support fishery habitat, as well as minimum instream flows required downstream of the Woodbridge Irrigation District (WID) dam.

Under the JSA water allocations and instream flow schedules during the period from October through March are determined based on the combined storage of water in Camanche and Pardee reservoirs on November 5, while water allocations and instream flows during the period from April through September are based on estimates of unimpaired runoff into Pardee Reservoir. The JSA offers opportunities to adaptively manage instream flows and in recent years, reductions in early spring baseflows have been used to accumulate water in storage which has then been released during the fall to provide attraction flows (pulse flows) for upstream migrating adult fall-run Chinook salmon. For example, instream flows during the early spring of 2013 were adaptively managed to accumulate approximately 4,200 AF of water that was stored in the reservoirs for adult salmon attraction pulse flows during the fall (October-early November) 2013. The 2013 pulse flow operations were further enhanced through coordinated operation of the WID dam to surcharge Lake Lodi from upstream releases and then rapidly release the water downstream to increase the magnitude of the pulse flows in the lower river. Periodic closure of the Delta Cross Channel gates during the fall appears to further benefit attraction of adult Chinook salmon into the Mokelumne River. Results of preliminary results of adult salmon monitoring in the river at the WID fish ladders suggests that adult salmon responded to the pulse flows and migrated upstream into the river.

The JSA also includes specific provisions for ramping rates as flows are reduced in magnitude from one level to another as well as provisions for gain sharing in which a portion of water developed through various projects within the watershed that would benefit EBMUD water supplies and reliability would be allocated to enhanced instream flows to support fishery habitat.

The JSA also includes provisions for non-flow actions such as cold-water pool management in Camanche Reservoir, including a goal to maintain a minimum hypolimnion volume of 28,000 AF during the summer and fall in combination with modified release operations from Camanche Reservoir to maintain suitable water temperatures for salmonids downstream of the dam throughout the year. The JSA includes provisions for operation of the Camanche Reservoir hypolimnetic oxygenation system to improve water quality within the reservoir (reduce hydrogen sulfide and increase dissolved oxygen concentrations) subsequently released to the Mokelumne River Fish Hatchery and lower river. The JSA also includes provisions for enhancing riparian vegetation, spawning gravel augmentation and habitat enhancement for salmonid spawning and juvenile rearing, fish passage enhancement in collaboration with WID construction and operation of a new dam and fish ladder complex, modifications to Mokelumne River Fish Hatchery operations such as brood stock selection and other genetic management activities and juvenile release strategies. The JSA also includes provisions for EBMUD monitoring of fishery resources, such as adult Chinook salmon and steelhead spawning escapement, redd construction, and juvenile outmigration, as well as habitat monitoring, maintenance, and enhancement.

3. Interactions between Flow, Sediment and Existing Geomorphic Conditions

It cannot be emphasized enough that on the Mokelumne River, all of the dams and reservoirs in the upper and lower watershed create sediment and flow discontinuities within the channel network. The large dams and reservoir systems of Pardee and Camanche Dams diminish flow and sediment between the upper and lower watershed. The watershed issues that arise from the discontinuity of sediments and water are fundamentally linked to the overall geomorphic health of the river-hillslope-floodplain ecosystem.

Since coarse sediment cannot move from the upper to the lower watershed, one of the most important natural "tools" used by the river for geomorphic work is fundamentally lost. In the upper watershed, sediments are captured in reservoirs, while at other locations concentrated flows may increase erosion and add sediment to the system. At the transition from upper to lower watershed, Pardee and Camanche Dams block larger sediments such as sands, gravels and cobbles from transporting downstream. These sediments therefore are not available to perform work within the lower watershed river-floodplain environment. Levees and other structural elements such as bridges and bank protection limit the ability of any available sediment that do move to fan out across the floodplain, potentially leading to channel incision instead. The sediment linkage that most strongly remains is that of suspended fine silts and clays that are still able to transport through the system, but those may affect water quality issues such as elevated nutrient transport and turbidity. The organic component of river load also fundamentally changes at the break between the upper and lower watershed, with loss of large wood and organic materials components of sediment transport. The continuity of organic materials that lend complexity to riverine conditions and habitat values is therefore truncated in a similar manner to that of inorganic sediment.

Water diversions for hydropower generation in the upper watershed leave some channel reaches with a water deficit and others with a surging-water effect. In channels with low flows due to diversion, sediment derived from hillslopes may not be moved, while in areas with concentrated flows, additional erosion may occur. Storage at the mid-watershed dams dampens variability in the flow hydrograph for the lower watershed year after year, leading to very different flow availabilities between the upper and lower basin, regardless of required flow schedules. Below the dams, the former bankfull flow is no longer achievable, so little geomorphic work is being performed in the channel. Levees and other structures do not allow what flows remain to move onto the floodplains. Suspended sediment particles move west into the Delta with flows, but also settle out and fill channel bed spaces in the gravel-bedded areas, creating potential problems for fish and other aquatic species by filling interstitial spaces between larger sediments. This process is damaging to spawning habitat and can smother salmon redds. Bankfull flows and larger flood flows—which now rarely occur in the lower watershed due to regulated flows—normally move fine particles onto the floodplains and replenish the rich soils found there; this process occurs much too infrequently to keep up with soil losses in the agricultural fields now located on floodplain areas.

