Below stressor descriptions from CWF biop:

Water Temperature, Redd Dewatering, Red Scour, Isolation and Stranding, Reduced Prey availability, Elevated turbidity and suspended sediment, Water Quality

Water Temperature

Chinook salmon depend on suitable water temperatures for spawning and essentially all life functions. Chinook salmon in California are at the southern end of their range within North America. Additionally, historical habitat in the Central Valley that provided suitable summer temperatures for adult holding, spawning, and early life stages is now blocked by dams.

Anadromous salmonids in the Sacramento River are now dependent on cold water temperature management in the upper Sacramento River below Keswick Dam. Winter-run and spring-run Chinook salmon in particular are sensitive to Keswick Reservoir water releases because they either spawn or hold in the upper Sacramento River during the summer months.

Based on several studies on Central Valley Chinook salmon, as well as more northern races of Chinook salmon, temperatures between 43°F and 54°F (6°C and 12°C) appear best suited to Chinook salmon egg and larval development (Myrick and Cech 2004). Several studies indicated that daily temperatures over 56°F (13.3°C) would lead to sub-lethal and lethal effects to incubating eggs (Seymour 1956; Boles 1988; USFWS1998; U.S. Environmental Protection Agency 2003). A 56°F (13.3°C) temperature compliance program was included in the NMFS 2009 BiOp to protect the sensitive life-stages of listed Chinook salmon (NMFS 2009). Consequently, the extent of habitat cold enough for spawning and early life stage survival changes every year in relation to where in the Sacramento River the upper temperature threshold of 56°F (13.3°C) can be maintained from May to October. Keswick and Shasta dams block salmon and steelhead from their historical habitat, confining them to a limited amount of thermally suitable habitat that varies in spatial extent within and between years.

Recently, a succession of dry years with low precipitation highlighted how difficult the upper river spawning area is to manage for successful spawning and embryo incubation. High mortality (greater than 95%) in the youngest life-stages (eggs, yolk-sac fry) resulted when temperature compliance points were not maintained under 56°F (13.3°C) for the spawning and embryo incubation season (Swart 2016).

Recent investigations into causes of mortality upstream also revealed that the 56°F (13.3°C) daily average temperature criteria mandated in the National Marine Fisheries Service (2009) biological opinion on the long-term operations of the CVP/SWP was not adequate to protect the earliest life stages (Swart 2016). Most of the egg/fry temperature studies relied on for this threshold were conducted in a laboratory with constant temperatures. In the river, managing for a daily average temperature of 56°F (13.3°C) can still result in a maximum daily temperature of greater than 60°F (15.5°C).

The U.S. Environmental Protection Agency (2003) provided comprehensive water temperature guidance concluding that a temperature criteria based on a seven-day average of daily maximum temperatures (7DADM) was better at accounting for diel water temperature fluctuations than a daily average criteria, and thus was better at determining suitable spawning and rearing temperatures for salmonids (U.S. Environmental Protection Agency 2003). The Shasta RPA actions in the National Marine Fisheries Service (2009) BiOp on the long-term operations of the CVP/SWP and the associated 2011 amendments are being adjusted because of the unprecedented mortality for two consecutive winter-run Chinook salmon brood years (2014 and 2015), the availability of new studies and models, including the River Assessment for Forecasting Temperature (RAFT) model, and the SWFSC's temperature-dependent Chinook salmon egg mortality model (Martin et al. 2016), and the poor status of winter- and spring-run Chinook salmon. The RAFT model more accurately predicts temperatures to better manage reservoir releases to maintain suitable instream temperatures in the upper Sacramento River (Pike et al. 2013).

The Martin et al. (2016a) egg mortality model found strong evidence that significant thermal mortality occurs during the embryonic stage in some years because of a >5°F reduction in thermal tolerance in the field compared to laboratory studies, suggesting that the 56°F (13.3°C) daily temperature criteria mandated in the NMFS 2009 BiOp is likely not sufficiently protective. To improve Sacramento River water temperature management for Chinook salmon, the criterion was adjusted in 2016 to the U.S. Environmental Protection Agency (2003) recommendation of 55°F 7DADM metric and applying it to the Bonneyview Bridge temperature control point (Swart 2016).

