MEMORANDUM

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To: SRAG Technical Group

From: Shawn Higgins, Rachel Kamman, and Greg Kamman

Subject: DRAFT: Design Flows for Salt River Ecosystem Restoration Project

1.0 Summary

This memorandum prepared by Kamman Hydrology and Engineering, Inc. (KHE) reviews hydrologic information from several sources in order to guide the selection of a range of defensible design freshwater inflows for the Salt River Ecosystem Restoration Project (SRERP).[1] The information presented below is intended to serve as:

1) support for SRAG technical group discussion and a consensus decision regarding desired in-channel conveyance capacity for the SRERP;
2) input to hydraulic modeling in support of the design process; and
3) background for review of input assumptions in the existing HEC-RAS model.

The information gathered examines inflows to the Salt River system and other watersheds in the area for which stream-gaging data are available. Based on this information, four alternative estimates of flow magnitudes at selected recurrence intervals on Francis Creek are summarized in Table 1. The basis for these estimates is provided in Section 2.

Table 1. Summary of Flood Frequency Estimates (in cfs) for the Francis Creek watershed

Method	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
(1) USGS Regional Regression	326	499	657	831	1008	1129
(2) USGS Bull. 17B, Drainage Area-Ratio (DAR)	431	714	924	1212	1441	1681
(3) USGS Bull. 17B, DAR * Precipitation Ratio	372	615	797	1045	1242	1449
(4) FEMA estimate	n/a	n/a	n/a	n/a	n/a	971
Approximate Range	105	150	275	370	430	710

Notes: n/a = not available
(1) Equations 1-6 of Table 1 in Waananan and Crippen (1977) using the following input parameters for Francis Creek: Drainage area = 3.2 mi^2; Mean annual precipitation = 50 in.; Altitude index = 1.0.
(2) Multiplied Jacoby Creek peak flood magnitudes by a drainage basin-ratio of 0.55.
(3) Multiplied Jacoby Creek peak flood magnitudes by a drainage basin-ratio of 0.55 and a precipitation ratio of 0.88.
(4) From Table 2 in FEMA, Flood Insurance Study, city of Ferndale, California, January l 7, 1998.

[1] Equally important are the timing and extent of influences from the adjacent Eel River system. This is particularly true during large (> 10yr) flood events. Characterization of the impacts of Eel River flows in terms of both inflows and drainage can be addressed in a separate technical memorandum.

Table 2 summarizes estimated inflows for the Wildcat tributaries (Figure 1) to the SRERP (excluding the Eel River) based on flood frequency estimates gathered for Jacoby Creek (following USGS Bulletin 17B guidelines) and adjusted by drainage area-ratio. It is important to note that the estimates presented in Table 2 do not include the volume of runoff generated from the portions of the Eel and Salt River delta plain contributing drainage to the Salt River - an approximately equivalent area to the Wildcat Hills drainage area considered in Table 2.

KHE recommends the SRAG technical group select a design return period based in part on the inflows presented below. To support the decision process, and as a logical next step in the design process, we recommend undertaking a preliminary conveyance assessment to determine the approximate channel size required to convey the range of design flows. The information generated will include:

1. Preliminary estimates of floodplain drainage contributions;
2. Preliminary estimates of channel geometry, bed slope and thalweg elevation; and
3. Preliminary estimates of the excavation volumes required to construct design channels.

This information will allow the SRAG technical group to make an informed decision regarding the channel design objectives for the SRERP, and gain an understanding of the other floodway conveyance and drainage requirements needed to provide effective flood management for the Salt/Eel River delta.

Table 2. Summary of flood frequency estimates for Wildcat tributary watersheds.

Sub basin	A_d	Q_2 (cfs)	Q_5 (cfs)	Q_{10} (cfs)	Q_{25} (cfs)	Q_{50} (cfs)	Q_{100} (cfs)
Reas Creek	1.9	253	419	543	712	847	988
Francis Creek	3.1	431	714	924	1212	1441	1681
Williams Creek	5.8	787	1303	1687	2212	2630	3068