4. Interactions between Flow, Geomorphic Function and Ecological Needs

The level of geomorphic function available to a river ecosystem directly affects the ability of the system to provide the services needed for healthy aquatic and riparian communities. The cumulative effects of a long series of human activities can be damaging, and leave little room for additional loss of function. Euphrat's (1992) work makes the point that new and potentially more severe effects act upon the tributaries of the Mokelumne as the level of disturbance increases. In other words, above certain thresholds, geomorphic and hydrologic effects can be more damaging and the damage can be more persistent. Mokelumne River collaborative members may wish to seek alternatives that do not exceed these thresholds. Euphrat's work was focused on upper watershed timber harvests, but the notion that loss of function increases exponentially with disturbance beyond certain thresholds can be extended to other changes throughout a river network. Some of these thresholds are self-evident. As one example, total interception of sediment transport can be more damaging than partial interception, and a longer period of time in which sediments are truncated produces greater effects—an example relevant to the Mokelumne River watershed. As the MokeWISE process moves forward, it will be important to avoid alternatives that induce proportionately greater loss of channel stability or other geomorphic functions.

Changes in geomorphic function can lead to loss of habitat or populations of fish or amphibians. The lower Mokelumne River supports more than 35 fish species, including five anadromous species: fall-run Chinook salmon, winter steelhead trout, American shad, striped bass and Pacific lamprey (Merz, 2004). Wild (in-river spawning salmon) Chinook salmon comprise a relatively small percentage of the fall-run population, with hatchery stock greatly enhancing natural spawning numbers produced in the rehabilitated channel directly below Camanche Dam (Johnson and others, 2012; Stephens, 2012). Prior to construction of Pardee and Camanche Dams, spawning areas accommodated approximately 40,000 adults at 400 cfs (CDFG, 1955). By the time Camanche Dam was built, about 85 percent of spring-run Chinook salmon and steelhead habitat was lost to both species. Post-Camanche Dam (1964-2012), Chinook salmon runs have averaged approximately 5,000 spawners (CDFW, 2013). USFWS (1997) called for a lower Mokelumne River fall-run Chinook salmon population target of 9,300. Average annual lower Mokelumne River salmon escapement has been monitored by video at Woodbridge Dam from1990-2013. Chinook escapement averages 6,839 (minimum 410; maximum 18,596). The Anadromous Fish Restoration Program doubling period average for the Mokelumne River is 8,372 salmon. Steelhead trout populations are quite low compared to Chinook, with an escapement of less than 100 in the early 2000's (Workman, 2003). Most anadromous spawning occurs in the 10 miles of channel between Camanche and Elliott Road.

It may be that more instream capability is expected in the lower Mokelumne River because it now serves as spawning, emergence, rearing and sheltering habitat for aquatic species. Prior to dam construction, much of the lower river could be seasonally dry, and was mainly used as a migration corridor, with salmon and steelhead, for instance, spawning further into the watershed network at higher elevations. A voluntary collaborative effort led by the Foothill Conservancy is considering the feasibility of restoring fall run Chinook salmon to the Mokelumne River above Pardee and Camanche Dams.

Through the 1990s and early 2000s, a consensus emerged that instream habitat rehabilitation is required to stave off further salmonid population declines and eventually recover self-sustaining wild populations. FERC (1993) ranked the various factors limiting the production of salmonids in the lower Mokelumne River and concluded that spawning habitat quality and quantity were the second most important factors. Examples of the numerous policy documents from that era stating that habitat is degraded and prioritizing spawning habitat rehabilitation as an important goal include Flosi and others (1995), USFWS (2001), DWR (1994), and CMARP (1999). The creation of spawning habitat below Camanche Dam was encouraged by FERC as a non-flow alternative to habitat improvement thorough addition of clean, river-run sediments of the sizes used for spawning.

In response to this consensus, spawning habitat rehabilitation was undertaken and continues today. In the earliest phase, riffle enhancement for improved spawning was instituted by EBMUD and others in 1990 and guided by on-site field biologists (Pasternack and others, 2004). In 2001, CALFED sponsored a three-year demonstration project to use the lower Mokelumne River as a testbed for a new framework for geomorphically guided river rehabilitation that would not only enhance spawning habitat in the short-term, but also restore key geomorphic processes that aid a river in self-sustaining its ecological functionality. That framework is now known as the Spawning Habitat Integrated Rehabilitation Approach (SHIRA). What sets SHIRA apart from pre-existing schemes is that it integrates widely accepted concepts from hydrology, civil engineering, aquatic biology, riparian ecology, and geomorphology to design alternative river configurations for a degraded section of river and then uses predictive computer models to evaluate the relative performance of the different configurations in their specific details before implementing a final design, thereby avoiding costly mistakes (Wheaton and others, 2004, a,b). Extensive information about the use of SHIRA on the lower Mokelumne River is available online at http://shira.lawr.ucdavis.edu/mokelumne.htm. A gravel augmentation program remains in effect as of 2013 in the 1 kilometer river reach adjacent to the Mokelumne Day Use Area just below Camanche Dam.

As part of the carefully designed and monitored river rehabilitation, approximately 54,000 metric tons (2,204 pounds per ton) of spawning-sized gravel and cobble were added to the channel from 1999 to 2012. The spawning gravel enhancement projects have included placement of suitable sized clean rounded gravel in addition to boulders and large woody debris to enhance areas for Chinook salmon and steelhead spawning, egg incubation, and juvenile rearing in the river in the reach adjacent to the day use area downstream of Comanche Dam. It is anticipated that additional gravel will continue to be added to the river in the future as part of habitat maintenance of spawning areas downstream of Comanche Dam. Gravel additions were sculpted by front loaders in the channel (Sawyer and others, 2009) according to grading plans designed through empirical analysis and computer simulations of project alternatives. Key immediate river enhancements included a steeper longitudinal profile, improved relief between naturalized riffles and pools, significant reduction in gravel armoring, improved connectivity between the channel and floodplain, habitat heterogeneity and hydraulic structures composed of boulders and/or streamwood, two side channels for rearing habitat, and available sediment supply to transport downstream (e.g., Wheaton and others, 2004c; Elkins and others, 2007; Wheaton and others, 2009). Over time, the river has experienced secondary positive responses, such as re-activation of bank scour to widen the channel, more frequent floodplain inundation, development of persistent freshwater wetlands, increased snag and streamwood production, and migration of sediment downstream. After a 5,000 cfs flood in 2005, a rehabilitated riffle on the river was observed to increase high-quality spawning habitat due to redistribution of placed sediment that occurred as predicted (Wheaton and others, 2009).

