Verifying Reported Historical Natural Barriers to the Upstream Migration of Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*Oncorhynchus mykiss*) in the Mokelumne River Watershed

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ABSTRACT

Substantial uncertainty exists regarding historical use of the Mokelumne River watershed by native anadromous salmonid runs. Determining the presence and location of historical natural migration barriers is an important element for delineating historically accessible habitats and understanding the historical species/run composition, distribution, and relative abundance of native salmon and steelhead runs in the watershed. Over 145 km (90 mi) of Mokelumne

River was surveyed to verify reported anadromous salmonid migration barriers and historical upstream limits of habitat use by Chinook salmon and steelhead. The findings of ground truth surveys coupled with information from technical reports and historical newspaper articles about fisheries in the region indicate fall-run Chinook salmon very likely had access to all habitats in the Mokelumne River Basin at elevations used by fall run salmon in other Central Valley tributaries. Spring and late-fall run Chinook salmon and winter run steelhead very likely had access to all habitats in the river up to Bald Rock Falls in the North Fork and at least to a boulder jam on the lower Middle Fork. Both structures are located in the steepest reaches of the Mokelumne River system between 350 m and 410 m elevation. The Middle Fork boulder jam has not been adequately evaluated for anadromous salmonid passage during spawning migrations. If passable the Middle and South Fork reaches could add over 48 rkm to the current estimate of about 150 rkm of historically accessible habitat for anadromous salmonids in the Mokelumne River system. This information will be useful for developing, clarifying, and prioritizing Mokelumne River fisheries management objectives.

Key Words: historical natural migration barrier, Chinook salmon, *Oncorhynchus tshawytscha*, steelhead, *Oncorhynchus mykiss*, Mokelumne River, barrier, migration, passage.

BACKGROUND

One element of the California's Ecosystem Restoration Program is the Fish Passage Improvement Program (FPIP) (NMFS 2005). The goal of the FPIP is to work with resource agencies and stakeholders to plan and implement projects to remove barriers that impede migration and spawning of anadromous fishes. The program relies on the California Passage Assessment Database for information regarding current and historical limits to fish migration, and current and historical quantities of usable spawning and rearing habitat within the FPIP geographic scope. NMFS (2005) describes the current geographical scope of FPIP as downstream of rim dam reservoirs in the Central Valley, yet their map of geographic scope includes Camanche Dam and reservoir. The boundary appears to be located near Arkansas Ferry at the site described by Nuzum in Yoshiyama et al. (1996, and 2001) as the historical limit to upstream fish migration. It also asserts fish passage will need to be re-established in historical habitats in order to recover salmon and steelhead populations to the point where they no longer need Endangered Species Act protections.

The earliest accounts of salmonids in the Mokelumne River are historical journal entries reported by Sullivan (1934) and Clark (1973) in Yoshiyama et al. (2001). One account is an entry from the diary of Jedediah Smith on 22 January 1828 indicating the trapper gave some tobacco to several Indians that visited his camp on "Rock River" (Mokelumne River), from whom three salmon were purchased. Another account recorded by Alfred Doten on 22 December 1851 indicated he had seen three fine salmon that had come from the "Moqueleme" (Mokelumne River). Yoshiyama et al. (2001) noted both accounts occurred during winter months and included comments on the “fine” condition of the salmon, indicating these fish were most likely late-fall run. Yoshiyama et al. (2001) also postulated that since the native Northern Sierra Miwok people on the Mokelumne River had a “first-salmon” rite associated with the onset of the spring-run harvest in other Central Valley streams (Aginski 1943), it suggests the Mokelumne River historically supported a spring-run Chinook salmon (*Oncorhynchus tschawytscha*) population.

The California Department of Fish and Game (CDFG) first delineated available salmon spawning grounds in the Mokelumne River that extended upstream from present day New Hope Landing, past Woodbridge Dam to Elliott Road Bridge near Lockeford (Clark 1929)(Figure 1). The CDFG also conducted a survey of the Mokelumne River, between Pardee Reservoir and Tiger Creek in 1946 to evaluate potential impacts to the fisheries in this river reach from new hydroelectric developments proposed by Pacific Gas and Electric Company. The resulting report (Woodhull 1946) identified Bald Rock Falls (BRF) in the north fork of the Mokelumne River, a 30+ foot (over 9 m) waterfall at about elevation 1400 ft (427 m), and concluded it was a complete barrier to upstream migrating fish (Figure 1). This is the earliest report found to date identifying a historical natural migration barrier in the Mokelumne River watershed.

The CDFG (1959) report regarding the influence of proposed water projects on the fisheries of the Mokelumne River indicated construction of Pardee Dam (completed in 1929) caused both the extinction of spring-run Chinook salmon in the Mokelumne River watershed, and enhanced conditions in the river below the dam for the reproduction of fall-run Chinook salmon.

On 21 June 1991, East Bay Municipal Utility District (EBMUD) staff tracked water quality trends in releases from Pardee Dam and took photographs of the river upstream of the Arkansas Ferry crossing, showing the location where the river flowed into the reservoir (Appendix A, photos 1a, 1b). Drought conditions at the time resulted in a reservoir surface elevation of 54.9 m (180 ft) leaving much of the lake bed exposed. The noticeable gradient shift in the photos coupled with a contour map generated from 1988 aerial photo data were apparently interpreted to indicate the presence of a natural, historic barrier to fish migration. It also seems likely the interpreter believed this was the location of the “30+ ft waterfall” reported by Woodhull (1946). This information was then reported as the historical upstream limit of accessible habitat for Chinook salmon by Nuzum in Yoshiyama et al. (1996 and 2001). This information was subsequently used by various researchers (McEwan 2001, NMFS 2005, Lindley et al. 2006) to predict historical distributions of salmon and steelhead (*Oncorhynchus mykiss*) in the Mokelumne River watershed.

Lindley et al. (2006) used a multi-phase modeling approach to describe the historical structure of the Central Valley steelhead evolutionarily significant unit (ESU). They identified 151 patches of potentially suitable habitat containing more than 10 km of stream habitat. They grouped clusters of basins into four geographic regions. The Mokelumne River was divided into 2 independent populations: the main-stem

Mokelumne/Sutter Creek population, and the North Fork Mokelumne population. They included the Mokelumne/Sutter Creek population in the “mostly tributaries to the Sacramento River” basins while the North Fork Mokelumne population was grouped with the “upper San Joaquin and tributaries draining the southern Sierra Nevada”. The habitat map in the paper indicates the vast majority of historically accessible summer rearing habitat for Mokelumne River steelhead can be found between elevation 250 m (823 ft) in the main-stem, and elevations 904 m (2966 ft) in the North Fork, 1172 m (3844 ft) in the Middle Fork, and 829 m (2721 ft) in the South Fork, totaling about 98 river km (61 mi).

Central Valley fisheries management efforts rely on the reported current and historical distributions of anadromous salmonids for developing species recovery plans, restoration projects, adaptive river management plans below impoundments and genetics management plans for hatcheries. The purpose of this study was to verify, and establish with as much certainty as possible, the locations of historical limits to upstream migration of anadromous salmonids in the Mokelumne River watershed.

METHODS

Historical scientific documentation regarding fish populations in the Mokelumne River is scant, so a search of historical newspaper articles written between 1860 and 1915, regarding fish in the region was conducted to locate relevant information regarding conditions and events that occurred during this important time frame (Appendix B).