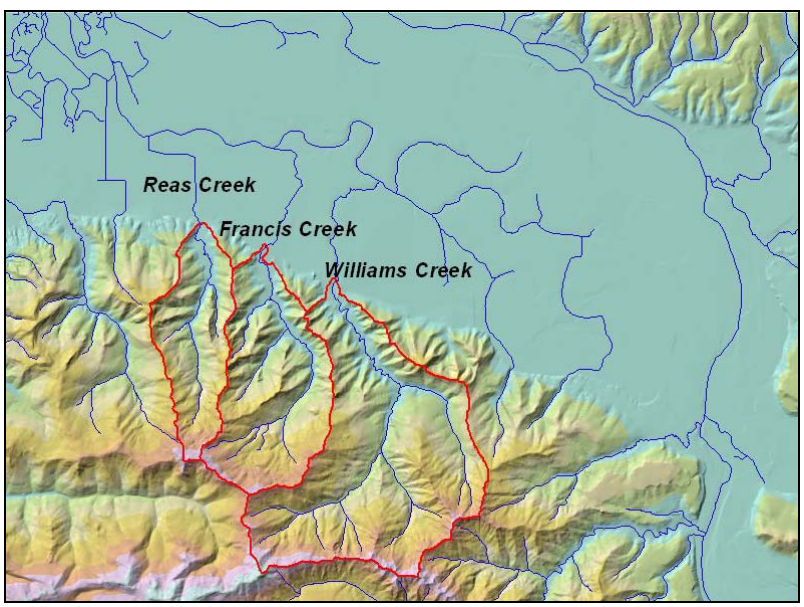

Figure 1. Delineation of Wildcat tributary basin inflows to the SRERP.

2.0 Flood Frequency Estimation

The following is a description of available local and regional hydrology information and approaches for characterizing tributary inflows to the SRERP. Eel river influences are not addressed.

2.1 Summary of Results

In general, peak flow estimates from the methods used in Table 1 provide comparable results within the range of uncertainty for any given peak flow estimate. Estimates derived from the USGS regional equation (1) were 24 to 33 percent lower than comparable flow estimates derived using the drainage basin area-ratio (DAR) method to adjust the flood frequency estimates for Jacoby Creek (2). Scaling peak flows by relative rainfall (3) lessens the difference between the estimates generated through regional regression equations (1) and more local gage records (2). The FEMA estimated 100-year flow is lower (less conservative) than those based on USGS recommended methods.

Review of other sources evaluating the USGS regional equations revealed mixed findings. Application of the USGS regional equation for the Jacoby Creek watershed (Section 2.2) yielded lower vales than the equivalent flood frequency estimates using the peak flow record from the stream-gaging station (following Bulletin 17B guidelines). This result is consistent with Mann et al.'s (2003) conclusion that the USGS north coast regional equations tend to underestimate flow magnitudes[2]. Randy Klein and Margaret Tauzer (personal communications, August 2007), however, have stated the USGS regional equations tend to overestimate peak flows. A 2005 report by Michael Love and Associates[3] lists the peak flow estimates from the USGS regional equation as slightly higher than equivalent estimates derived from local stream-gaging data for a small tributary stream of Humboldt Bay.

2.2 USGS Regional Equations

The USGS regional peak flow equations for California[4] relate peak flow estimates at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals to basin characteristics such as drainage area, precipitation, and altitude (Table 3). Table 4 summarizes flood magnitudes calculated for Francis Creek, Williams Creek, and Jacoby Creek using the regional equations.

Table 3. USGS regional flood-frequency equations. Q_n indicates peak discharge for recurrence interval of *x* years; *A* is drainage area (mi^2); *P* is mean annual precipitation (in.); *H* is altitude index (ft x 10^6) and has a minimum value of 1.

$Q_2 = 3.52\, A^{0.90}\, P^{0.89}\, H^{-0.47}$

$Q_5 = 5.04\, A^{0.89}\, P^{0.91}\, H^{-0.35}$

$Q_{10} = 6.21\, A^{0.88}\, P^{0.93}\, H^{-0.27}$

$Q_{25} = 7.64\, A^{0.87}\, P^{0.94}\, H^{-0.17}$

$Q_{50} = 8.57\, A^{0.87}\, P^{0.96}\, H^{-0.08}$

$Q_{100} = 9.23\, A^{0.87}\, P^{0.97}$

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[2] Mann, M., Rizzardo, J., and Satkowski, R., 2004, *Evaluation of Methods Used for estimating Selected Streamflow Statistics, and Flood Frequency and Magnitude, for Small Basins in North Coastal California*, U.S. Geological Survey Scientific Investigations Report 2004-5068.

[3] Design Report for Janes Creek Roughened Channel, August 15, 2005.

[4] Waanan, A., and Crippen, J., 1977, Magnitude and Frequency of Floods in California, U.S. Geological Survey Water Resource Investigation 77-21.

