This technical memorandum provides a description of methodology, assumptions and results for an assessment of fishery ecosystem benefits resulting from the Kern Fan Groundwater Storage Project (Project).

1. Project operations for ecosystem benefits

The WSIP identifies sixteen priorities for ecosystem benefits. Cramer Fish Sciences (CFS) consulted with MBK Engineers and Irvine Ranch Water District to recommend how 18 thousand acre-feet (TAF) of additional water supply made available by proposed Project could be used to provide the greatest benefit to ecosystem priorities and relative environmental value criteria (Revs). CFS recommended a pulse released from Lake Oroville in the month of April. CALSIM analysis provided by MBK Engineers indicated the project could, with 1922-2003 hydrology, provide for six April flow pulses (of 18 TAF) in dry or critically dry years.

CFS recommended and assumed the 18TAF would be applied as a 3.75 day, 2,400cfs increase in Feather River flows released from the Thermalito Afterbay Outlet (TAO). Releasing this water from the TAO is important because the Feather River downstream of TAO has no ramping criteria for flows greater than 2,500 cfs (NMFS 2016a).

2. Methods for quantifying ecosystem benefits

Two ecosystem priorities are the primary beneficiaries of an April flow pulse on the Feather River. Ecosystem Priority 2 (P2) calls for “fl ows to improve habitat conditions for in-river rearing and downstream migration of juvenile salmonids. April is a period of “high” relative abundance for downstream migration and rearing of juvenile spring Chinook and juvenile steelhead in the Feather River and in the Sacramento downstream of Verona (NMFS 2016a). Also in April, juvenile winter-run Chinook are at “low” abundance in the Sacramento River downstream of Verona (NMFS 2016a).

Ecosystem Priority 12 (P12) calls for enhanced “access to fish spawning, rearing, and holding habitat by eliminating barriers to migration”. Upstream migration of adult green sturgeon in Feather Rivers is “high” for the month of April and upstream passage for green sturgeon appears to be positively influenced by river flow (NMFS 2016a).

Though April flow pulses are expected to benefit multiple fish species and life stages, our quantitative analysis focuses on assessing benefits (or impacts) to outmigrating juvenile spring-run Chinook and winter-run Chinook salmon. The Feather River hosts natural and hatchery origin spring-run Chinook. NMFS considers both in-river and hatchery spawning Feather River spring-run Chinook salmon to be part of the listed CV spring-run Chinook salmon ESU (NMFS 2016b). NMFS, in their most recent five-year review of CV spring-run, assigned a recovery priority for
spring-run Chinook salmon in the Feather River of 5 (with 1 being the highest priority, 12 being the lowest priority) (NMFS 2016b). These determinations are based upon the evolutionary legacy the Feather River spring-run stock represents, because the stock continues to exhibit a CV spring-run Chinook salmon migration timing, and because of habitat and management improvements required as part of the Oroville Facilities FERC Relicensing Settlement Agreement.

Data and sources used to evaluate effects of the proposed project on the survival of Feather River spring-run Chinook salmon are summarized in Table 1. The monthly number of hatchery origin spring-run smolts entering the Sacramento River \( (S_{FH}) \) from the Feather River is estimated by

\[
S_{FH} \times rel_m \times relf \times surv_m
\]

and the monthly number of natural origin spring-run smolts entering the Sacramento River from the Feather River \( (S_{FRW}) \) is estimated by

\[
S_{FN} \times MIG_m \times MIG_p \times surv_m.
\]

Survival for both hatchery and natural origin smolts are modeled as a function of monthly Feather River flows

\[
\text{logit}(surv_m) = B0 + B1 \times Q_m
\]

where B0 and B1 are model parameters (Table 1), and Qm is monthly Feather River flows standardized relative to all monthly Feather River flow observations provided by CALSIM. Monthly flow data (1922 through 2003) representing four future conditions (WISP 2030, WISP 2030, WF_Base and WF) and two scenarios (project and no project) were provided by MBK Engineers (see MBK 2017). A total of eight different CALSIM scenarios were analyzed.
Survival rates for migrating juvenile Chinook salmon from Verona (Sacramento River) to San Francisco Bay was estimated using the Delta Passage Model (CWF 2016). The Delta Passage Model (DPM) was developed by Cramer Fish Sciences to integrate empirical study findings related to how water project operations influence the survival of juvenile Chinook salmon. Although the DPM is based primarily on studies of winter-run Chinook salmon smolt surrogates (late fall–run Chinook salmon), it is applied here for winter-run and spring-run Chinook salmon by adjusting emigration timing (Figure 1) and assuming that all migrating Chinook salmon smolts will respond similarly to Delta conditions. The DPM has undergone substantial revisions based on comments received through Cal Water Fix (previously BDCP) anadromous team meetings and in particular through feedback received during a workshop held on August 24, 2010, a 2-day workshop held June 23–24, 2011, and since then from various meetings of a workgroup consisting of agency biologists and consultants. The DPM analysis used for here has not been revised since September 2015 and is the same version used to analyze effects for Cal Water Fix (CWF 2016).