Every salmonid life stage is dependent on suitable temperatures. Besides spawning and egg incubation, juvenile rearing also occurs in the upper Sacramento River. Salmonids with a stream life history, such as spring-run Chinook salmon and steelhead, need suitable spawning and rearing temperatures to be maintained year round. The larger salmonid juvenile life stages are less sensitive to temperature than the alevins and yolk-sac fry, but will suffer lethal and sub-lethal effects when not in optimal instream temperatures. EPA guidelines recommend water temperatures do not exceed 61°F (16°C) 7DADM for juvenile rearing salmonids in the upper basin of natal rivers and do not exceed 64°F (18°C) in the lower basin of natal rivers (U.S. Environmental Protection Agency 2003). Potential sub-lethal temperature effects on juvenile salmonids include slowed growth, delayed smoltification, desmoltification, and extreme physiological changes, which can lead to disease and increased predation.

Myrick and Cech (2004) reviewed the published information on Central Valley salmon and steelhead temperature tolerance and growth and noted that several studies suggest that the optimal temperature for Chinook salmon growth lies within the 63°F to 68°F (17 to 20°C) range, provided that food is not limiting, and other factors, such as disease, predation, and competition have a minimal effect (Brett et al. 1982; Clarke and Shelbourn 1985, 1988; Myrick and Cech 2002; Marine and Cech 2004 as cited by Myrick and Cech 2004). It is unlikely that Chinook salmon in field conditions will feed at 100% satiation, however, and the effects of disease, competition, and predation should also be taken into account.

Green sturgeon have different temperature requirements than salmonids in the upper Sacramento River. The majority of green sturgeon spawn above Red Bluff Diversion Dam. Suitable spawning temperatures must remain below 63°F (17.5°C) to reduce sub-lethal and lethal effects. Temperatures in the range of 57° to 62°F (14 to 17°C) appear to be optimal for embryonic development (Van Eenennaam et al. 2005). Juvenile sturgeon can tolerate higher temperatures and optimal bioenergetics performance was found to be between 59 to 66°F (15 to 19°C) (Mayfield and Cech 2004).

Reservoir releases from Keswick Reservoir influence flows and temperatures in the upper and lower Sacramento River, which is critical habitat for several ESA-listed species, including two runs (winter and spring) of Chinook salmon, Central Valley steelhead, and green sturgeon. Any change in seasonal, monthly, and daily water releases out of Shasta Dam under the PA have been analyzed for potential effects on critical habitat. Changes in release patterns expected and modeled under the dual conveyance capabilities of the PA are addressed in this Opinion.

RED DEWATERING

Redd dewatering is a risk to incubating salmonid eggs and alevin. Water must move through a redd at a swift enough velocity to sweep out fine sediment and metabolic waste. Otherwise, incubating eggs do not receive sufficiently clean, oxygenated water to support proper development (Vaux 1968). Salmonid redd dewatering can occur when water levels decrease after redd construction and spawning, exposing buried and otherwise submerged eggs or alevins to air.

Dewatering can affect eggs and alevins in multiple ways. Dewatered gravel must maintain near 100% humidity for eggs and embryos to survive over successive days. While inadequate moisture and dissolved oxygen have been shown to affect the survival of all egg stages, the post-hatch eleuthroembryo and alevin stage are most sensitive to redd dewatering and usually die within 24 hours (Becker et al. 1983). Studies have shown that dewatering can impair egg and alevin development and cause direct mortality due to desiccation, insufficient oxygen levels, waste metabolite toxicity, and thermal stress (Reiser and White 1983, Becker and Neitzel 1985).

Redd dewatering can be a major source of salmonid population mortality in any water year type. Salmonid redds require cool, oxygenated, low turbidity water for approximately three to four months to complete the egg-alevin life stages (Williams 2006). Therefore, the water level conditions at spawning should be maintained for at least three months after eggs are deposited in the gravel. Any reduction in water level within that period introduces a dewatering risk, almost regardless of the spawning condition. Because instream flows on the Sacramento and American rivers are primarily dependent on reservoir releases, the risk of redd dewatering can in large part be controlled through water operations.

