American River Floods: Historic to Theoretical

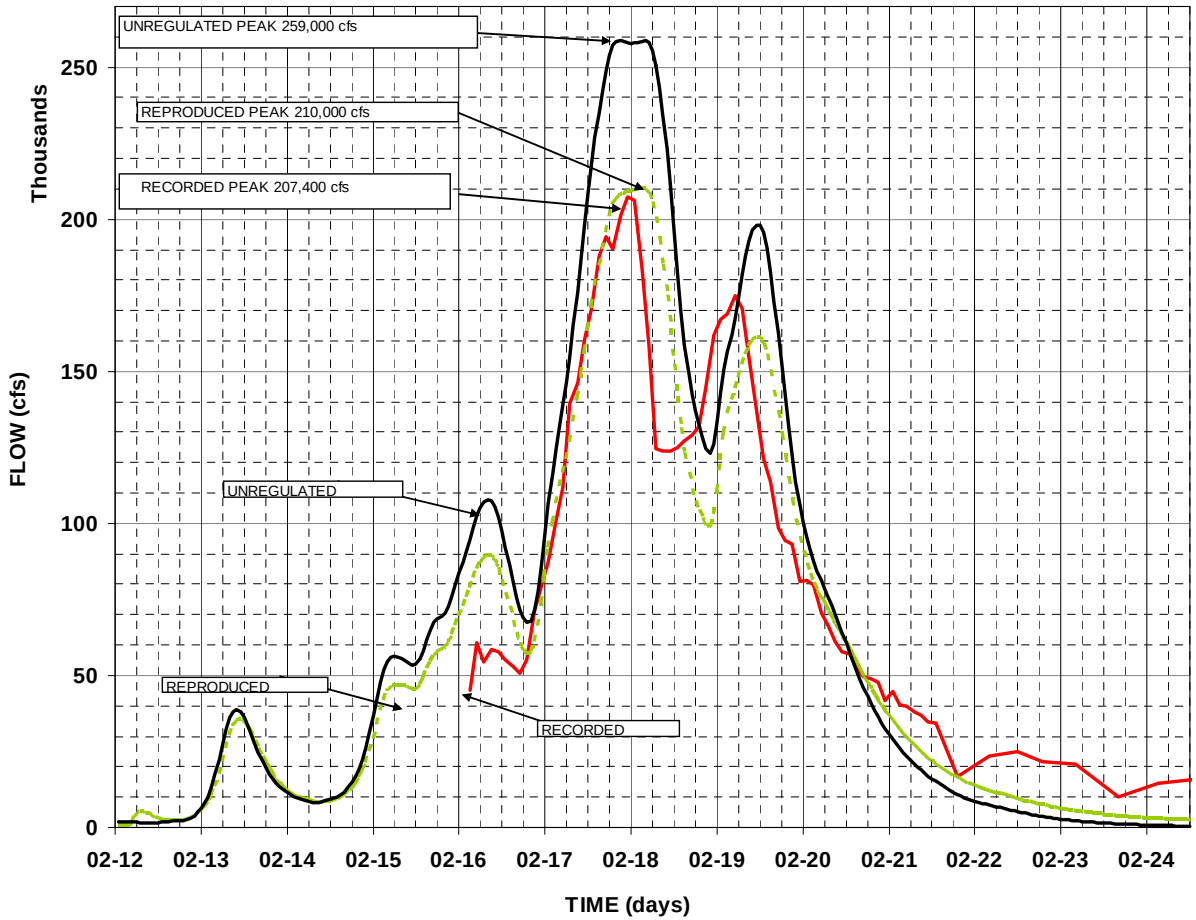
Robert F. Collins, P.H.
District Hydrologist
Hydrology Section
Sacramento District
U.S. Army Corps of Engineers
1325 J Street, 11th Floor
Sacramento, CA 95814

Tel: (916) 557-7132
Fax: (520) 621-8229
Email: Robert.F.Collins@usace.army.mil
Web: http://www.spk-wc.usace.army.mil

BIOGRAPHICAL SKETCH

Bob Colllins began his career with the Sacramento District, U.S. Army Corps of Engineers in September 1969. His career has focused on hydrology and is the District Hydrologist. He is a Professional Hydrologist certified by the American Institute of Hydrology. He is a recognized expert on probable maximum storms and floods. He was a major architect of the well-known Comprehensive Study for the Central Valley covering the watersheds of the Sacramento and San Joaquin Rivers.

American River Floods : Historic to Theoretical



The making of a historic storm

American River Floods: Historic to Theoretical

- Analyzing recorded historic floods reveals clues that help us to create larger theoretical floods.
- Discover factors that created the historic floods of record by discovering the ingredients that produced the recorded floods.
- Recreate those historic floods.
- Analyze the flood producing ingredients to understand their limits.
- Create theoretical floods.
- Route the new theoretical floods.