Despite these successes, the profound loss of appropriate riverbed substrate and instream large wood structure as well as long-term degradation of channel bed features means that the need for more patches of channel suitable for fish spawning, rearing and migration may remain. Regulatory and stakeholder groups may agree at some further time that maintenance of existing habitat will be sufficient. Gravel augmentation is but one component of rehabilitation steps that are needed to provide the suite of functions necessary to maintain geomorphic and ecologic integrity of the channel below Camanche Dam, and none of these components will truly bring back historic conditions. For example, Senter and Pasternack (2011) showed that large wood plays an important role in the geomorphic structure of landforms in the Lower Mokelumne River and also aids Chinook salmon spawning where habitat is otherwise insufficient. Likewise, Elkins and others (2007) showed that slope creation was an important component to increasing the downstream limit of suitable spawning rehabilitation habitat; at some point the low gradients in the lower

Mokelumne may preclude extending rehabilitation achievements further downstream.

Nevertheless, some mitigation and local increases in resilience may be achievable. To explore interactions between hydrologically-driven geomorphic functions and ecological need conditions of salmonid spawning reaches on the Mokelumne River pre- and post-gravel augmentation, a functional flows model was developed to assess how rejuvenation of ecological conditions is linked to sediment transport regimes (Escobar-Arias and Pasternack, 2010). Functional flows are defined as discharge values that provide enough shear stress to mobilize bed sediments, leading to geomorphic changes in bed morphology that serve ecological purposes.

Input variables included discharge, slope, median grain size, a depth parameter, and shear stress, along with topographic data for the channel reaches being studied. To calibrate the model and to provide relevance to current environmental needs, physical habitat requirements needed by fall-run Chinook salmon spawners were used (other biological species or lifestages could be used in place of Chinook spawning needs). Requirements for spawning Chinook include (1) the need for flows that mobilize sediments and revitalize the channel bed prior to spawning activities; and (2) flows that enhance egg-nest preparation, survival rates of incubating salmon eggs, and support the emergence of salmon fry.

Physical processes driven by discharge and necessary for spawning salmon include bed-renovation periods where (1) the channel bed is fully mobilized, (2) interstitial fines are mobilized, and (3) superficial fines are mobilized (Escobar-Arias and Pasternack, 2011). Each type of mobility plays a role in the ecological health of the system. Model results showed that gravel augmentation increased the number of days in which existing flows performed functional work, but that the range in flows was small. The study concluded that the next step in increasing ecological functionality below Camanche Dam would be to provide a greater range in flows. However, a known limitation is that due to flood risk, operations are currently designed to prevent flows above 5,000 cfs and to minimize flows greater than 3,000 cfs when possible, thus narrowing the ability for additional changes to functional flows without additional changes to dam operations.

5. High Priority Focal Species

Within the Mokelumne River watershed, three fish species receive the highest priority attention. Within the watershed upstream of Pardee Reservoir, resident rainbow trout have been identified as the priority species. Rainbow trout support recreational angling and serve as an indicator of overall habitat conditions for the resident fish community inhabiting the upper portions of the Mokelumne River watershed. Foothill Yellow-Legged Frogs in the North Fork above Tiger Creek After Bay are also a species of special concern and frogs require more specific management than trout. Much of the current emphasis on species management in the upper watershed has focused attention of Yellow-Legged Frogs and resident rainbow trout. Currently there is interest among a collaborative group of watershed stakeholders including, but not limited to the Foothill Conservancy, Trout Unlimited, California Sportfishing Protection Alliance, EBMUD, CDFW, USFWS, NMFS and others to explore opportunities for relocating fall-run Chinook salmon into the upper watershed above Pardee Reservoir. Early consideration in the process for assessing opportunities include defining the goals and objectives of relocation (e.g., simply moving some Chinook salmon into the upper watershed, re-establishing a self-sustaining population, etc.), determining habitat suitability and potential barriers or impediments to fish movement, and other elements of the initial planning process. A key consideration is to avoid potential impacts to maintaining the existing fall-run Chinook salmon population inhabiting the lower river and meeting the JSA fishery management goals and objectives. The planning and feasibility discussions regarding relocation of fall-run Chinook salmon into the upper watershed are in the early stages of development.

Downstream of Camanche Reservoir the two priority fish species that receive the greatest attention are fall-run Chinook salmon and anadromous steelhead. Fall-run Chinook salmon support an important commercial and recreational fishery. Anadromous steelhead are a native fish species currently listed as threatened under the federal Endangered Species Act (ESA) by the National Marine Fisheries Service (NMFS) and a species of special concern by the CDFW. Both Chinook salmon and steelhead serve as important indicators of the quality and availability of fishery habitat within the lower Mokelumne River. It has generally been assumed by regulators and resource managers that if habitat conditions support healthy and robust populations of resident rainbow trout, fall-run Chinook salmon, and anadromous steelhead, the watershed is assumed to be properly functioning and would provide habitat conditions that would maintain a diverse fishery community in good condition.