Dewatering of green sturgeon spawning areas is not a concern because of the different spawning habitat that these fish use in contrast to the type of habitat conditions necessary for salmonid spawning. Green sturgeon spawning primarily occurs in cool sections of the upper mainstem Sacramento River in deep pools containing small to medium sized gravel, cobble or boulder substrate (Klimley et al. 2015, Poytress et al. 2015). Sturgeon eggs primarily adhere to gravel or cobble substrates, or settle into crevices (Moyle et al. 1995, Van Eenennaam et al. 2001, Poytress et al. 2015) where they incubate for a period of seven to nine days and remain near the hatching area for 18 to 35 days prior to dispersing (Van Eenennaam et al. 2001, Deng et al. 2002, Poytress et al. 2015). Larval activity is primarily nocturnal, with peaks in migration between dusk and dawn (Poytress et al. 2015). Larvae utilize benthic structure (Van Eenennaam et al. 2001, Deng et al. 2002, Kynard et al. 2005) and seek refuge within crevices, but will forage over hard surfaces (Nguyen and Crocker 2006).

REDD SCOUR

Streambed scour resulting from high flows is a physical factor that can reduce salmonid egg survival and limit population productivity. High flows can mobilize sediments in the river bed causing direct egg mortality if scour occurs to the depth of the top of the egg pocket. Scour can also increase fine sediment infiltration and indirectly decrease egg survival (DeVries 1997).

This redd scour analysis directly incorporates the methods and results presented in the BA. The redd scour analysis primarily relies upon a flow analysis whereby the probability of flows occurring under the PA and the NAA that would be high enough to mobilize sediments and scour Chinook salmon and steelhead redds was estimated from CALSIM II estimates of mean monthly flows by applying a relationship determined from the historical record between actual mean monthly flow and maximum daily flow (BA Appendix 5.D, Section 5.D.2.2, Spawning Flows Methods). The actual monthly and daily flow data used in the analysis are from gage records just below Keswick Dam and at Bend Bridge. CALSIM II estimates used to compare probabilities of redd scour for the PA and the NAA are for the Keswick Dam and Red Bluff locations. As discussed in Appendix 5.D, Section 5.D.2.2, Spawning Flow Methods of the BA, 40,000 cfs is treated as the minimum daily flow at which redd scour occurs in the Sacramento River. Analysis of the Keswick Dam gage data shows that for months with a mean monthly flow of at least 27,300 cfs, the maximum daily flow in that month is always at least 40,000 cfs. The Bend Bridge gage data show that for months with a mean flow of at least 21,800 cfs, the maximum daily flow in that month is always 40,000 cfs. Therefore, redd scour probabilities for the PA and the NAA were evaluated by comparing frequencies of CALSIM II flows greater than 27,300 cfs at Keswick Dam or greater than 21,800 cfs at Red Bluff during the respective spawning and incubation periods for winter-run Chinook salmon, spring-run Chinook salmon, steelhead, fall-run Chinook salmon, and late fall-run Chinook salmon. Further information on the redd scour analysis methods is provided in the BA in Appendix 5.D, Section 5.D.2.2, Spawning Flows Methods.

Secondarily, redd scour impacts were assessed through SALMOD, which predicts “incubation” mortality as a combination of redd scour and dewatering. Because it is impossible to evaluate redd scour and dewatering independently through SALMOD, conclusions as to whether redd scour under the PA would adversely affect each species are based more so on the redd scour flow thresholds analysis.

ISOLATION AND STRANDING

Rapid reductions in flow can adversely affect fish. Juvenile salmonids are particularly susceptible to isolation or fry stranding during rapid reductions in flow. Isolation can occur when the rate of reductions in stream flow inhibits an individual’s ability to escape an area that becomes isolated from the main channel or dewatered (USFWS 2006). The effect of juvenile isolation on production of Chinook salmon and steelhead populations is not well understood, but isolation is frequently identified as a potentially important mortality factor for the populations in the Sacramento River and its tributaries (Jarrett and Killam 2014, 2015, Cramer Fish Sciences 2014, NMFS 2009, Bureau of Reclamation 2008, Water Forum 2005, CDFG 2001, USFWS 2001).

Juveniles typically rest in shallow, slow-moving water between feeding forays into swifter water. These shallower, low-velocity margin areas are more likely than other areas to dewater and become isolated with flow changes (Jarrett and Killam 2015). Accordingly, juveniles are most vulnerable to isolation during periods of high and fluctuating flow when they typically move into inundated side channel habitats. Isolation can lead to direct mortality when these areas drain or dry up or to indirect mortality from predators or rising water temperatures and deteriorating water quality.