Table 4. Flood magnitudes of selected frequency for Francis Creek (*A* = 3.2 mi^2; *P* = 50 in.; *H* = 1), Williams Creek (*A* = 6.4 mi^2, *P* = 52 in.; *H* = 1), and Jacoby Creek (*A* = 5.8 mi^2, *P* = 58 in.; *H* = 1.5)computed using the USGS regional flood frequency equation.

	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Francis Creek	326	499	657	831	1008	1129
Williams Creek	630	958	1254	1576	1913	2143
Jacoby Creek	525	841	1141	1496	1888	2187

2.3 Drainage Basin Area-Ratio Method

Data from selected stream gaging stations (Table 5) in the vicinity of the Salt River Basin were considered to develop drainage basin area-ratio estimates for ungaged locations in the Salt River Basin.

Table 5. Stream-gaging stations in the vicinity of the Salt River Basin.

Station Name	Years of Record	Drainage Area (mi^2)	Elevation (ft)	(MAF[5]) Mean Annual Flood (cfs)	MAF per Unit Area (cfs/mi^2)
Lower Jacoby Creek[6]	4	12.4	40	n/a	n/a
Upper Jacoby Creek[7]	24	5.8	760	871	150
Bull Creek (near Weott)	46	28.1	269	2,991	106
Little River (near Trinidad)	52	40.5	18	5,313	131
Van Duzen River (near Bridgeville)	67	222	358	22,234	100
Mattole River (near Petrolia)	58	245	49	37,740	154
Mad River (near Arcata)	14	485	13	37,910	78
Eel River (near Scotia)	95	3,113	36	183,298	59

The Upper Jacoby Creek stream-gaging station was selected for further analysis due to its comparable drainage area to the Wildcat Mountain tributaries as well as its length of peak flow measurements. The 19 years of peak flow data collected by the USGS during the period 1955-1974 were supplemented with additional peak flow data for the period 2001-2005 and analyzed with the USGS software program PEAKFQ[8] to obtain flood frequency estimates following the Bulletin 17B guidelines. The results of the flood frequency analysis for Jacoby Creek were used to estimate flood magnitudes in the Francis Creek watershed (Table 6) by scaling the flow magnitudes by the ratio of contributing drainage areas (Equation 1).

$$Q_n = Q_g * (A_f / A_g) \qquad (1)$$

where Q_n is the *n*-year peak discharge at the ungaged site, Q_g is peak flow at the Jacoby Creek stream-gaging station, A_f is the drainage area of Francis Creek and A_g is the drainage area at the Jacoby Creek.

Table 6. Flood frequency analysis based on drainage area ratio using the stream-gaging station at Jacoby Creek for reference values. Units of discharge are cfs.

	A_d (mi^2)	$Q_{1.11}$	$Q_{1.5}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Upper Jacoby Crk	5.8	353	600	782	1,294	1,675	2,197	2,612	3,047
Francis Creek	3.2	195	331	431	714	924	1,212	1,441	1,681
Williams Creek	5.8	356	605	787	1,303	1,687	2,212	2,630	3,068

[5] MAF is calculated as the arithmetic mean of an annual maximum flood series
[6] Data for Lower Jacoby Creek from Randy Klein.
[7] Maintained by USGS from 1955 to 1974. Also by the Redwood Sciences Lab (USDA) from 2001-2005.
[8] PeakFQ Flood Frequency Analysis Based on Bulletin 17b < http://water.usgs.gov/software/peakfq.html >

The drainage basin area-ratio method assumes that peak flows at the ungaged site are equivalent per unit area to the peak flows at the stream-gaging station. The method is most effective at estimating peak flows for locations within the same drainage basin as the gaging station. Use of the Jacoby Creek data to estimate peak flow magnitudes in the Francis Creek watershed may not provide accurate results if peak flows per unit area differ due to physiographic or climatic differences. An attempt was made to adjust the data by a precipitation ratio that compared mean annual precipitation between the two watersheds (Eqn. 2). Mean annual precipitation was calculated as an average for the watershed using a GIS analysis of isohyetal maps[9]. Resulting flood frequency estimates are shown in Table 7.

$$Q_n = Q_g * (A_f / A_g) * (P_f / P_g) \qquad (2)$$

where P_f is mean annual precipitation of the Francis Creek watershed (50 in.) and P_g is mean annual precipitation of the Jacoby Creek watershed (58 in.)

Table 7. Flood frequency analysis based on drainage area and precipitation ratios using the gaging station at Jacoby Creek for reference values. Units of discharge are cfs.