Ground truth surveys were conducted on the Mokelumne River from the confluence with the San Joaquin River in the California Bay-Delta, upstream, to points located approximately 3.2 km (2 mi) into the North and Middle Forks to clear up discrepancies in the reported historical limits to fish migration (Table 1). Surveys were conducted during the fall of 2008 and 2009, and the spring of 2011 and 2012 to identify any natural structures that could be a barrier to the upstream migration of anadromous salmonids. The locations of larger waterfalls and rock jams were recorded using a Trimble® GeoXH Global Positioning Unit (GPS). The heights of these structures were measured using an Advantage® laser rangefinder with compass and inclinometer (Laser Atlanta Optics, Inc. Norcross, GA). Three parameters were recorded for each height measurement taken; range at 90˚ inclination (level), and inclination of the top and bottom of the structure. The heights of the natural structures found were compared to the maximum jumping heights criteria for Chinook salmon and steelhead (Table 2), developed by Reiser and Peacock (1985), to determine if the structure had the capacity to impede or block upstream migration of salmon or steelhead. One site was inundated with lake water so a boat mounted fathometer, Lowrance LMS-320 DF Fish-finding Sonar and Mapping Global Positioning System (GPS) unit, was used to collect a series of sonar readings linked to GPS coordinates. These data were used to generate a bathymetric map of the river channel in and around the reported barrier site using ARCMAP©. The locations of all potential natural migration barriers, stream confluences, reported migration barriers, some reported habitat preference boundaries and major dams and bridge crossings were listed with associated stream bed elevation and distance from the river mouth (Table 3), for reference purposes.

RESULTS

Mokelumne River Mouth to Arkansas Ferry Crossing

No natural structures were found in the river, downstream of Camanche Dam that appeared to impede the upstream migration of anadromous salmonids. This assertion has multiple sources of support: adult return data from the Mokelumne River Fish Hatchery (CDFG 1964 thru 2012), annual redd survey reports (EBMUDb 1995 – 2012), and Chinook salmon and steelhead carcass survey data (EBMUDc 2003 – 2013). There have been no reports and there is no evidence of any historical natural structural migration barriers in this reach of the Mokelumne River or in the reach between Camanche Dam and the Arkansas Ferry Crossing. An early CDFG fisheries report (1959) indicates Chinook salmon spawned above Pardee and Camanche Dams prior to their construction.

Arkansas Ferry Crossing to Pardee Dam

Personnel from the EBMUD Fisheries and Wildlife Department conducted a survey of this area on 11/4/08. Photographs of the area, taken by EBMUD personnel tracking the 1996 flows from Pardee Dam, were used to establish the location of the reported fish migration barrier (Appendix A, photos 1a - d). The 256 m (840 ft) stream reach between Arkansas Ferry Bridge abutments and the first river bend above the reported waterfall site was submerged under Camanche Reservoir during the ground truth survey so GPS and depth data were collected at 1259 locations within this section. These data were used to generate a bathymetric map of the site with 0.3 m (1 ft) depth contours (Figure 2).

Impoundments tend to block the recruitment of sand, gravel, and boulders from upstream sources so the proximity of this reported migration barrier to Pardee Dam makes it very unlikely that sedimentation has obliterated a historic waterfall in this reach.

Turbidities in the section were low enough to allow visual inspection of the riverbed throughout most of the section. The riverbed in this section and throughout this reach to Pardee Dam was rocky with a relatively steep gradient, but no 30+ ft (9 m) waterfalls or natural structures of any kind were found that appeared to be capable of blocking historical anadromous fish passage. This finding is consistent with assertions made in the CDFG 1959 report that "an undetermined number of salmon spawned in the river above Pardee Dam prior to its construction", and that a number of salmon were seen at the base of Pardee Dam following construction. This finding would also have to be true for adult striped bass to have ascended the river to Big Bar prior to construction of Pardee Dam, as the Amador Ledger reported September 27, 1907 (Appendix B).

Pardee Dam to Above Electra

No reports have been found of any natural structural migration barriers in the river between Pardee Dam and Electra. A trail along the river between Middle Bar Bridge and Hwy. 49 Bridge, and 9.6 km (6 mi) Electra Road, between Hwy 49 and Electra Powerhouse, allowed close visual inspection of this entire reach. A concrete regulator dam crossing the river channel just below the Electra Powerhouse at elevation 204 m (669 ft), was the only structure seen in this reach with the potential to impede or block anadromous fish upstream migration at normal flow rates (Appendix A, photos 2a, 2b).

The seasonal spawning migration of kokanee salmon (*Oncorhynchus nerka*) from Pardee Reservoir past the regulator dam demonstrates the structure allows passage of this species, at least at some flow rates. Maximum jumping heights for Chinook salmon and steelhead are much greater than for kokanee, so presumably Chinook salmon and steelhead would find this structure passable at similar flow rates. No natural structures were found in this stream reach that appear to be capable of impeding salmon or steelhead migration, within a broad range of flows.

Above Electra to China Camp

Private property and rough terrain limited surveying to 5 km (3 mi), or about 65% of this reach. A trail along the river above the Electra powerhouse allowed close inspection of the lower 3.2 km (2 mi) of this reach. Binoculars were used to view about 0.75 km (0.5 mi) of river below Ponderosa Way Bridge, and about 0.5 km (0.3 mi) above the bridge from various vantage points. Road access also allowed close inspection of a 0.5 km (0.3 mi) stretch directly downstream of China Camp. Salmon were observed spawning in the river near Ponderosa Way Bridge in the early 1960’s by Elton Rodman (E.V. Rodman 2009. Roaring Camp Owner, pers. comm.). The salmon Mr. Rodman reported would most likely have been kokanee salmon from Pardee Reservoir, introduced there in 1961 (Noble and McClendon 1999). Pardee Dam blocked upstream migration of adult salmon from the ocean since 1929, and although there is an unpublished record of Chinook salmon being introduced by CDFG into Camanche Reservoir in 1989, no records were found of any salmon other than kokanee being released into or above Pardee Reservoir. The presence of kokanee at the Ponderosa Bridge suggests there were no natural barriers to upstream salmonid migration between Pardee reservoir and the bridge. Additionally, Woodhull's (1946) evaluation report on fisheries resources between Pardee Reservoir and Tiger Creek on the North Fork mentions no barriers to the upstream migration of fish in the main-stem.

China Camp to North and Middle Forks Confluence

Rodman (2009, pers. comm.) also reported a waterfall at China Camp was the first large natural geologic structure in the river above Ponderosa Bridge (Appendix A, photos 3a - d). The height of the tallest waterfall was found to be 1.3 m (4.3 ft), well below the maximum jumping height for Chinook salmon or steelhead. The configuration of China Camp Falls appeared to be passable in both directions, for healthy adult salmonids at a broad range of flows, whenever water temperatures are within acceptable limits. It is unknown if some previous form of this structure blocked or impeded fish passage in the past. Mr. Rodman indicated several large boulders below the falls were part of the falls back in the 1960's suggesting even large boulders are transitory in this high gradient stream reach.