Different water management and water use actions can cause isolation. High, rapidly changing flows that then quickly decrease may result from flow release pulses to meet Delta water quality standards, from flood control releases, or from tributary freshets following rain events (Jarrett and Killam 2015, Bureau of Reclamation 2008). Isolation may also occur during periods of controlled flow reductions, such as when irrigation demand declines in the fall (NMFS 2009) or following gate removal at the ACID dam in November (NMFS 2009).

Isolation is currently a potential stressor in the upper Sacramento River, though mechanisms such as ramping restrictions exist that are intended to reduce the risk of occurrence. The upper Sacramento River has numerous side channel-like gravel bars that are used by juveniles as resting stops when inundated by higher flows. These areas can become isolated pools or even completely dewatered when reservoir releases are reduced. Although the NMFS biological opinion on the long-term operations of the CVP/SWP (NMFS 2009) includes ramping restrictions for reservoir releases, CDFW rescues fish from these channel margin pools every year (CDFW 2013, 2014, 2015, 2016). CDFW monitoring reports show a range of numbers of different species and runs of anadromous fish observed and rescued in these efforts. The dependence of isolation risk on factors such as rate of sediment mobilization, rate of sediment settling in channel margin areas, and timing and rate of flow reductions makes the quantification of stranding risk difficult.

Juvenile isolation risk would likely remain during operations of the proposed action, but the magnitude is difficult to predict. Juvenile isolation generally results from reductions in flow that occur over short periods of time. The isolation analysis in the biological assessment uses the monthly flow results provided by CALSIM modeling of PA operations. This monthly time step is too coarse for a meaningful analysis of the short-term drivers of juvenile isolation and fry stranding. Though all ramping restrictions for dams on the Sacramento River and its tributaries would not change under the PA, reservoir releases may vary from year to year in timing of flow fluctuations. There is therefore uncertainty to the level of effect of possible isolation and stranding on fish. Continued monitoring will be vital to understanding the level of effect and identifying if additional minimization measures are needed.

REDUCED PREY AVAILABILITY

One of the most important habitat attributes of the riverbed to listed anadromous fish species in the action area is the production of food resources for rearing and migrating juveniles, such as drifting and benthic invertebrates, forage fish, and fish eggs. Benthic invertebrates, such as oligochaetes and chironomids (dipterans), are the predominant juvenile salmonid and sDPS green sturgeon food items produced in the silty and sandy substrates of the action area. Although specific information on food resources for green sturgeon within freshwater riverine systems is lacking, they are presumed to be generalists and opportunists that feed on similar prey to other sturgeons (Israel and Klimley 2008), such as the population of white sturgeon present and coexisting with green sturgeon in the Sacramento basin. Seasonally abundant drifting and benthic invertebrates have been shown to be the major food items of white sturgeon in the lower Columbia River (Muir et al. 2000). As sturgeons grow, they begin to feed on oligochaetes, amphipods, smaller fish, and fish eggs as represented in the diets of white sturgeon (Muir et al. 2000).

Contaminants may impact food sources, which can result in bioaccumulation of contaminants from feeding on them, adversely affecting anadromous fish (see previous discussion in Section 2.5.1.1.3 Contaminant Exposure). In this section, we discuss how disturbance of the riverbed is likely to occur during construction of the PA through pile-driving activities, barge traffic, geotechnical analysis, dredging, and clearing and grubbing, which has the potential to reduce prey availability for anadromous fish species in the action area. The activity resulting in the largest disturbance is through dredging, which has the potential to entrain and thereby remove populations of small demersal fish and benthic invertebrates from the channels within the action area, which represents a loss of the forage base to outmigrating juvenile salmonids and rearing green sturgeon.

The loss of benthic food resources, such as amphipods or isopods, could reduce fish growth rates and increase the energy expended searching for food, depending on the density of the animal assemblages on the channel bottom and the benthic invertebrate population recovery rate, which can be months to years (McCauley et al. 1976; Oliver et al. 1977; Currie and Parry 1996; Tuck et al. 1998; Watling et al. 2001).

Impacts from loss of food resources within the action area are more likely to occur to green sturgeon, which are specialized benthic feeders, but also may affect juvenile salmon and steelhead. NMFS expects that small invertebrates—such as annelids, crustaceans (amphipods, isopods), and other benthic fauna—would be unable to escape the suction of a hydraulic dredge and be lost to the system. Also, many benthic invertebrates have pelagic, surface-oriented larvae. Therefore, the loss of these benthic invertebrates may reduce the abundance of localized zooplankton populations in the upper regions of the water column where juvenile salmonids migrate through the Delta.