	A_d (mi^2)	$Q_{1.11}$	$Q_{1.5}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Upper Jacoby Creek	5.8	353	600	782	1,294	1,675	2,197	2,612	3,047
Francis Creek	3.2	168	286	372	615	797	1,045	1,242	1,449
Williams Creek	5.8	319	542	705	1,168	1,512	1,983	2,358	2,751

2.4 FEMA Flood Frequency Estimates

The Federal Emergency Management Agency (FEMA) Flood Insurance Study for the city of Ferndale, California includes hydrologic analyses of Francis Creek. The FEMA study selected Jacoby Creek as a model for its hydrologic analyses. A HEC-1 model was first constructed for Francis Creek using input data from a previous NRCS study. The resulting Q_{100} estimate from the HEC-1 model for Francis Creek was consistent with the NRCS study, however, hydraulic analysis of the resulting flows indicated that such a flow in Francis Creek was contained by the existing geometry. This result countered observations of Francis Creek overflowing during previous storm events. The Curve Numbers in the model were then adjusted using the Jacoby Creek watershed for calibration. The calibrated model yielded a larger Q_{100} estimate used by the FEMA study for Francis Creek as well as breakout flows in the Eastside Drainage (Table 8). These flows were than summed for comparison to other flood frequency estimates.

Table 8. Summary of discharges from FEMA Flood Insurance Study, City of Ferndale, California.

		Q_{100} (cfs)
Francis Creek		831
Eastside Drainage		140
	Sum	971

[9] Spatially gridded average annual precipitation for the climatological period 1971-2000 obtained from the Oregon State University PRISM group <http://prism.oregonstate.edu>

3.0 Review of Preliminary Design Flows in HEC-RAS Model

3.1 Summary of Design Flow Inputs

A preliminary HEC-RAS model was developed to initiate analysis of design alternatives for the SRERP. The HEC-RAS model (Tauzer, 2007) specifies a suite of design flows (Table 9) that includes: (1) a large flood event equivalent to a peak flow of 800 cfs on Francis Creek, (2) a more common flood event equivalent to a peak flow of 168 cfs on Francis Creek, (3) a typical upper, and (4) lower fish passage design flow. These preliminary design flows were estimated for the Francis Creek watershed and then scaled by contributing drainage area for additional components of the Salt River system.

Table 9. Flow estimates for the HEC-RAS model reaches of the largest tributaries in the Salt River Basin. Provided by M. Tauzer (6/27/07).

	A_d (mi^2)	Low flow	Typ. storm	> ann. Storm	Qdesign
Francis Creek	3.2	30	60	168	800
Williams Creek	5.9	56	111	311	1482
Reas Creek	2.0	20	38	107	511

3.2 Basis for Design Flow Inputs

The 800 cfs channel design flow specified is based on the estimated magnitude of a 2002 flood event on Francis Creek (See section 3.3). This flow magnitude was chosen as the basis for channel design because it represented a successfully conveyed flood following the implementation of the Francis Creek flood mitigation project. As such, the channel geometry in the existing HEC model reflects the design goal of 800cfs flow conveyance. (M. Tauzer, personal communication, August 2007). Uncertainty regarding this estimate exists, and is discussed further below.

3.3 Information from Francis Creek Hazard Mitigation Project

Between 2000 and 20002, the City of Ferndale, completed work on the Francis Creek flood mitigation project funded through the Department of Water Resources-Proposition 13 and Caltrans. A number of hydrology and hydraulic studies were completed as part of the planning and design of this project. The project was designed to safely pass a 25-year recurrence flood flow estimated at 750-cfs (Scott Kelly, Spencer Engineering & Construction Management, Inc. and Ferndale City Engineer, personal communication, August 2007). Based on City of Ferndale records, Francis Creek conveyance capacity was only 350-cfs prior to the project. After construction of the project, Francis Creek safely conveyed the December 2002 storm. The “estimated 860-cfs” peak flow rate experienced during the December 2002 event was derived by extrapolation of a stage-flow relationship that existed at the time. Scott Kelly, Spencer Engineering & Construction Management, Inc. and Ferndale City Engineer (personal communication, August 2007) stated that this should be considered a rough estimate because the rating curve used to estimate the peak flow for the December storm did not contain any stage-discharge relationships within the high flow range experienced during the storm. To

date, no additional information is available to further characterize the storm event in the Salt River basin.