North Fork Confluence to Bald Rock Falls

A series of natural geologic structures was found in a 0.95 km (0.6 mi), steep-sloped (~12%) section of the North Fork between elevation 295 m (967 ft) and 395 m (1295 ft), that would likely impede upstream passage of both salmon and steelhead at a range of flows (Appendix A, photos 4a - d). One of these structures was a 2.4 m (8 ft) high natural waterfall on the day of the survey (10/05/09). This structure is located at elevation 380 m (1248 ft), and exceeded the maximum jumping height criteria established by Reiser and Peacock (1985) for Chinook salmon that day and would be near the upper limit for steelhead. Additionally, there is a bedrock skirt at the crest of the waterfall that separates the crest from the pool above the fall by a few feet, possibly increasing the difficulty of steelhead passage. The depth of the approach pool is unknown, preventing comparison of ratios of structure height to pool depth with jumping height standards to determine maximum jumping heights a salmon or steelhead could achieve in a given pool. However, using Reiser and Peacock's (1985) jumping height criteria, pool depth would likely have to be near 3 m (10 ft) for a steelhead to be able to jump the height of this waterfall at these flows. Spring flows and storm events with substantial precipitation could make this structure passable to both salmon and steelhead. The other two structures observed were a waterfall and a small rock pile. The waterfall appeared to be passable at high spring flow rates, and the rock pile appeared to be passable at all seasonal flow rates.

Bald Rock Falls is bound by steep, narrow, bedrock canyon walls (Appendix A, Photos 4d, 5a – c). It appeared to have been formed by a geologic fault in granitic bedrock that transects the river channel (Eldridge Moores, Professor Emeritus, UCD Geology Dept. 2011, pers. comm.). Aerial photos and comments by Roaring Camp guides were consistent with the location Woodhull (1946) reported. The height of Bald Rock Falls found in the North Fork at elevation 406 m (1333 ft) was found to be closer to 5.5 m (18 ft) than the 30+ ft (>9 m) height reported by Woodhull (1946). It's not clear if the dimensions changed between surveys, or if measurement precision differed. In any case, the height of Bald Rock Falls easily exceeds the Reiser and Peacock (1985) maximum jumping height criteria for both Chinook salmon and steelhead regardless of pool depth and appeared to be impassable to salmon and steelhead within the historical range of seasonal flows (Figure 4). The conclusion drawn in Woodhull (1946) regarding BRF appears to be true, this structure is a complete and relatively permanent barrier to fish migration, and it seems very likely the habitats above the falls were historically inaccessible to native Mokelumne River salmon and steelhead for a large part of their evolutionary history. Additionally, a series of waterfalls above Bald Rock Falls was observed from BRF during the 10/6/2009 survey that would likely impede and possibly block upstream migration of anadromous salmonids (Appendix A, Photo 5d).

Middle Fork Confluence to Middle Fork Boulder Jam

A series of natural geologic structures was found in a 1.5 km (0.9 mi) long, steep sloped (~6.3%) reach of the Middle Fork between elevation 259 m (850 ft) and 288 m (945 ft) that would likely impede upstream migration of fish within a broad range of flow rates, and possibly block it entirely at some flow rates. A boulder jam was found at elevation 356 m (1169 ft) on the Middle Fork (38°22'24.15"N, 120°35'35.81"W), composed of a 6.7 m (22 ft) high pile of boulders wedged between narrow bedrock walls (Appendix A, photos 6a – 6c). Fish passage would presumably be a matter of burst speed not jumping height, since the river flows between the boulders providing the possibility for upstream migrating fish to migrate past the boulder jam by swimming through it. The current configuration of rocks might be seasonally impassible to salmon and steelhead at a range of fall and summer flows (Figure 3). A seasonal migration barrier at this location would eliminate seasonal access to most of the river habitat on the Middle Fork and all river habitats in the South and Licking Forks and their tributaries. This would primarily affect adult steelhead upstream passage during fall and winter months. This geologic structure is subject to a wide range of seasonal flows and this type of structure, composed of large rounded boulders is presumably relatively dynamic or even transient in nature

DISCUSSION

The natural geologic structures in the Mokelumne River Watershed that have the greatest potential to impede the historical upstream migration of salmonids are located on the North Fork and Middle Fork, in rugged terrain near the bottom of the steepest stream reaches in the system (Figure 4). These geologic structures are found at elevations above 305 m (1000 ft). Fall and late-fall runs of Chinook salmon have been found to utilize spawning habitats below this elevation in other Central Valley tributaries (Yoshiyama et al. 2001), so historical migrations of these runs were presumably unaffected by these structures. The stream-type spring-run Chinook and steelhead would likely have utilized spawning, holding and rearing habitat found in the watersheds of the Middle and South Forks, if they had access to them. The CDFG's (1959) report stating spring-run Chinook were eliminated by Pardee Dam suggests the habitats above the boulder jam in the Middle Fork were historically accessible to native Mokelumne River salmonids and/or the steep gradient of the North Fork between elevations 305 m (1000 ft) and 610 m (2000 ft) expedited the flow of cold water from higher elevations to mid-elevations, providing suitable over-summer holding and rearing habitat at lower elevations in the Mokelumne River than what has been found in other major central valley tributaries.

The non-scientific information regarding historical Mokelumne River anadromous fish populations is scant, consisting of a few newspaper articles published by the Amador Ledger, Daily Alta California, Pacific Rural Press, Sacramento Daily Union and the Sausalito News (Appendix B), entries from the journals of Jedediah Smith and Alfred Doten, and ethnographic information summarized in Yoshiyama et al. (2001), and a first-hand account by Elton Rodman, the owner of Roaring Camp. The newspaper articles published from 1868 to 1908 regarding fish passage demonstrate the importance of salmon to the people (native American and settlers) of California, and indicates the Mokelumne River provided spawning habitat for sizable salmon populations during this time period and suggests sizable Mokelumne River salmon populations were the norm prior to substantial ecological changes associated with hydraulic gold mining and stream blockage by dams (Appendix B, Sacramento Daily Union 1868, 1881; Pacific Rural Press 1886, 1888, and 1889; and Daily Alta California 1886).

Chinook salmon, steelhead and striped bass (*Morone saxatilis*) have anadromous life forms, and while Chinook salmon and steelhead are known for their ability to jump substantial obstacles during their spawning migrations, striped bass are not, so it follows that since striped bass were able to ascend the river to Middle Bar in large numbers in 1907 (Appendix B, Pacific Rural Press 1891, 1907), it is very likely salmon and steelhead did as well. The newspaper articles support the idea that there were no natural structures that constituted barriers to salmon and steelhead migration in the Mokelumne River from the Delta to Big Bar and both Mr. Rodman's (2009) account and Woodhull's (1946) report support the idea that neither the Electra site nor the reach between Electra and China Camp contained natural structures that determined the historical limit to upstream passage of adult salmonids in the Mokelumne River.