The time needed to fully recolonize the disturbed channel bottom is unknown and further complicated by the variable frequency and timing of channel bottom disturbances, as well as the various reach locations where these disturbances are likely to occur. The variable cycles of channel bottom disturbances in the particular activity area between June 15 and October 31 in any given year may preclude replacement of the forage base through recruitment from surrounding areas before the onset of the following winter and spring migration period of anadromous fishes through the action area (Nightingale and Simenstad 2001) and will likely pose a barrier to the re-establishment of a natural climax of benthic invertebrate assemblage in any specific reach, throughout the construction period.

As these organisms occupy habitat types that are prone to disturbance under natural conditions, however, they would likely recolonize these areas fairly rapidly by drifting and crawling from adjacent non-disturbed areas (Mackay 1992; Nichols and Pamatmat 1988). There are no indications as to what the species richness or diversity of the recolonizing community might be within the action area, however, or the proportion of native to invasive species in the resulting community structure and the nutritional value of those prey resources to listed anadromous fish species.

Overall, reduced prey availability in the migration and rearing habitats of listed anadromous fishes may impact the viability of those populations by increasing stress and reducing the overall fitness of individuals migrating through or rearing in the Delta. Furthermore, nutritional deficiencies and reduced fitness of individuals may result in an abbreviated residence time in the waters of the Delta, stunted growth rates, and diminished resiliency for survival in the ocean, in addition to the potential for increased susceptibility to disease, contaminants, predation, entrainment, and other project-related effects that are likely to be compounded by exposure to multiple stressors during their residence in and migration through the action area.

Elevated turbidity and suspended sediment

Elevated turbidity and suspended sediment levels have the potential to adversely affect salmonids during all freshwater life stages by clogging or abrading gill surfaces, adhering to eggs, hampering fry emergence (Phillips and Campbell 1961), burying eggs or alevins, scouring and filling in pools and riffles, reducing primary productivity and photosynthesis activity (Cordone and Kelley 1961), and affecting intergravel permeability and dissolved oxygen levels (Zimmerman and Lapointe 2005; Lisle and Eads 1991).

Fish behavioral and physiological responses indicative of stress include: gill flaring, coughing, avoidance, and increased blood sugar levels (Berg and Northcote 1985; Servizi and Martens 1992). Excessive sedimentation over time can cause substrates to become embedded, which reduces successful salmonid spawning and egg and fry survival (Waters 1995).

Increased turbidity and suspended sediment levels associated with proposed action construction activities will occur downstream of primary spawning, egg incubation, and fry emergence areas and therefore are not expected to impact redds or incubating eggs.

Given the activity locations, increased turbidity and suspended sediment levels may negatively impact fish populations temporarily when deposition of fine sediments fills interstitial substrate spaces in food-producing riffles, reducing the abundance and availability of aquatic insects and cover for juvenile salmonids (Bjornn and Reiser 1991).

Suspended solids and turbidity generally do not acutely affect aquatic organisms unless they reach extremely high levels (i.e., levels of suspended solids reaching 25 mg/L). At these high levels, suspended solids can adversely affect the physiology and behavior of aquatic organisms and may suppress photosynthetic activity at the base of food webs, affecting aquatic organisms either directly or indirectly (Alabaster and Lloyd 1980, Lloyd 1987, Waters 1995).

Another impact to fish from suspended sediment is exposure to contaminant-laden sediments released into the water column. As contaminants remaining in buried sediments are re-suspended, introduction of compounds into the overlying water column result in exposure risks to passing aquatic organisms, including listed salmonids and green sturgeon. This is discussed further in Section 2.5.1.1.3 Contaminant Exposure.

Increased sediment concentrations can also affect fish by reducing feeding efficiency or success and stimulating behavioral changes. Sigler et al. (1984) found that turbidities between 25 and 50 NTUs reduced growth of juvenile coho salmon and steelhead, and Bisson and Bilby (1982) reported that juvenile coho salmon avoid turbidities exceeding 70 NTUs. Turbidity likely affects Chinook salmon in much the same way it affects juvenile steelhead and coho salmon because of similar physiological and life history requirements between the species. Newcombe and Jensen (1996) also found increases in turbidity could lead to reduced feeding rate (sublethal effects) and behavioral changes such as alarm reactions, displacement or abandonment of cover, and avoidance, which can lead to increased predation and reduced feeding. At high suspended sediment concentrations for prolonged periods, lethal effects can occur.