6. Environmental Water Needs

Instream flows and associated water quality conditions, including seasonal water temperatures and dissolved oxygen concentrations, are a key element in determining the quality and quantity of suitable habitat available for resident and migratory fish species. Instream flows that support various physical processes and meet the habitat requirements for various lifestages of fish typically follow a natural seasonal hydrologic pattern with the greatest instream flows occurring during the late winter and spring months, lower but stable flows during the summer and early fall months, and periodic increases in pulse flows during the fall months and early winter associated with precipitation and stormwater runoff. Fish species inhabiting the Mokelumne River watershed have evolved and adapted to these seasonal patterns as well as inter- and intra-annual variation in flows and water quality conditions under natural unimpaired hydrologic conditions as reflected by variation in habitat requirements by lifestage. The most effective instream flow schedule is based on a consideration of seasonal patterns in hydrologic conditions, seasonal water temperatures, dissolved oxygen concentrations, periodic flushing flows that scour fine silts and sediments from spawning gravel as well as provide bedload transport for gravel recruitment into areas that serve as spawning and juvenile rearing habitat. Currently the JSA establishes a framework on the lower Mokelumne River for allocating water storage and instream flow releases. The JSA flows were developed based on consideration of the relationship between instream flow and habitat quality and availability for various lifestages of salmonids, The JSA flows were also based on consideration of maintaining cold water pool reserves that help achieve suitable water temperature conditions that vary depending on seasonal time periods, habitat requirements for various lifestages, and water supply availability within Camanche and Pardee reservoirs. Instream flow schedules have also been established for storage and release from hydroelectric generation facilities located in the upper portions of the Mokelumne River watershed, with minimum streamflow based on month and water year type, and approximately mimicking the annual natural hydrograph in terms of magnitude, times and duration (FERC, 2000; FERC, 2001). Instream flow schedules to support habitat for resident and migratory fish species in both the upper and lower portions of the Mokelumne River system are required as provisions of SWRCB water right permits and FERC licenses.

7. Geomorphic and fisheries related opportunities, challenges and trade-offs

The following sections provide an overview of geomorphic- and fishery-related opportunities, challenges, and trade-offs associated with water resources management in the Mokelumne River basin.

7.1 Geomorphic Opportunities and Challenges

Opportunity G1: In the upper watershed, the timing of hydropower generation could potentially be changed such that large flow pulses do not dominate flow dynamics. These could potentially be achieved via adaptive management decisions as discovered during the 30-year licensing agreement and the attendant monitoring program.

Challenge G1: In the upper watershed, flows are rerouted to support hydropower capabilities. However, the need for hydropower generation will remain, so a return to more natural flow dynamics will be difficult to achieve. Adjustments to flow pulses has been achieved as stipulated out in the FERC relicensing agreement for PG&E’s upper watershed Mokelumne River project 137; additional changes may or may not be achievable given current conditions.

Opportunity G2: Below Camanche Dam, (a) an increase in sediment supply, (b) a return to a flow regime that mobilizes the bed and banks at frequencies similar to or approaching those which prevailed historically, and (c) additional (re)connection of the river with its historic floodplain are three of the most important management actions that could help reinstitute sustainable geomorphic functions and ecosystem health.

Challenge G2: Camanche and Pardee Dams and flow regulation are not going away, so lower watershed flows should be managed to achieve essential geomorphic functions that aid self-sustainability to the extent possible (e.g., Richter and Thomas, 2007). In addition, flows must be managed to minimize potential downstream flooding impacts.

Opportunity G3: Peak flows could be increased during yearly flood events so that significant geomorphic work might be accomplished during those windows of opportunity. This principle is in line with the concept of environmental and functional flows needed to maintain healthy aquatic ecosystems. The potential to increase the variability of flow timing or rates during wet years may be achievable through such means as operating the dam at higher levels earlier in the season, allowing larger flood flows to pass-through more than occurs now, and conscious management of the duration, timing and magnitude of flood flows to meet specific geomorphic and biological thresholds,

Challenge G3: Management of flood control releases to meet geomorphic and biological thresholds adds to the complexity of dam operations. Flood control releases must be managed to minimize potential downstream flooding impact. In addition, potential future conditions hinge in part on how water is managed within the system from this point forward. A major unknown is climate change, which may determine future conditions. Climate change models generally predict an increase in air temperatures across the Sierra Nevada (Null and others, 2012). These changes could alter precipitation patterns (i.e., more rain, less snow), both of which could dramatically affect snowpack and runoff patterns. While much remains unknown about future conditions, preparation for episodic-event scenarios such as flood conditions, landsliding, fire, or drought will be important management components in future years.

Opportunity G3A: Implement a spring flow requirement that requires release of a percent of unimpaired flow downstream of Camanche Dam; this approach could replace or be overlaid on the JSA flows, in a defined subset of years or in all water years. This would increase the variability of flows downstream of Camanche and potentially increase the frequency of flows that do geomorphic work. Replicating natural rates of recession could also improve the settling and sorting of sediment in the river channel.

Challenge G3A: Water supply impacts and operational complexity. Physical constraints and limitations of facilities and stream channel.

Opportunity G3B: The potential to increase groundwater recharge to supplement irrigation in subsequent years may be achievable by physical improvements in the available wetted area and by dovetailing geomorphic actions with area diversions further downstream to groundwater recharge areas and facilities.
Challenge G3B: Physical manipulation of the stream channel and its floodplain has land ownership constraints, may create local flooding concerns, and may require substantial financial investment, Groundwater recharge areas and facilities must be sufficiently sized and efficient to allow diversion of water when it is available; many geomorphic functions require flow much higher than the diversion capacity of groundwater facilities likely to be constructed.

Opportunity G4: Whereas channel configuration and microrelief in other regulated rivers in the region such as the lower Stanislaus, American, Yuba, and Feather Rivers have now been comprehensively mapped, the lower Mokelumne River has not been mapped (e.g. Lower Yuba River Accord, River Management Team documents, www.yubaaccordrmt.com). A detailed topographic map of the river is an important geomorphic foundation to many analyses and engineering opportunities.
Challenge G4: Funding for additional projects can be difficult to achieve.