Very little scientific documentation exists regarding the historical fish fauna of the Mokelumne River. Clark's (1929) map of available salmon spawning habitat in the Mokelumne River appears to be hypothetical because the delineated habitat was likely not suitable for salmonid spawning. The gradient in most of it is too flat for suitable spawning gravel to accumulate and roughly half of it is currently under tidal influence. Woodhull's (1946) work documented the presence and location of a migration barrier on the North Fork, but seems to imply the historical fisheries resources in the Middle and South Forks and associated tributaries were insignificant. His fisheries investigation concentrated primarily on the North Fork and main-stem reaches between Salt Springs and Pardee Reservoirs. There was little mention of the Middle and South Forks and no mention of the larger tributaries to the Middle Fork like Forest Creek, Hunter Creek, Bear Creek or Lion Creek or to the South Fork like the Licking Fork, Wet Gulch, Airola Creek, Hayward Creek, Swampy Creek or the Little Mokelumne River; and no mention of associated fisheries resources or of the effects of the proposed project on these fisheries. In his discussion about the Middle Section of the Mokelumne River between Bald Rock Falls and Electra, Woodhull reported "There are no constant flowing tributaries", implying there were no major tributaries that support substantial fishery resources in this reach and that no further investigation was needed. Despite this he provides a graphic illustrating the mean yearly discharge of the Middle and South Forks was 2.1 $m^3 sec^{-1}$ (74 $ft^3 sec^{-1}$), with a range of 0.23 to 22.7 $m^3 sec^{-1}$ (8 to 800 $ft^3 sec^{-1}$) for the 1943-44 water year. He goes on to state the runoff on the Mokelumne Drainage during that water year was 70% of the mean flows for the previous 16 years, suggesting actual mean annual discharge in these tributaries was closer to 2.7 $m^3 sec^{-1}$ (96 $ft^3 sec^{-1}$).

The evidence to date supports the assertion by Woodhull (1946) and Yoshiyama et al. (2001) that Bald Rock Falls, the prehistoric, natural bed-rock structure, placed historical limits to upstream passage of adult salmonids. The ground truth surveys confirmed Bald Rock Falls is located on the North Fork approximately 12.6 km (7.8 mi) upstream of the Electra Powerhouse, and approximately 3.2 km (2 mi) upstream of the North Fork, Middle Fork confluence (38°23'51.00"N, 120°36'32.62"W). This means that while spring-run Chinook salmon and winter-run steelhead likely had no access to nearly all of the North Fork, they may have had access to elevations in the Middle and South Forks and their associated tributaries, in the range of elevations that they typically use for spawning and over-summer holding in other Central Valley tributaries.

The boulder jam on the Middle Fork of the Mokelumne River located downstream of the confluence of the Middle and South Forks, has yet to be evaluated adequately for fish passage, so it’s still unclear if this natural and perhaps transient structure placed historical limits on the upstream migration of Chinook salmon and steelhead in the Middle Fork and South Fork Mokelumne River Watersheds. The river flows through the boulders that have collected at the upstream opening of this narrow bedrock canyon, which may provide the opportunity for year-round upstream passage for adult salmonids. The nearly bare granite walls containing this structure suggest it is still periodically inundated by high flows associated with snow melt or large storm events, which could be expected to provide or vary fish passage conditions seasonally. Additionally, the migratory fish documented at Westmoreland Dam "swarming" in July of 1881 and "early returning" in February of 1886 resulting from fish ladder outages (Appendix B - Sac. Daily Union 1881, Vol. 4, No.9; Pacific Rural Press 1886, Feb. 9; Daily Alta California 1886, Vol.40, No. 13321), fit the life history migration pattern of Central Valley spring-run Chinook salmon (Yoshiyama et al. 2001), suggesting suitable over-summer holding habitat was accessible to spring-run Chinook for some time prior to the construction of Pardee Dam in 1929.

Despite the fact Bald Rock Falls blocked migration access to most of the North Fork the typical spring stream flow pattern for this tributary would certainly provide cues to attract spring Chinook and winter steelhead from the Delta into the Mokelumne River. It seems reasonable many of these fish would end up holding over and spawning in the smaller Middle and South Forks if they were accessible.

The findings of the ground truth surveys indicate fall-run Chinook salmon very likely had access to all habitats in the Mokelumne River at elevations used by fall-run Chinook salmon in other Central Valley tributaries. Spring-run and late-fall run Chinook salmon and winter-run steelhead likely had access to all habitats in the river up to Bald Rock

Falls in the North Fork and the boulder jam on the Middle Fork. If this boulder jam is determined to be passable for upmigrating anadromous salmonids, it could add over 48 rkm (30 rmi) of over-summer holding habitat to the current estimate by Lindley et al. (2006) of about 150 rkm (93 rmi) of suitable accessible habitat for anadromous salmonids in the Mokelumne River system, with nearly all of it above elevation 457 m (1500 ft). The findings also do nothing to counter the suggestion by Yoshiyama et al. (2001) that the Mokelumne River supported a late-fall Chinook salmon run at one time.

The survey results do not support reports regarding the location of natural migration barriers near Arkansas Ferry and Electra Powerhouse, (Yoshiyama et al. 1996 and 2001, NMFS 2005), or habitat historically accessible to steelhead within the Upper Mokelumne River (Lindley et al. 2006, McEwan 2001). The near inaccessibility of these stream reaches to humans may be partly responsible for these discrepancies and the scant historical documentation of fisheries resources in the Upper Mokelumne River. Clearly the information generated by the ground-truthing, the review of historical newspaper articles, journal entries, and personal communications with people who witnessed certain events can enhance the existing body of scientific literature regarding Mokelumne River fisheries.

Understanding the timing, magnitude and frequency of high flow events in the Middle and South Forks, conducting fish passage studies at the boulder jam, and seasonal water temperature modeling would help characterize historical conditions and provide evidence for determining if spring-run Chinook salmon and winter-run steelhead had sufficient access to spawning, holding and rearing habitats, above the boulder jam, to sustain healthy populations.

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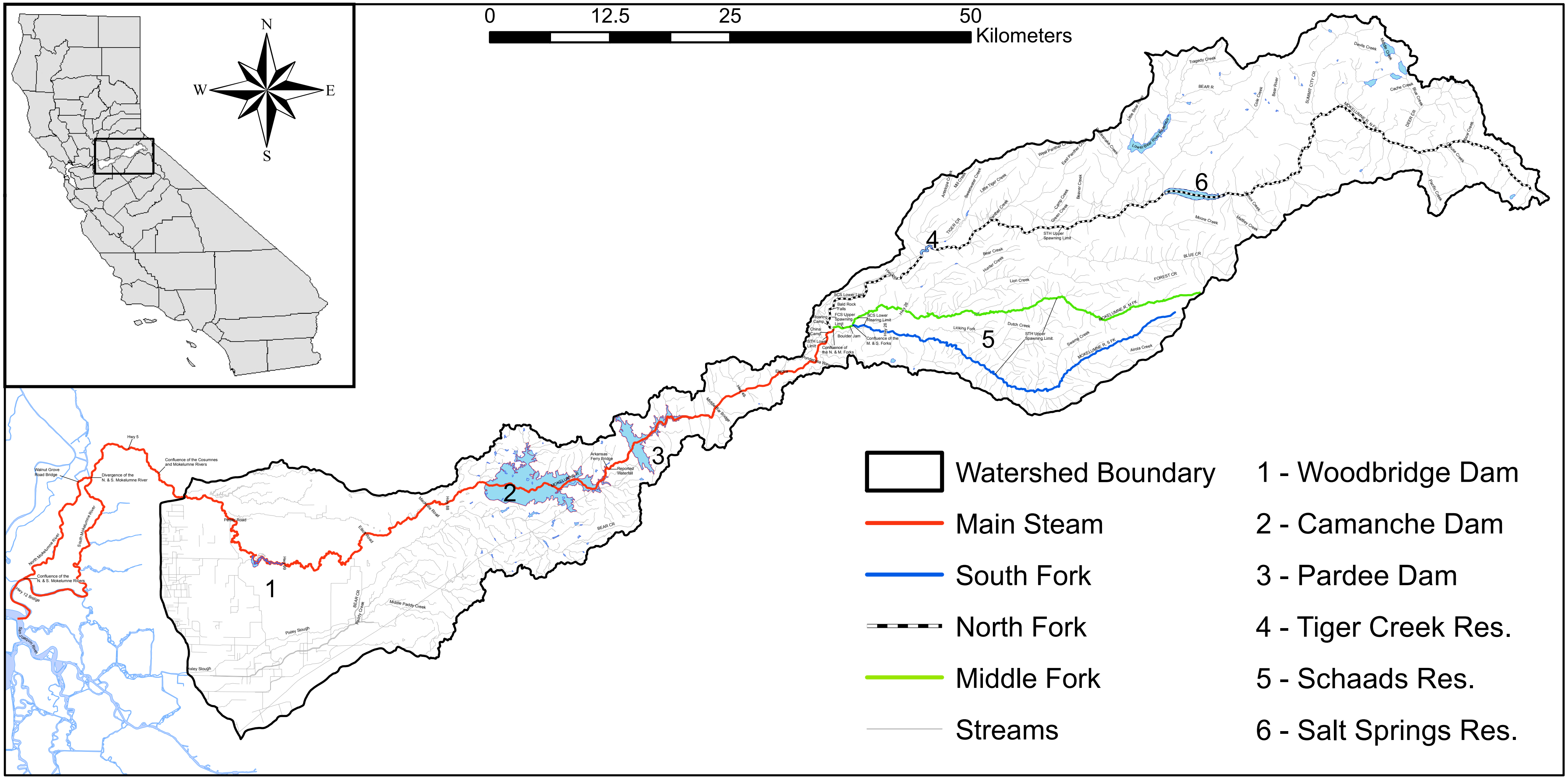