WATER QUALITY

Many freshwater taxa in the Central Valley are in noticeable decline. This notably includes ESA-listed species and their designated critical habitat, which are susceptible to contaminants, many of which interact with other stressors such as pathogens to cause mortality, reproductive failure, and other losses to individual fitness. Many ESA-listed fish species are highly mobile and traverse hundreds of kilometers of freshwater habitat from the Sacramento-San Joaquin River Delta on their migration path to and from the ocean (Quinn 2005). The degree of sediment mobility and the increased contaminant exposure due to aggregated impacts of pollution from resuspension of sediment by various actions such as large vessel operations (Macneale et al. 2014) within the action area are a particularly important consideration for listed species and their designated critical habitats.

Areas with low human impacts frequently have low contaminant burdens and, therefore, lower levels of potentially harmful toxicants in the aquatic system (Relyea 2009). Legacy contaminants such as mercury, methyl mercury, polychlorinated biphenyls (PCBs), heavy metals, and persistent organochlorine pesticides, however, continue to be found in watersheds throughout the Central Valley. For example, persistent organic pollutants such as PCBs disrupt immune system function in exposed fish, thereby rendering exposed fish more susceptible to disease. PCBs are considered persistent pollutants because they resist degradation in the environment, by processes that are either biotic (e.g., microbial breakdown) or abiotic (e.g., photolysis in response to sunlight). They accumulate in sediments and can be resuspended and redistributed in aquatic habitat by dredging and similar forms of human disturbance.

One of the contaminants potentially present is selenium, which was identified as one of the pollutants in San Francisco Bay and the western Delta on the Clean Water Act section 303(d) List (State Water Resources Control Board 2011). Within the Delta, there are multiple sources of selenium. Presser and Luoma (2013) identify oil refinery wastewaters from processing crude oils at North Bay refineries and irrigation drainage from agricultural lands in the western San Joaquin Valley (mainly via the San Joaquin River) as the two primary sources. Agricultural drainage in the Sacramento Valley west-side creeks in the Yolo Bypass and non-oil industries and wastewater treatment effluents are minor sources of selenium in the Delta. Selenium can elicit a short- and long-term response from aquatic biota depending on the quantity, quality, and duration of selenium exposure. The primary exposure pathway for fish and other aquatic organisms to selenium is through their diet (Presser and Luoma 2010a, 2010b, 2013; Stewart et al. 2010). Continued exposure of selenium can result in bioaccumulation and/or toxicity to fish in the Delta. Because adult salmon and steelhead do not forage extensively while in the Delta before spawning upstream in the rivers (Sasaki 1966), their exposure is likely to be much less than exposure for juveniles, which spend most of their time in the Delta feeding and foraging for food. Thus, exposures that may affect survival and growth of juvenile salmonids are included below in the analyses of potential selenium effects, due to the timing in which those juveniles occur and feed within the proposed action area. Green sturgeon migrate from major rivers to the Delta and reside within the Delta or in the Pacific Ocean (USFWS 2008). Therefore, all life stages of sturgeon have the potential to be exposed to selenium in the Delta.

Adult salmonid exposure within the Delta is limited and not likely to affect reproduction. However, survival and growth of juvenile salmonids will potentially be affected. In contrast, green sturgeon may remain in or return to the Delta at all life stages such that survival, growth, and reproduction are all important characteristics to consider for green sturgeon. Therefore, the attributes of individual-level survival or growth (all species) and reproduction (sturgeon only) were evaluated for the PA.

Metals, PCBs, and hydrocarbons (typically oil and grease) are common urban contaminants that are introduced to aquatic systems via nonpoint-source stormwater drainage, industrial discharges, and municipal wastewater discharges. Many of these contaminants readily adhere to sediment particles and tend to settle out of solution relatively close to the primary source of contaminants. PCBs are persistent, adsorb to soil and organic matter, and accumulate in the food web. Lead and other metals also will adhere to particulates and can bioaccumulate to levels sufficient to cause adverse biological effects. Mercury is also present in the Sacramento River system and could be sequestered in riverbed sediments. Hydrocarbons biodegrade over time in an aqueous environment and do not tend to bioaccumulate or persist in aquatic systems. This suite of contaminants could pose a risk to listed fish if resuspension of contaminated sediments increases exposure.