7.2 Fishery Opportunities and Challenges

There has been substantial improvement in habitat quality and availability for fishery populations inhabiting the lower Mokelumne River. Many of the early sources of habitat degradation, such as runoff from mine tailings, discharge of organic material resulting in depressed dissolved oxygen concentrations, loss of spawning gravels as a result of sand and gravel mining activity, and others have been largely addressed and resolved over the past 50 years. The 1998 JSA (with voluntary operations and instream flows according to the JSA schedule implemented since 1996), as well as additional habitat improvements such as spawning gravel augmentation downstream of Camanche Dam, have resulted in improvements in habitat conditions for salmonids and other fish species as reflected in an increasing trend in abundance of fall-run Chinook salmon originating from the Mokelumne River. A process is now underway whose goal is to reintroduce fall run salmon to the upper watershed. Building on the foundation provided by the JSA, additional opportunities and constraints for further enhancing fishery habitat conditions have been identified, many of which reflect greater reliability in meeting habitat needs under all hydrologic conditions, which include, but are not limited to, the following.

Opportunity F1: Modify flood control management and operations to increase water storage and support ecological processes without undue risk of flood damage.
Challenge F1: Modifying existing Army Corps of Engineers flood control management rules in a way that does not increase the risk of flooding and damage downstream of the dams. For actions at reservoir levels below the Corps' rule curve, risk of water costs. Flood liability and the risk of property damage are major concerns.s.

Opportunity F2: Modify channel margins to reduce the risk of flood damage and increase access to seasonally inundated floodplain habitat.
Challenge F2: Challenges include limited funding, limited access to private property along the river channel, durability of physical improvements, and existing infrastructure constraints.

Opportunity F3: Manage Camanche and Pardee Reservoirs in a manner that optimizes for water temperature in the lower rivers and needed to provide suitable habitat for salmonids.
Challenge F3: Challenges include reservoir storage management to meet a variety of beneficial uses in combination with periods of drought and low reservoir inflows.

Opportunity F4: Close the Delta Cross Channel throughout the period October 1 to November 15 in all years. Closure of the Delta Cross Channel in the fall offers benefits to reducing straying and enhancing returns of adult fall-run Chinook salmon to the Mokelumne River.
Challenge F4: Closure of the Delta Cross Channel may contribute to degraded water quality (e.g., increased water quality concerns such as electrical conductivity in the central and south Delta). Several efforts are currently underway to find ways to balance these competing fishery and water quality goals including (1) exploration of the potential application of an electrical barrier to help guide adult salmon from migrating upstream into the Delta Cross Channel and providing benefits to increased adult returns to the Mokelumne River, and (2) exploration of opportunities for partial opening of the Delta Cross Channel

gates during the fall (e.g., closing the gates during the night for fishery benefits and opening the gates during the daytime for water quality benefits, opening the gates partially to allow water to pass under the gates into the central Delta while guiding downstream migrating juvenile Chinook salmon downstream in the Sacramento River, etc.). Testing has been conducted in recent years, and additional gate operational testing is anticipated in early 2014, to evaluate some of these alternative operational strategies for meeting both fishery and water quality goals

Opportunity F4A: Make flow releases from Camanche Dam and operate the Mokelumne River Hatchery in coordination with the operation of the Cross Channel Gates and Delta exports, with the goal of improving outmigration success of Mokelumne River salmon and steelhead.
Challenge F4A: Open Cross Channel Gates in spring could improve outmigration success of Mokelumne fish, but spring export operations of the CVP and SWP exports in the spring entrain juvenile salmon and steelhead from the Mokelumne, changing a potential benefit into a severe impact. Export operations also diminish the benefit of spring flow increases and pulses in the Mokelumne River.

Opportunity F5: Continue to meet the minimum JSA instream flow requirements in all years.
Challenge F5: Challenges include predicting runoff and reservoir storage, managing reservoir releases to meet multiple beneficial uses, and low flow levels for Camanche Reservoir releases and flows downstream of WID dam under dry and critically dry JSA conditions.

Opportunity F5A: Implement a spring flow requirement that requires release of a percent of unimpaired flow downstream of Camanche Dam; this approach could replace or be overlaid on the JSA flows, in a defined subset of years or in all water years. This would increase the variability of flows downstream of Camanche and provide natural biological cues.
Challenge F5A: Water supply impacts and operational complexity. Physical constraints and limitations of facilities and stream channel.

Opportunity F6: Maintain spawning gravel supplies through gravel augmentation (annual average estimated augmentation of 600-1,200 cubic yards of suitable gravel). Spawning

gravel augmentation has been shown to benefit fall-run Chinook salmon spawning in the lower river. It is expected that in the future additional gravel will be added to the river in the reach immediately downstream of Camanche Dam to maintain suitable spawning habitat. In addition, habitat enhancement projects have been conducted to provide access to shallow water lower velocity side channel habitat immediately downstream of the dam to benefit juvenile salmonids rearing and provide velocity refugia during periods of high spring flows when salmon and steelhead fry and juveniles are rearing within the river.
Challenge F6: Challenges include securing funding through AFRP to assist in gravel purchase and placement, and identifying local sources of gravel of suitable size for spawning.

Opportunity F7: Increase availability of seasonally inundated floodplain habitat for juvenile salmon rearing.
Challenge F7: Challenges include limited funding and limits to the locations where topography and proximity to the river are suitable for improving access to seasonally inundated floodplain habitat for juvenile rearing.

Opportunity F8: Increase availability of lower velocity side channel habitat.
Challenge F8: Challenges include limited funding and limits to the locations where topography and proximity to the river are suitable for developing side channel habitat for juvenile rearing. Durability of physical improvements during high flow events is also a concern.