N
S
W
E
0
12.5
25
50
Kilometers
Watershed Boundary
Main Steam
South Fork
North Fork
Middle Fork
Streams
1 - Woodbridge Dam
2 - Camanche Dam
3 - Pardee Dam
4 - Tiger Creek Res.
5 - Schaads Res.
6 - Salt Springs Res.

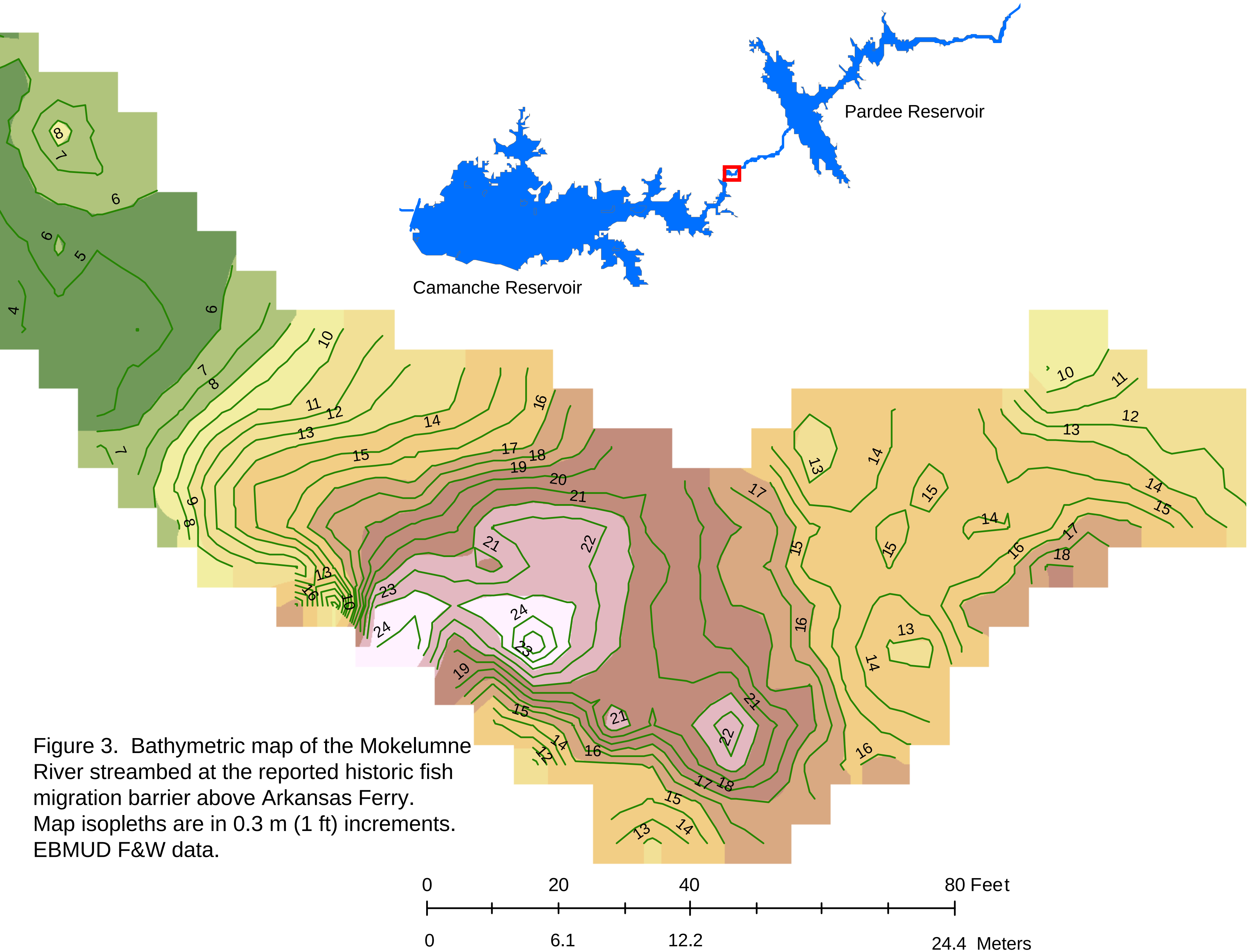


Figure 3. Bathymetric map of the Mokelumne River streambed at the reported historic fish migration barrier above Arkansas Ferry. Map isopleths are in 0.3 m (1 ft) increments. EBMUD F&W data.

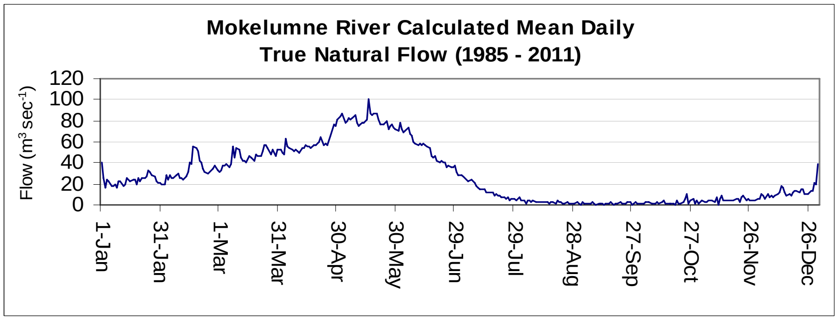


Figure 3. Mokelumne River calculated mean daily unimpared flow for years 1985 thru 2011 at Mokelumne Hill. Note the rough ascending arm of the hydrograph during winter and spring months indicating highly variable flow rates caused by storm events (EBMUD WSP data).