Resuspended sediment can expose legacy contaminants that have previously been buried in the waterway's bottom sediment. Sediment is usually considered a sink for anthropogenic contaminants in marine and freshwater environments. Regardless of whether discharges originate from air, rivers, urban or agriculture runoff, or effluents from wastewater treatment plants, contaminants such as heavy metals and organic pollutants are typically scavenged by suspended, fine grained, mineral, and organic particles in the aqueous environment and will eventually settle out of the water column when quiescent hydrodynamic conditions prevail (Lepland et al. 2010, Roberts 2012).

Benthic and infauna species are primarily exposed to these contaminated sediment horizons. When sediment is resuspended, the bound contaminants are remobilized into the water column and become bioavailable to an additional assemblage of aquatic species through chemical processes that change their charge and chemical properties (e.g., oxidation in the aerobic water). While most of the material will likely settle out of suspension in close proximity to the disturbance, some of it may be transported considerable distances from the point of disturbance due to tidal or river currents. The resuspended material can be thought of as a pulsed disturbance resulting in episodic (pulsed) exposures of organisms to the contaminants. To fully understand the responses of exposed organisms, one must know not only the toxicological effects of the contaminant exposure to different organisms and the aquatic community, but also the frequency, magnitude, and duration of the disturbance event (Roberts 2012).

In 2010 the EPA listed the Sacramento River as impaired under Clean Water Act section 303(d) due to high levels of pesticides and heavy metals. The U.S. Army Corps of Engineers has identified polycyclic aromatic hydrocarbons (PAHs), organophosphates, chlorinated herbicides, ammonia, oil, grease, glyphosate, a-amino-3-hydroxy-5-methyl-4-isoxazolepro-pionate (i.e., AMPA), dioxin, heavy metals, and other constituents as potential contaminants within the action area. Some of these contaminants have been found to cause effects of acute and chronic stress that are sublethal and lethal to salmonids (Allen and Hardy 1980). Although most of these contaminants are at low concentrations in the food chain, they continue to work their way into the base of the food web, particularly when sediments are disturbed and previously entombed compounds are released into the water column.

If bioaccumulative contaminants such as organochlorines are released as a result of dredging they biomagnify in aquatic food webs. That is, they become proportionately more concentrated at higher trophic levels. Consequently, they present a greater risk to fish that feed at or near the top of aquatic food webs. Disturbing benthic sediments through dredging and dredge material disposal, as well as through the mechanisms of effluent return flows from dredged material placement sites, is expected to mobilize and redistribute a variety of contaminants in the water column. If contaminants are released during dredging or dredged material disposal activities, their effects may be subtle and difficult to directly observe.

Exposure to contaminated food sources and bioaccumulation of contaminants from feeding on them may create delayed sublethal effects that negatively affect the growth, reproductive development, and reproductive success of listed anadromous fishes, thereby reducing their overall fitness and survival (Laetz et al. 2009). The effects of bioaccumulation are of particular concern as pollutants can reach concentrations in higher trophic level organisms (e.g., salmonids) that far exceed ambient environmental levels (Allen and Hardy 1980).

Bioaccumulation may therefore cause delayed stress, injury, or death as contaminants are transported from lower trophic levels (e.g., benthic invertebrates or other prey species) to predators long after the contaminants have entered the environment or food chain. Many contaminants lack defined regulatory exposure criteria that are relevant to listed salmonids and yet may have effects on salmonids (Ewing 1999). It follows that some organisms may be negatively affected by contaminants while regulatory thresholds for the contaminants are not exceeded during measurements of water or sediments.

Sublethal or nonlethal effects indicate that death is not the primary toxic endpoint. Rand (1995) stated that the most common sublethal endpoints in aquatic organisms are behavioral (e.g., swimming, feeding, attraction-avoidance, and predator-prey interactions), physiological (e.g., growth, reproduction, and development), biochemical (e.g., blood enzyme and ion levels), and histological changes. Some sublethal effects may result in indirect mortality, for example, when a fish already stressed due to toxicity encounters an additional stressor and the combination of those causes death. Changes in certain behaviors, such as swimming or olfactory responses, may diminish the ability of listed fish to find food or escape from predators and may ultimately result in death. Some sublethal effects may have little or no long-term consequences to the fish because they are rapidly reversible or diminish and cease with time. Individual fish of the same species may exhibit different responses to the same concentration of toxicant. In addition, the individual condition of the fish can significantly influence the outcome of the toxicant exposure. Fish with greater energy stores will be better able to survive a temporary decline in foraging ability or have sufficient metabolic stores to swim to areas with better environmental conditions. Fish that are already stressed are more susceptible to the deleterious effects of contaminants and may succumb to toxicant levels that are considered sublethal to a healthy fish.