Opportunity F9: Implement habitat restoration and conservation actions along the lower river channel to protect and enhance riparian vegetation, reduce erosion, and reduce disturbance to channel banks and adjacent areas.
Challenge F9: Challenges include limited access to private property along the river channel for restoration actions and existing land use.

Opportunity F10: Encourage installation of state-of-the-art positive barrier fish screens on all water diversions from the river.
Challenge F10: Challenges include a lack of funding for fish screen installation and maintenance, concerns by private property owners regarding the cost and maintenance of fish screens, and the lack of authority to require fish screen installation and operation.

Opportunity F11: Optimize operations with a goal to maintain water temperatures in the reach from the Camanche Dam to Elliott Road at less than 56 F (13.3 C) from November 15 through March 15 for Chinook salmon and steelhead egg incubation.
Challenge F11: Challenges include managing cold water pool volume and releases from the dams, and exposure of the river to elevated seasonal air temperatures that increase water temperatures as a function of distance downstream of the dam.

Opportunity F12: Optimize operations with a goal to maintain water temperatures in the reach from the Camanche Dam to Elliott Road at less than 64 F (18 C) from March 15 through October 31 for juvenile salmon and steelhead rearing and migration.
Challenge F12: Challenges include managing cold water pool volume and releases from the dams, and exposure of the river to elevated seasonal air temperatures that increase water temperatures as a function of distance downstream of the dam.

Opportunity F13: Avoid flow fluctuations (reductions) during the period from November 15 through March 31 that would result in redd dewatering.
Challenge F13: Challenges include managing fall pulse flow releases in October and early November that provide short duration attraction pulses but avoid dewatering redds if surveys determine spawning has begun.

Opportunity F14: Continue to manage instream flows using existing approved ramping rates in all years, except during flood releases and in case of emergency, to reduce the risk of fish stranding.
Challenge F14: Rapid ramping rates during flow increases and decreases associated with fall adult salmon pulse attraction flows, as implemented in 2012 and 2013, occur at a time of year when the risk of juvenile standing is low. Given limited water supplies, the benefits of multiple short-duration pulse releases is considered to be substantially greater than the risk of stranding during the fall

Opportunity F15: Provide water to support several fall pulse flow events during October for adult Chinook salmon attraction and upstream migration; coordinate fall pulse releases with Woodbridge Dam operations and releases from Lodi Lake.
Challenge F15: Challenges include implementing adaptive management operations to

accumulate water supplies to support fall pulse flows. Water supplies for fall pulse flows have been made available through adaptive management of Camanche Reservoir releases in the late winter and early spring but require approval by JSA participating agencies and the State Water Resources Control Board for implementation.

Opportunity F16: Reduce predation mortality on juvenile salmonids through management actions such as harvest, relocation, and/or habitat modifications. Striped bass have been identified as a major predator inhabiting the river downstream of the WID dam that prey of juvenile salmon during the spring downstream migration period. In addition, results of juvenile salmon survival studies have shown substantial losses in the reach upstream of the WID dam that are likely to be associated with predation in Lake Lodi by species such as largemouth bass.
Challenge F16: Challenges include rapid recolonization of areas of the river where predatory fish have been removed, cost and labor required for ongoing predator capture and relocation, uncertainty regarding the overall effectiveness of predator management actions in improving juvenile salmonid survival, and public and agency concerns regarding mortality and disposition of predatory fish collected as part of a predator removal effort.

Opportunity F17: Operate the hypolimnetic oxygenation system to maintain dissolved oxygen concentrations in Camanche Reservoir hypolimnion greater than 2 mg/L at CAMC from May to November in all years. The oxygenation system has proven to work reliability and be effective in reducing hydrosulfide and increasing dissolved oxygen concentration is water released from Camanche Reservoir to the hatchery and lower river.
Challenge F17: Challenges include the costs of operation and maintenance of the system.

Opportunity F18: Continue to manage and operate the Mokelumne River Fish Hatchery to produce Mokelumne River origin Chinook salmon and steelhead and manage releases to improve juvenile survival while reducing adult straying. Manage the hatchery to maintain genetic diversity of the stocks and reduce and avoid impacts to salmonids spawning and rearing in the river.
Challenge F18: Challenges include brood stock selection and other hatchery management actions that provide genetic diversity and produce healthy salmonids. Additional challenges include identifying suitable release sites that improve juvenile survival, reduce adult straying, and are compatible with river flows, water temperatures, and other

environmental conditions. The hatchery operations are currently undergoing a major review and recommendation for modifying hatchery facilities or operations may prove to be a future challenge.

Opportunity F19: Increase game warden presence and fishing regulation enforcement to reduce poaching and illegal harvest of Chinook salmon, steelhead, and other fish in the lower river.
Challenge F19: Challenges include limited warden staffing, limited funding, competing needs for enforcement in other watersheds, and limitation of access to areas of the river by private property.

Opportunity F20: Manage Camanche and Pardee reservoir fish planting for recreational angling to avoid potential impacts to steelhead downstream of the dams (e.g., plant triploid rainbow trout). Actions such as planting triploid fish offer an opportunity to avoid interbreeding between wild and planted stocks.
Challenge F20: Challenges include increased costs and additional complexity associated with obtaining stocks for planting in support of recreational fishing.

Opportunity F21: Explore the feasibility and potential benefits of relocating fall-run Chinook salmon into habitats in the watershed upstream of Camanche Reservoir. As briefly discussed above, a collaborative effort among stakeholders has begun to investigate the potential habitat suitability and opportunities to relocate salmon upstream of Camanche and Pardee Reservoirs.
Challenges F21: Challenges to this effort include achieving a collaborative consensus on the goals and approach for relocation, habitat suitability and existence of passage barriers and impediments to migration, predation by resident fish and other wildlife, potential management conflicts with other species such as Yellow-Legged Frogs, the inability of salmon upstream of the dams to successfully complete an anadromous life history, and potential conflicts with maintaining the fall-run Chinook salmon population downstream of Camanche Dam and continued successful implementation of the JSA fishery management program. Any action ultimately selected to reintroduce anadromous fish upstream of Pardee Reservoir will require funding.