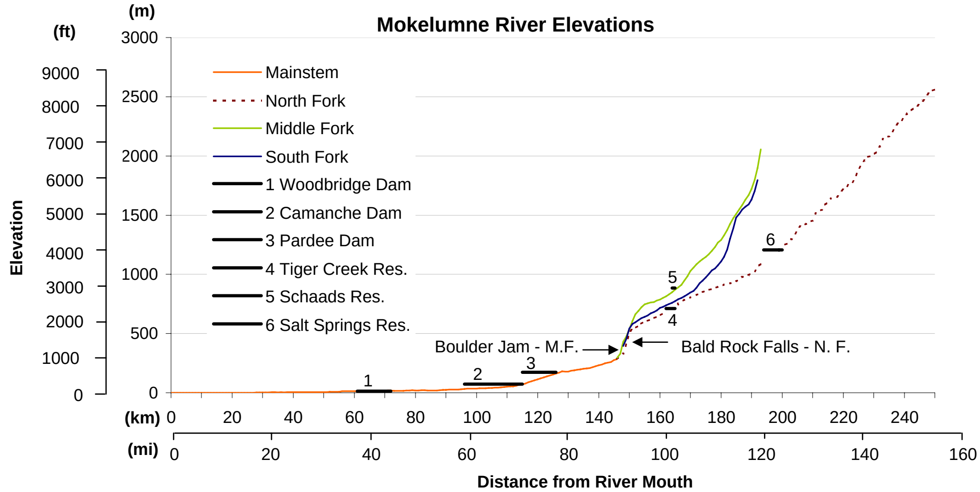


Figure 4. Mokelumne River elevations, starting at the confluence with the San Joaquin River in Sacramento and San Joaquin Counties, proceeding upstream through the North Mokelumne River, arrows show the locations of Bald Rock Falls on the North Fork and the boulder jam on the Middle Fork, and black bars represent locations of major impoundments currently in the watershed. Distance and elevation curves are incomplete for all three forks in the upper watershed (USGS and EBMUD data).

Table 1. Reported limits to the upstream migration of Mokelumne River salmonids

Species	Location	Type	Reach	Elevation m (ft)	Rkm[a] (mi)	Status
All salmonids	Woodbridge Dam	Engineered Dam	Main Stem near tidal influence	9.4 (31)	54.9 (34.1)	A
All salmonids	Camanche Dam	Engineered Dam	Lower Main Stem	31.1 (102)	95.6 (59.4)	B
All salmonids	Westmoreland Dam	Engineered Dam	Lower Main Stem	48.8 (160)	108.9 (67.7)	C
All salmonids	Falls near Arkansas Ferry	Natural Barrier (30+ ft waterfall)	Lower Main Stem	53.3 (175)	112.5 (69.6)	D
All salmonids	Pardee Dam	Engineered Dam	Upper Mainstem	76.2 (250)	115.1 (71.5)	E
All salmonids	Electra Powerhouse	Engineered Dam	Upper Mainstem	204.5 (671)	135.7 (84.3)	F
All salmonids	Bald Rock Falls	Natural Barrier (waterfall)	North Fork	406.3 (1333)	149.0 (92.6)	G

a - River kilometers and miles were measured using Google Earth ™ starting from the mouth of the Mokelumne River at the confluence with the San Joaquin River.

A - The likely historical seasonal limit to upstream migration of salmonids between 1910 and 1929
B - The current limit to upstream migration of salmonids since 1964 (Yoshiyama et.al. 1996, and 2001)
C - The reported limit to upstream migration of salmonids between 1881 and 1889 (Sacramento Daily Union, 1881; Pacific rural Press, 1886 and 1889)
D - The reported historical limit to upstream migration of salmonids (Nuzun in Yoshiyama et.al. 1996, and 2001)
E - Anadromous salmonid migration barrier between 1928 and 1964 (Yoshiyama et.al. 1996, and 2001).
F - Engineered dam reported as a natural historic migration barrier barrier (NMFS 2001)
G - The likely historical limit to upstream migration of salmonids in the North Fork Mokelumne River (Woodhull 1946)