Exposure to sublethal levels of contaminants has been shown to cause serious implications for salmonid health and survival. Studies have shown that low concentrations of commonly available pesticides can induce significant sublethal effects on salmonids. Scholz et al. (2000) and Moore and Waring (1996) have found that diazinon interferes with a range of physiological biochemical pathways that regulate olfaction, negatively affecting homing, reproductive, and anti-predator behavior of salmonids. Waring and Moore (1997) also found that the carbofuran had significant effects on olfactory mediated behavior and physiology in Atlantic salmon (Salmo salar). Scientific literature on the effects of pesticides on salmonids and identified a wide range of sublethal effects such as impaired swimming performance, increased predation of juveniles, altered temperature selection behavior, reduced schooling behavior, impaired migratory abilities, and impaired seawater adaptation (Sandahl et al. 2000; Baldwin et al. 2009; Laetz et al. 2009; Laetz et al. 2013; McIntryre et al. 2012) are reviewed in Ewing (1999). Other non-pesticide compounds that are common constituents of urban pollution and agricultural runoff also have the potential to negatively affect salmonids.

Pollution risks vary depending on the particular chemical, the amount transported in stormwater, and environmental persistence. Even short-term exposure to aquatic pollutants (i.e., copper) can cause acute lethality or a variety of sub-lethal adverse effects to aquatic species (Baldwin et al. 2003, Hecht et al. 2007, McCarthy 2008). Recent studies in the Pacific Northwest provide insight on the ecological impacts of stormwater, particularly in urban streams, on the growth and survival of listed coho salmon (Sandahl 2007, Feist et al. 2011, Scholz et al. 2011, Spromberg 2011). Exposure to chlorinated hydrocarbons and aromatic hydrocarbons causes immunosuppression and increased disease susceptibility (Arkoosh et al. 1994). In areas where chemical contaminant levels are elevated, disease may reduce the health and survival of affected fish populations (Arkoosh et al. 1994). Environmental stresses as a result of low water quality can lower reproductive success and may account for low productivity rates in fish.

The Southern DPS of North American green sturgeon are expected to be more vulnerable than salmonids to the negative effects of dredging due to their benthic-oriented behavior, which conceivably put them in closer proximity to the contaminated sediment horizon, although it is presently unclear if juveniles exhibit this behavior to the same extent that adults do (Presser and Luoma 2010, 2013). Their “inactive” resting behavior on substrate may potentially put them in dermal contact with contaminated sites, which can lead to lesions and the production of tumors from materials in the substrate. Sturgeon are also benthic invertebrate feeders that forage on organisms that can sequester contaminants at much higher levels than the ambient water or sediment content, such as the Asian clams Corbicula and Potamocorbula that are prevalent in the action area. The great longevity of sturgeons also places them at risk for the bioaccumulation of contaminants to levels that create physiologically adverse conditions within the body of the fish.

As noted above, the literature suggests that certain contaminants may affect the biology of salmonids. At present, regulatory thresholds are likely inadequate to account for these effects because some contaminants do not have established salmonid exposure or bioaccumulation criteria. Therefore, we expect the proposed action to have sublethal effects on listed salmonids as described above. We also anticipate green sturgeon to experience sublethal effects to the same or a greater extent than listed salmonids due to their year-round presence in the action area and dermal contact with sediment because of their benthic lifestyle. Sublethal effects may include behavioral (e.g., swimming, feeding, attraction-avoidance, and predator-prey interactions), physiological (e.g., growth, reproduction, and development), biochemical (e.g., blood enzyme and ion levels), and histological changes.

Because of uncertainties regarding the contaminants present, however, and the concentration at these specific sites, there may be more appropriate specific measures that have not yet been defined. To address these uncertainties, Reclamation and DWR propose to work with NMFS to develop and implement a hazardous materials management plan with specific steps to monitor and measure contaminant level and type, address the containment of contaminants, and describe handling, storing, and disposing of contaminated sediments.