Opportunity F22: Removal of existing dams and passage barriers from the upper watershed. Opportunities exist to potentially remove several small dams from the watershed such as East Panther Dam and a small dam located on a tributary east of West Point.

Challenges F22: Challenges include permitting, potential releases of accumulated sediments, changes in channel erosion following dam removal and funding.

Opportunity F23: The Ponderosa Way Restoration Project would restore Ponderosa Way to minimize erosion, provide watershed access to fire service, and allow river access to the public for recreation. The restoration project is a collaborative effort that has been planned in three phases with the first phase restoration of Ponderosa Way having received funding.

Challenge F23: Challenges include completing restoration actions in a steep grade and implementing a successful storm runoff system that reduces and avoids erosion. Erosion of the area has been accelerated by 4-well vehicle traffic during the wet season.

7.3 Additional Fishery Challenges

There are a number of challenges and impediments associated with implementing various management actions that would enhance conditions for fishery resources on the Mokelumne River. For example, changes in flood control operations of Camanche and Pardee reservoirs are a complex technical and regulatory challenge. There are also challenges associated with other planned or proposed changes to water operations and facilities in the upper watershed that would have an effect of hydrology and instream flows and other factors that may impact fish and other wildlife such as Yellow-Legged Frogs. For example, Pacific Gas and Electric Company has considered developing a pumped storage project that would raise Little Bear Reservoir approximately 8 feet with an interconnection to Salt Springs Reservoir. Water levels in the reservoirs would fluctuate approximately 6-7 feet daily in response to pumped storage operations. The project would require a number of approvals (e.g., FERC) before implementation. In addition, consideration has been given to raising the level of Lower Bear Reservoir by approximately 20-28 feet to increase winter storage that could then be released down the river during the summer for conjunctive use with power operations. This project could conflict with restoration efforts focused on Yellow-Legged Frogs and would require a number of approvals (e.g., amendment to PG&Es FERC license) before being implemented.

Additional challenges to implementing many of the potential management actions designed to enhance fishery habitat are determined by hydrologic conditions and runoff within the watershed. Runoff varies substantially within and among years and is difficult to accurately predict from one year to the next. Therefore variation in hydrologic conditions and runoff poses a major challenge to effectively managing water storage allocations and instream flows to maximize benefits for fisheries. For example, maintaining a minimum hypolimnetic volume of 28,000 AF in Camanche Reservoir in every water year represents a major water supply challenge, particularly during periods of multiyear critically dry drought conditions. Similarly, maintaining water temperatures that would be optimally suitable for all lifestages of salmonids and other fishery resources in all water years during all months represents a major challenge based on seasonal variation in air temperature as well as variation in cold-water storage availability to meet downstream temperature requirements.

Preliminary results of studies in progress on attraction and straying of adult fall-run Chinook salmon between the Mokelumne River and the American River suggest that pulse flow releases from Camanche Reservoir during the months of October and possibly November, in combination with closure of the Delta Cross Channel gates during the fall period of adult Chinook salmon upstream migration, suggest that these actions contribute to increased adult salmon returns to the Mokelumne River and reduced straying of adults of Mokelumne River origin to the American River. Pulse flow studies have been conducted during the fall using Mokelumne River pulse flows over the past several years but require further analysis and review, in addition to potentially more testing, as part of the continuing efforts to identify and refine fishery management actions that benefit the Mokelumne River while avoiding and minimizing adverse effects to other water users (e.g., work with WID operations, avoid adverse water quality conditions in the Delta, etc.). Providing water supplies to support the fall pulse flows for adult salmon attraction and upstream migration represents a water supply challenge that has been addressed, in part, through JSA adaptive management. Closure of the Delta Cross Channel gates during the fall months, however, represents a major water quality and institutional challenge within the Delta. Closure of the Delta Cross Channel gates during the fall results in reduced flushing of high quality water from the Sacramento River system through the central portions of the Delta and results in localized increases in salt concentrations. The US Bureau of Reclamation (USBR) operates and manages the Delta Cross Channel gates, in part, to help meet water quality conditions within the Delta during the fall months by keeping the Delta Cross Channel gates open. Modifying Delta Cross Channel gate operations to include prolonged gate closures during the fall represents a challenge in terms of water quality for municipal and agricultural usage within the Delta as well as institutional challenges associated with SWRCB D – 1641 and other regulatory requirements to maintain water quality conditions (e.g., salinity) within the Delta within acceptable limits.

7.4 Trade-Offs

Efforts to increase and enhance habitat conditions for fishery resources within the Mokelumne River are currently accomplished by balancing competing interests and demands. Modifying the existing balance of management actions has the potential to result in major trade-offs among competing needs. For example, modifying reservoir operations and flood control rules to increase winter storage within the reservoirs for fishery purposes has the potential to result in a greater frequency of flooding and damage to property along the Mokelumne River downstream of Camanche Dam. Similarly, an increase in instream flows released from Camanche Reservoir to the lower Mokelumne River, depending on reservoir storage and subsequent hydrologic conditions, has the potential to deplete cold water storage within the reservoir resulting in adverse fish habitat impacts associated with exposure to elevated water temperatures. Evaluating the competing interests and needs, in these examples, between flood control risk and increased storage for fishery allocation, or between increased instream flow releases and the potential expense of exposure to stressful or unsuitable seasonal water temperatures for salmonids, requires substantial modeling and technical analysis.