The DPM is based on a detailed accounting of migratory pathways and reach-specific mortality as Chinook salmon smolts travel through a simplified network of reaches and junctions (CWF 2016, Figure 5.D-40). The biological functionality of the DPM is based on the foundation provided by Perry et al. (2010) as well as other acoustic tagging–based studies (Holbrook et al. 2009) and coded wire tag (CWT)–based studies (Newman and Brandes 2010; Newman 2008).

The major model functions in the DPM are as follows.

1. Delta Entry Timing, which models the temporal distribution of smolts entering the Delta for each race of Chinook salmon.
2. Fish Behavior at Junctions, which models fish routing as they reach channel junctions.
3. Migration Speed, which models reach-specific smolt migration speed and travel time.
4. Route-Specific Survival, which models route-specific survival response to non-flow factors.
5. Flow-Dependent Survival, which models reach-specific survival response to flow.
Functional relationships used in the DPM are described in detail in CWF (2016) Section 5.D.1.2.2.2.5, Model Functions.

Monthly CALSIM flow data for key Sacramento River, the Feather River and Delta water diversions were provided as inputs to the DPM (see CWF 2016 for details). The DPM produced annual survival rates weighted by monthly emigration timing for spring-run and winter-run Chinook salmon (Figure 1).

$S_{FRH}$ and $S_{FRW}$ provided inputs to the Delta Passage Model (DPM) representing Feather River Hatchery origin spring-run Chinook and Feather River natural origin spring-run Chinook, respectively. The number of spring-run ($S_{SSRC}$) and winter-run ($S_{SWRC}$) Chinook smolts entering from the Sacramento River basin are indicated in Table 1.

Total annual adult returns of spring-run Chinook salmon were calculated as

$$(S_{FRH} + S_{FRW} + S_{SSRC}) \times S_{DPM, SRC} \times S_a$$

and total annual adult returns of winter-run Chinook salmon were calculated as

$$S_{SWRC} \times S_{DPM, WRC} \times S_a$$

Where...

$S_{DPM, SRC}$ is the DPM-based estimate of survival for spring-run Chinook smolts to Delta exit;

$S_{DPM, WRC}$ is the DPM-based estimate of survival for winter-run Chinook smolts to Delta exit;

and where $S_a$ is survival rate for smolts exiting the Delta to return as adults.

### 3. Results from quantitative analysis

MBK (2017) describes water project operations, river flows and water supply results associated with the project. Using these same simulated flows and water project operations, our analysis shows substantial net benefits to spring-run and winter-run Chinook (Table 2).

<table>
<thead>
<tr>
<th>Future Condition</th>
<th>Change in Adult Chinook Salmon Abundance from 50 years with Project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring-run</td>
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<tr>
<td>2030</td>
<td>586</td>
</tr>
<tr>
<td>2070</td>
<td>428</td>
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<tr>
<td>WF_Base</td>
<td>516</td>
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<td>WF</td>
<td>452</td>
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</tbody>
</table>

As expected, benefits for Chinook salmon occur in years when the project allows for a Feather River flow pulse. In most years, Chinook salmon are not affected positively or negatively by the
project. For spring-run Chinook, benefits equaling 107 to 252 additional adult Chinook occur in six years for the 2030 condition, and five years for the 2070 condition (Figure 2). Reductions in estimated annual adult Chinook occur in some years as a result of increased Delta diversions associated with the project, but these losses are outweighed by much larger benefits which accumulate across all years (Table 2).

Benefits from the project are also apparent for winter-run Chinook salmon. Though winter-run Chinook salmon are not present in the Feather River, the flow pulse originating from the Feather River reaches the Sacramento River and provides benefits from Verona to Delta exit. In most years, winter-run Chinook salmon are not effected positively or negatively by the project. Benefits ranging from 20 to 38 additional adult Chinook winter-run occur in six years for the 2030 condition, and five years for the 2070 condition (Figure 3). Most winter-run Chinook smolts emigrate through Delta prior to April and are thus sometimes exposed to increased winter exports sometimes associated with the project (MBK 2017). As with spring-run Chinook, Delta losses occur but are outweighed by larger benefits which accumulate across all years except for the WF future condition (Table 2). The WF future condition shows a net loss of winter Chinook because North Delta diversions associated with Cal Water Fix more directly impact winter-run Chinook smolts than do South Delta exports.
Figure 3. Annual change in adult winter-run Chinook spawning returns associated with the project under 2030 and 2070 future conditions.

**Literature cited**