Table 2. Maximum jumping heights of Chinook salmon and steelhead

	Maximum Jumping Height	
Chinook Salmon	2.4 m	7.8 ft
Steelhead	3.4 m	11.2 ft

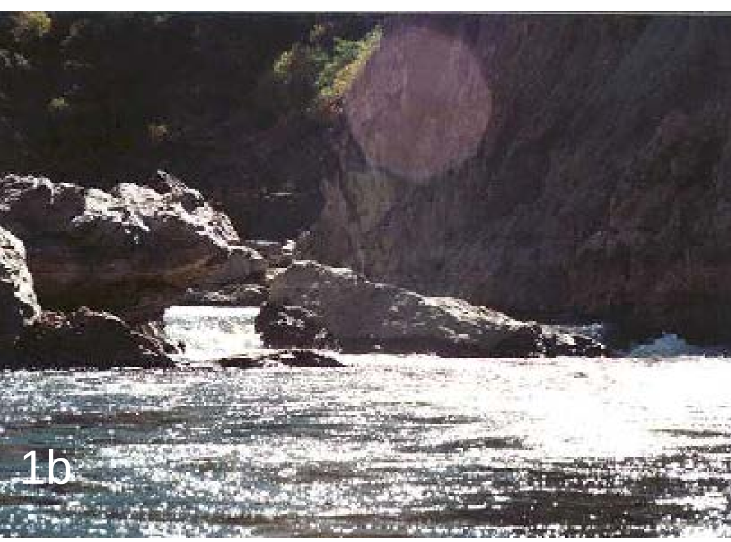
Data from Reiser and Peacock 1985

Mokelumne River Locations	Stream Reach	Streambed[a] Elevation ft (m)	River Mile[b]	River Kilometer[b]
Confluence with San Joaquin River	Mainstem	< 0	0	0
Highway 12 Bridge	Mainstem	< 0	3.3	5.3
Confluence of N. Mokelumne and S. Mokelumne	Mainstem	< 0	4.2	6.8
Walnut Grove Road Bridge	N. Mokelumne	< 0	13.3	21.4
Divergence of N. Mokelumne and S. Mokelumne	Mainstem	0 (0)	14.3	23.0
Highway 5 Bridge	Mainstem	9 (2.7)	18.6	29.9
Confluence of Mokelumne and Cosumnes rivers	Mainstem	12 (3.7)	21.8	35.1
Peltier Road Bridge	Mainstem	18 (5.5)	29.3	47.2
Woodbridge Dam	Mainstem	31 (9.4)	34.1	54.9
Highway 99 Bridge	Mainstem	46 (14.0)	38.7	62.3
Elliot Road Bridge	Mainstem	64 (19.5)	49.2	79.2
Mackville Road Bridge	Mainstem	68 (20.7)	54.6	87.9
Highway 88 Bridge	Mainstem	82 (25.0)	56.4	90.8
Camanche Dam	Mainstem	102 (31.1)	59.4	95.6
Westmoreland Dam	Mainstem	160 (48.8)	67.7	108.9
Arkansas Ferry Bridge	Mainstem	175 (53.3)	69.3	111.5
Waterfall Location reported by Nuzum	Mainstem	177 (53.9)	69.4	111.7
Pardee Dam	Mainstem	250 (76.2)	71.5	115.1
Middle Bar Bridge	Mainstem	584 (178.0)	79.3	127.6
Highway 49 Bridge	Mainstem	607 (185.0)	81.3	130.8
Electra Regulator Dam	Mainstem	671 (204.5)	84.3	135.7
Electra Powerplant	Mainstem	680 (207.3)	84.8	136.5
Ponderosa Way Bridge	Mainstem	772 (235.3)	87.3	140.5
Steelhead Lower Elevation Limit (summer rearing)[c]	Mainstem	820 (250.0)	88.2	142.0
China Camp/China City Rapid	Mainstem	869 (264.9)	89.6	144.2
Confluence of the North Fork and Middle Fork	Mainstem	920 (280.4)	90.3	145.3
Roaring Camp Headquarters	North Fork	937 (285.6)	90.7	146.0
Fall Chinook Upper Elevation Limit (spawning)	North Fork	1000 (304.8)	91.3	146.9
Bald Rock Falls	North Fork	1333 (406.3)	92.6	149.0
Spring Chinook Lower Elevation Limit (summer rearing)[d]	North Fork	1500 (457.2)	92.9	149.5
Hwy 26 Bridge	North Fork	2027 (617.8)	97.5	156.9
Tiger Creek Reservoir	North Fork	2244 (683.9)	100.5	161.8
Steelhead Upper Elevation Limit (spawning)[c]	North Fork	2966 (904.0)	111.8	179.9
Salt Springs Dam	North Fork	3684 (1122.9)	120.2	193.5
Fall Chinook Upper Elevation Limit	Middle Fork	1000 (304.8)	91.0	146.5
Boulder Jam	Middle Fork	1169 (356.3)	91.4	147.1
Confluence of the Middle Fork and South Fork	Middle Fork	1261(384.4)	91.7	147.6
Hwy 26 Bridge	Middle Fork	2455 (748.3)	96.4	155.1
Spring Chinook Lower Elevation Limit (summer rearing)[d]	Middle Fork	1500 (457.2)	92.3	148.6
Schaad's Reservoir	Middle Fork	2900 (883.9)	100.9	162.5
Steelhead Upper Elevation Limit (spawning)[c]	Middle Fork	3844 (1171.7)	108	173.8
Spring Chinook Lower Elevation Limit (summer rearing)[d]	South Fork	1500 (457.2)	93.1	149.9
Hwy 26 Bridge	South Fork	1969 (600.2)	94.4	151.87
Steelhead Upper Elevation Limit (spawning)[c]	South Fork	2721 (829.4)	105.1	169.1

a - Data Source: 2012 Google, and USDA Farm Service Agency,
b - Distances from the river mouth were measured along the alignment of the North Mokelumne River
c - Approximate location of predicted upper limit for steelhead spawning - based on elevation (Lindley et.al. 2006)
d - Approximate location of predicted lower limit of spring Chinook summer rearing habitat (Yoshiyama et al. 2001)

Table 3. List of major impoundments, stream confluences, bridge crossings, reported habitat boundaries and reported impediments to the upstream migration of anadromous salmonids in the Mokelumne River watershed, with associated elevations and distances from the river mouth. These features can be found on the PDF version of the Figure 1 watershed map. (click here for PDF file of the watershed map).

Reported Historical Fish Migration Barrier
Site Near Arkansas Ferry



Photos 1a, 1b Pardee release enters Camanche Reservoir near Arkansas Ferry, 21 June 1991. Elev. 180, Q = 410 cfs. Note pyramid shaped rock in background. EBMUD WSE staff photos.

Photos 1c, 1d Pardee release meets Camanche Reservoir near Arkansas Ferry, 4 Nov. 2008. Elevation 189, Q = 701 cfs. Note pyramid shaped rock in center. EBMUD F&W staff photos.

Reported Historical Fish Migration Barrier Site Near Electra Power Plant

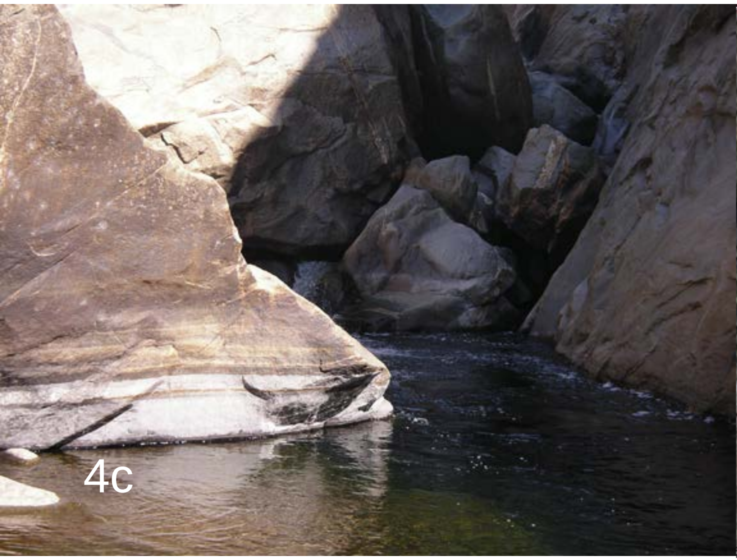
Photo 2a. Current aerial photo of the Electra Power Plant and the old regulator dam approximately 1000ft downstream.
Google Earth, Inc. image.

Photo 2b. Current photo of the Electra Regulator Dam approximately 1000ft downstream of the power plant. Photo by EBMUD F&W staff.

China Camp Falls, North Fork Mokelumne River

Photos 3a, b, c, and d are of the falls and associated deep pool at China Camp. EBMUD staff photos 6 October, 2009.

Likely Historical Fish Migration Impediments
North Fork Mokelumne River



Photos 4a, 4b, 4c and 4d. Series of natural structures located on the North Fork Mokelumne River, within 2 miles of the confluence with the Middle Fork that have the potential to block access of migrating salmonids to upstream habitats. The crest of the waterfall in photo 4a is estimated to be 8 ft above downstream pool surface. Series of cascading pools in photo 4b and boulder jam in photo 4c. Photos 4a-c EBMUD F&W staff photos (20 October, 2008), Photo 4d Google Earth, Inc. image.

Bald Rock Falls, North Fork Mokelumne River

Photos 5a, 5b, 5c and 5d are of Bald Rock Falls on the North Fork of the Mokelumne River. Photos 5a and 5b were taken from a single vantage point downstream of the structure at a range of 501 ft, 5b with 2.8X magnification. Photos 5c and 5d were taken from a single vantage point at a range of 144 ft, 5d with 2.8X magnification. All vegetation has been scoured by spring runoff events far up the canyon walls.
Photos 5a-d EBMUD F&W staff photos (6 October, 2009).

Likely Historical Fish Migration Impediment
Middle Fork Mokelumne River

Photos 6a, 6b and 6c. A natural structure located on the Middle Fork Mokelumne River, within 2 miles of the confluence with the North Fork. This structure has the potential to block access of migrating salmonids to upstream habitats. EBMUD F&W staff photos (20 October, 2008).