8. Conclusions

The following sections provide general conclusions; recommendations, including future data collection and studies; and closing remarks to serve as guidelines as the Mokelumne Collaborative Group assesses future water management actions.

8.1 General Conclusions

a. The hydrology of the entire Mokelumne River watershed is highly manipulated, changing the channel and overbank environment throughout the watershed. The type of alterations varies to some degree due to differences in land and water uses between the upper watershed and the lower watershed. Typically, these changes result in net loss of both geomorphic and ecological function. A return to conditions more closely mimicking historical flow regimes must be balanced with potential for downstream flooding impacts.
b. Regulated flows result in loss of natural functions that often reside at the intersection between flow conveyance, conjunctive use and functional flows that serve environmental needs.
c. Flow attenuation and the inability of most sediment to transport from the upper watershed into the lower watershed are large drivers, but not the only drivers, contributing to loss of geomorphic integrity in the system.
d. The seasonal timing of instream flows to meet habitat requirements for various species and lifestages of fish need to meet habitat requirements for adult migration, holding, spawning and egg incubation, juvenile rearing, and juvenile migration. Changes in instream flows alter water surface elevations, water depths and velocities important to determining the quality and availability of aquatic habitat. While instream flow requirements are meant to mimic natural flows to some degree, regulated flows do not

and cannot replace the natural flow regime. It is nevertheless an important goal to provide as close to a natural flow regime as is possible given the constraints of current conditions (i.e., minimizing potential downstream flooding impacts).

e. Drought conditions represent a major challenge for meeting and improving habitat conditions for fish within the watershed.

8.2 General Recommendations

- Planning should anticipate the types of changes in the seasonal hydrograph and frequency of rain-on-snow and other episodic events associated with climate change predictions, including a greater likelihood of fire and a higher degree of variability in yearly precipitation.
- The intensified use of the lower river corridor by species of all sorts, and thus the activities and conditions that exist in the lower Mokelumne River may warrant an increased level of attention. Such attention can be seen in the efforts by many stakeholders over recent decades. It may be that the MokeWISE stakeholders identify alternatives which seek even more habitat or denser species populations in the lower Mokelumne River. Functional flows analyses using various instream flow values may be useful here.
- Geomorphic data collection efforts that would enhance basin-scale planning include:
    a. Geomorphic characterization of the upper watershed above Pardee Dam to supplement previous stream geomorphology characterization (PG&E, 2011), if needed
    b. Measurement of reservoir sedimentation in Pardee Reservoir and Camanche Reservoir to understand upstream sediment yield responses to large-scale logging and road building in a forested watershed (Kattelmann, 1996)
    c. Measurement of sedimentation in upper watershed reservoirs and diversion structures.
    d. High-resolution topographic mapping of the lower Mokelumne River
    e. High-resolution topographic mapping of selected channels in the upper Mokelumne River basin

A great deal of information is available on the role of instream flows and water quality on fishery habitat within the Mokelumne River system. Adaptive management of limited water supplies can be and has been used, as a management tools for improving habitat conditions (e.g., providing pulse flows in the fall for adult Chinook salmon upstream attraction and migration and flows related to instream conditions for Foothill Yellow-Legged Frogs in the upper watershed). Challenges exist in providing more reliable habitat conditions over a range of hydrologic conditions as well as meeting institutional and regulatory needs for competing beneficial uses. The FERC Joint Settlement Agreement provides a foundation for exploring opportunities to further enhance habitat for Chinook salmon, steelhead, other fish species, and other aquatic and terrestrial species that depend on instream flows. Collaborative stakeholder efforts and restoration programs are also underway in the upper watershed to benefit resident fisheries, amphibians, and other wildlife.

8.3 Closing

What the future will bring, specific to the Mokelumne River watershed, is unknown. It has been well documented that sediment and flow discontinuities fundamentally alter the geomorphic character and ecosystem functions of the system, both on the Mokelumne River and worldwide. Nonetheless, opportunities are possible as shown in the story of gravel augmentation and spawning habitat renewal. Trends in climate will play a large role in flow dynamics in the coming decades, with potential changes to flow frequency, timing, duration, magnitude and rates of change on top of those already in place due to flow regulation, which will provide plenty of challenges in the years ahead. Assessing potential opportunities and constraints for enhancing habitat conditions for aquatic resources and geomorphic processes on the Mokelumne River will involve consideration of a number of potentially competing and conflicting objectives, outcomes, risks, and benefits. These challenges are accentuated by large interannual variation in hydrologic conditions within the watershed. Planning to address these interacting factors will require an understanding of the physical and biological processes affecting habitat on the river as well as interdisciplinary consideration of balancing tradeoffs as part of short- and long-term planning and enhancement.

The assessment of additional or specific trends in the geomorphic functions discussed herein should include not only water management during typical ranges of conditions, but also recovery from legacy effects, as well as adaption to future conditions associated with watershed management and climate change. It should also recognize that all channels will be periodically disturbed by episodic events, such as major floods, wildfires or droughts. It is important to understand that geomorphic change, although predictable in a broad sense and when specific drivers are in place such as dam operations, is also a very unpredictable process, with complex effects that will change as further adjustments occur in the sediment budget, water supply, and other human activities and natural processes. We agree with the primacy of 'typical ranges of conditions', but have learned over the years that there will be periods of episodic disturbances in most Western US stream. It is important to have a common understanding of and standards for those periods when typical ranges of conditions do not prevail. Once stakeholders identify alternatives or component ideas, engaging in the development of sustainable, productive and dynamic equilibrium conditions between consumptive and conjunctive uses of water resources and the geomorphic and ecological integrity of specific concepts can be addressed more thoroughly.

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