3.4 Comparison of Recent Francis Creek Peak Flows to Other Area Gaging Stations

In an effort to further resolve uncertainties regarding the flood magnitude of the 12/16/2002 storm, KHE gathered information on subsequent flow measurements and estimated return periods on Francis Creek and in nearby gauged watersheds (Table 10).

Table 10. Summary of recent flow events.

2/16/2002	A_d (mi^2)	Q_{peak} (cfs)	Q/A_d (cfs/mi^2)	Recurrence Interval (years)[10]	Period of Record (years)
Francis Creek	3.2	860	250	8 to 25	---
upper Jacoby Creek	5.8	608	105	1.6	24
lower Jacoby Creek	12.4	674	54	1	---
Bull Creek	28.1	5,970	212	9.4	46
Little River	40.5	3,250	80	1.3	52
Van Duzen River	222.0	32,500	146	6.8	67
Mattole River	245.0	41,800	171	3	58
Mad River	485.0	24,000	49	1.3	59
Lower Eel River	3,113.0	226,000	73	4	95
12/27/2006					
Francis Creek	3.2	638	199	5 to 10	---
lower Jacoby Creek	12.4	300	24	1	24
Bull Creek	28.1	1,830	65	1.5	---
Little River	40.5	1,740	43	1.1	46
Van Duzen River	222.0	11,600	52	1.1	52
Mattole River	245.0	31,700	129	2	67
Mad River	485.0	10,600	22	1.01	58
Lower Eel River	3,113.0	73,200	24	1.1	59
2/10 - 2/11/2007					
Francis Creek	3.2	175	55	~ 1	---
lower Jacoby Creek	12.4	400	32	1.05	24
Bull Creek	28.1	1,410	50	1.25	---
Little River	40.5	1,180	29	1.05	46
Van Duzen River	222.0	6,580	30	1.05	52
Mattole River	245.0	15,300	62	1.05	67
Mad River	485.0	8,340	17	1.01	58
Lower Eel River	3,113.0	63,300	20	1.11	59
2/21 - 2/22/2007					
Francis Creek	3.2	168	53	~ 1	---
lower Jacoby Creek	12.4	1,030	83	1.5	24
Bull Creek	28.1	1,140	41	1.1	---
Little River	40.5	2,270	56	1.1	46
Van Duzen River	222.0	8,600	39	1.05	52
Mattole River	245.0	38,800	158	2.3	67
Mad River	485.0	15,200	31	1.11	58
Lower Eel River	3,113.0	38,800	12	1	59

[10] Recurrence interval of flows on Francis Creek based on range of estimates in Table 1. Recurrence interval of flows on lower Jacoby Creek based on drainage basin area-ratio to Upper Jacoby Creek. All other estimates derived with flood frequency analysis of USGS records following Bulletin 17B guidelines.

Note that recorded peak flows for the 12/16/2002 event were much higher per unit area on streams south of Eureka than those measured on streams north of Eureka. Flows on the Van Duzen River and Bull Creek were a 7- and 10-year event, respectively. The 860 cfs flow estimate on Francis Creek for this event falls between an 8- and 25- year event based on regional flood frequency equations and flood frequency estimates based on Jacoby Creek flow data.

The 12/27/2006 event also stands out in that the flow on Francs Creek appears anomalously high relative to the other watersheds when normalized by unit area. It is our opinion that there is likely a higher level of accuracy in the two flow measurements completed on Francis Creek in February 2007 than the earlier measurements. As with the 12/16/02 flow estimate by Spencer Engineering, the December 2006 peak flow estimate was generated by extrapolating the recently developed stream-flow rating curve well outside the range of flows used to develop it.

3.5 Conclusions Regarding HEC-RAS Preliminary Design Flows

Initial review of the preliminary design flows in the HEC-RAS model suggested that the current design flow approaches a flood magnitude with an 8- to 25-year recurrence interval[11]. Containing this magnitude event is proving difficult in the mainstem Salt River and generates large excavation volumes that would likely render implementation infeasible. During storms greater then a 10-year event, it is also likely that floodwaters from the Eel River would overwhelm the Salt River system yielding a substantially different hydraulic result.

This initial evaluation is instructive in that it clarifies the need to select an appropriate design flow and associated channel network that is feasible to construct, meets the goals of the SRERP and functions within a regionally sustainable flood mitigation effort.

[11] Estimated from a drainage basin area-ratio to Jacoby Creek (see section 2.1) and the USGS regional flood frequency equations (see section 2.2), respectively.