Appendix B

Historical newspaper article excerpts containing pertinent information regarding fish migration barriers in the Mokelumne River Watershed Source: California Digital Newspaper Collection. http://www.cdnc.ucr.edu/cdnc

"An act for the protection of salmon was placed on file. The act declares every weir, dam, stop-net, fence, or other obstruction on streams or sloughs a nuisance, and makes it unlawful to cast, draw or make use of any line or net to catch salmon between April 1 and October 31, Indians excepted." **Sacramento Daily Union, Vol. 35, No. 5299, 23 March 1868.**

"S.V. Treadway, President of the Mokelumne Ditch and Irrigation Company, is here (Stockton, CA) searching for stone masons, the object being to finish a large dam now being constructed near Westmoreland's bridge, before the heavy rains. Fifty men are now at work, and it is being pushed forward with great energy. When work commences on the Company's canal, a large number of laboring men will be wanted. **Daily Alta California, Vol. 32, No. 10078, 11 November 1877.**

Work commenced on the construction of Westmoreland Dam October 18, 1877. **Pacific Rural Press, Vol. 15, No. 6, 9 February 1878.**

"In July 1879, the Board of California Fish Commissioners imported from the Navesink River, New Jersey, 3000 striped bass, and a number of female lobsters, laden with eggs. The bass were the first ever brought alive into this State, and averaged from 1½ to 2½ inches in length. They were put, in prime condition, into the water in Carquinez Straits. Monday the first capture of the lot was made, between Saucelito (Sausalito) and Alcatraz. The bass measures 12½ inches and weighs about one pound. The large size attained by the fish in so short a time is surprising, and very gratifying to the Commissioners, as demonstrating the adaptability of these waters for the fish, and no doubt is now entertained of the success of the experiment. The lobsters which were placed in the water near Duxbury Reef, outside of the North Head, have not been heard from. **Daily Alta California, Vol. 32, No. 11013, 9 June 1880.**

"The dam across the Mokelumne River at Lancha Plana is causing serious and just complaint both in this county and Amador. The Amador papers have repeatedly called attention to the nuisance, as it is at present, and the people on this side of the river are beginning to complain loudly against the existence of the dam in its present condition. It is constructed of solid masonry, and is a complete obstruction to the progress of fish up the river. We are informed that the waters of the river are swarming with fish below the dam, while above it there are none, owing to the absence of means for the fish to get over it." **Sacramento Daily Union, Vol. 13, No. 115, 5 July 1881.**

The fish ladder on Westmoreland Dam washed away. Some "early returning fish are camped under the fall." **Pacific Rural Press, 9 February, 1886.**

“The Mokelumne River fish-ladder at Westmoreland’s Dam was washed away by the recent high water, and some of the early running fish are camped under the fall awaiting its restoration.” **Daily Alta California, Vol. 40, No. 13321, 15 February 1886.**

“B.F. Langford has been arrested by the Sheriff of Amador county for obstructing the Mokelumne river and preventing fish from ascending by building a dam across it near Westmorelands bridge. The suit is virtually against the Mokelumne Ditch and Irrigation Company, of which he is the president.” **Sausalito News, Vol. 4, No. 9, 5 April 1888.**

“B.F. Langford of Lodi, a stockholder in the Mokelumne Irrigation Company, was convicted in the Justice Court at Jackson, for maintaining a dam across the Mokelumne River, near Lancha Plana, unprovided with fish ladders, and was fined $250, or 100 days in jail.” **Pacific Rural Press, Vol. 35, No. 18, 5 May, 1888.**

“Senator Langford, president of the Mokelumne Ditch and Irrigation Co., has informed the District Attorney of Amador county that the fish ladder, for the non-construction of which suits had been brought against both Mr. Langford and the company, has been completed at the Westmoreland Dam on the Mokelumne river near Lancha Plana. It is said to be one of the best fish-ladders in the State. This will probably put a stop to all further proceedings in the matter when existing judgments and orders of court are satisfied.” **Pacific Rural Press, Vol. 37, No. 1, 5 January 1889.**

“The Woodbridge Canal and Irrigation Company has incorporated for the purpose of acquiring water rights and privileges on the Mokelumne river at Woodbridge, San Joaquin county, and other streams in San Joaquin, Calaveras, Amador and Alpine counties, and to distribute water for irrigation, domestic use, and mining business. Directors - Martin V. B. Watson and Benjamin a Laws of San Francisco, William E. Green of Oakland, Byron D. Beckwith of Woodbridge, and Thomas Creighton of Visalia. Capital stock, $300,000.” **Daily Alta California, Vol. 80, No. 120, 30 April 1889**

The Mokelumne Ditch & Irrigation Co.’s dam is situated a few yards below Westmoreland’s bridge, the banks of the river at that place being solid rock. The dam, a small portion of which was built a number of years ago, is 277 feet long, 40 wide at the base, and 7 feet wide at the top, and is 32 feet high. It is built of rock and cement, containing over 8000 cubic yards of material. At the east end of the dam is a solid stone pier, 30 feet long, 10 feet wide and 22 feet high, between which and the stone bank is the headgate, 34 feet long, built of best and heaviest timber, firmly cemented and mortised into the rock at the bottom and sides. From here the canal, 32 feet wide on the bottom, is cut through solid rock for some distance. About 55 yards from the headgate is the wastegate, 16 feet wide, which, like the headgate, is cemented and mortised between two massive stone pillars, and is there to stay. From the gate to the river is constructed a fish-ladder substantially constructed of redwood, the sides and bottom being of 3-inch plank. It is 108 feet long, 5 feet wide and 22 inched deep, the pitch being one foot in four. At intervals of two feet on each side of the ladder are built aprons three feet long, slanting toward the waste-gate, thus breaking the force of the current so the fish can “go up the flume.”” **Pacific Rural Press, Vol. 37, No. 2, 12 January 1889.**

“The dam built by the Mokelumne Ditch and Irrigation Company across the Mokelumne River, near Lancha Plana, and known at the Westmoreland dam, was washed away last Monday (May 20, 1889). The water made a breach eighty feet wide and fifteen feet deep. It is believed that it was caused by a flood in the river. The earthquake shock during Sunday morning may have had something to do with it. It will cost many thousand dollars to repair the damage.” **Daily Alta California, Vol. 80, No. 144, 24 May 1889. (also reported by the Sausalito News, Vol. 5, No. 17, 31 May 1889, and the Sacramento Daily Union, Vol. 61, No. 78, 24 May 1889)**

“The last opening in the Woodbridge Canal and Irrigation Co.’s dam at Woodbridge, was closed this morning at 7:45 amid the general rejoicing of the people of whom had collected on the river banks at this early hour to witness the work. Few public enterprises of this magnitude have ever been commenced and pushed through to completion that have met with the unanimous support of all classes of the people, as has been awarded to the grand system of canals now nearly completed by the Woodbridge canal and Irrigation Co. This system of canals is among the largest on the coast, and the result will be to change over 200 square miles of choicest wheat fields of northern San Joaquin county into what may properly be termed a flower garden. A grand celebration will be had by the people of the surrounding country in the near future over the event.” **Pacific Rural Press, Vol. 42, No. 18, 31 October 1891.**

“Lovers of fishing are having a good time at present along the Mokelumne river, and especially at the ruins of the dam at the old Westmoreland Bridge, where your correspondent has seen fish taken out weighing four and five pounds. The river seems to be better stocked this year with larger fish than previously, probably owing to the high water in March.” **Amador Ledger, 31 May 1907.**

“William Sozzie, who resides at the Big Bar bridge, caught a striped bass in the river at that place one day last week that measured 2½ feet in length and weighed nine pounds. The Federal Fishery Bureau planted in an arm of San Francisco bay in the year 1879, one hundred and thirty-five striped bass one and a half to three inches in length from the Naversiuk river (Navesink River), New Jersey, and in 1882 three hundred more small fish were planted.” “They have been catching striped bass in the Mokelumne river below the old Westmoreland dam for a number of years past, but since the dam was carried away by a high water a few years ago the bass have been gradually traveling higher up the stream and there is now quite a number in the river between the Big Bar and Middle Bar Bridges.” **Amador Ledger, 27 September 1907.**