Flood ingredients that produce large floods

- Basin States
- Antecedent conditions
- Storm
- Produce runoff

Basin States

- Basin Shape
- Basin Orientation
- Soils
- Ground Cover
  - Undamaged or damaged
  - Dynamically changing basin due to climate
- Topography

Antecedent conditions

- Soil Moisture
- Snow Pack
  - SWE
  - Depth
  - Density

Storm

- Depth
- Distribution
- Duration
- Laps Rate
- Temperature
- Winds

American River Floods: Historic to Theoretical

- 1805
- January 1862
- March 1907
- December 1955
- December 1964
- February 1986
- January 1997
- SPF's (1952 to 1980) Project Design Recommendations, 0.05% to 0.02% exceedance (200 to 500 Year Events)
- Frequency Design Floods 1981 to Present
- PMF 1930's - Present (IDF or Spillway Design)

American River Floods: Historic to Theoretical

American River at Fair Oaks

PMF and Maximum Unregulated Historic Rain Floods

Ordered by Maximum 3-day Flow				
Water Year	Date of Peak	Peak cfs	1-day cfs	3-day cfs
PMF	Dec-Jan	906,000	698,000	472,000
1862	9-Jan	300,000 est.	208,000 est.	180,000est
1986	9-Jan	265,000	160,000	166,000
1997 [1]	2-Feb	302,000 [2]	252,500 [1]	165,000
1997 [3]	2-Feb	300,000 [2]	248,900 [3]	164,200 [3]
1965	23-Dec	260,000	183,200	140,300
1956	23-Dec	219,000	189,100	127,400

Notes:

[1] Derived from USGS Water-Data Report published in 1998.

[2] COE peak estimate for the 1997 flood.

[3] Data provided by DWR's CDEC database used in the latest COE frequency analysis and results from 2001 Folsom PMF Report.

Definition:

- Standard Project Flood (SPF)
- Estimates representing flood discharges that may be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographical region involved, excluding extremely rare combinations**.** (SPS or Standard Project Storms are usually limited to 120 hours in length.) East of 105° longitude.

Definitions

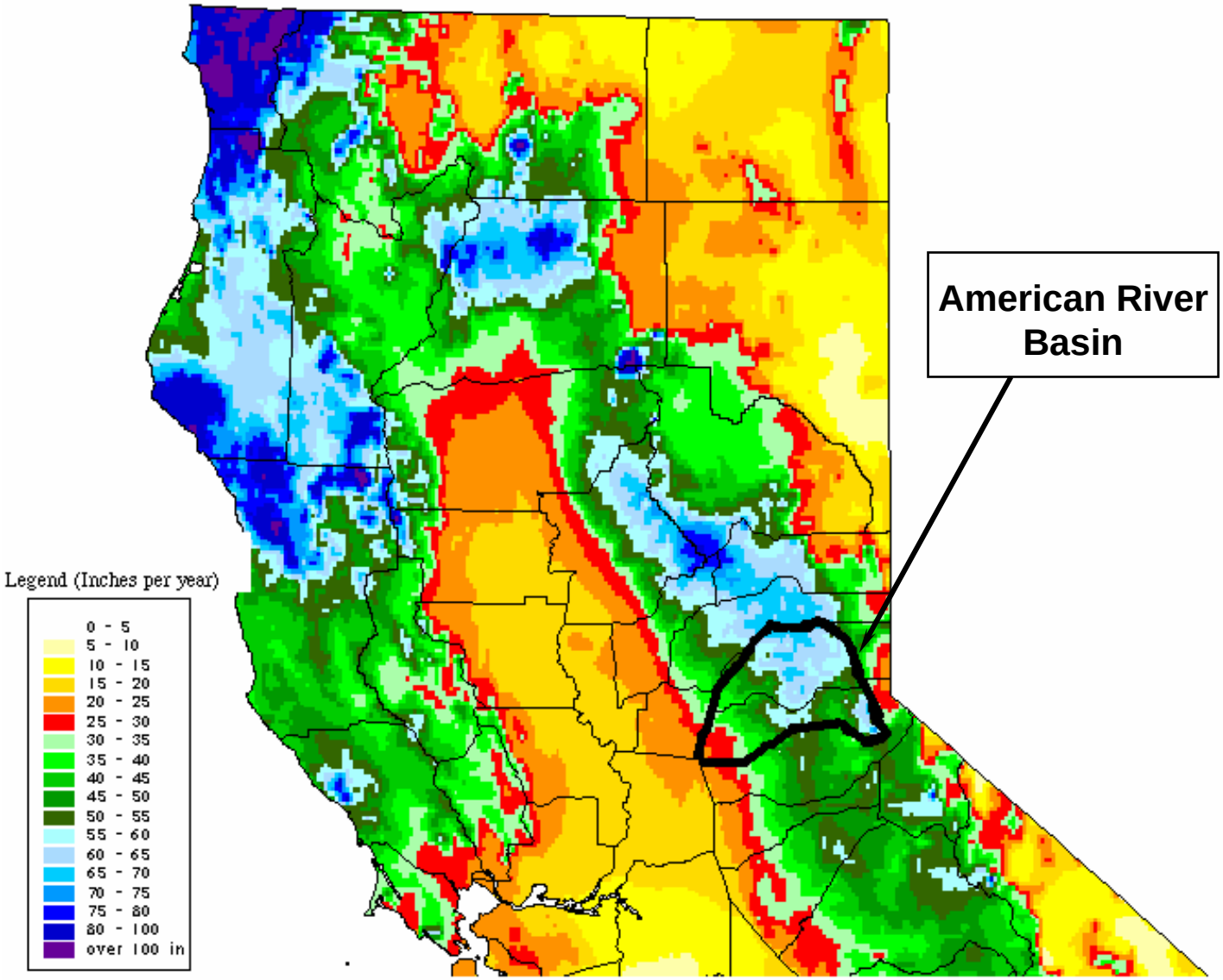
- Probable Maximum Flood (PMF) - The flood discharge that would result from the combination of the most severe and critical meteorological and hydrologic conditions considered reasonably possible in a region. It is produced by the combination of the Probable Maximum Storm (PMS), basin snowmelt (if applicable), and basin runoff characteristics that result in maximum runoff. The PMF reflects those conditions, such as storm center location and loss rates, that cause maximum peak flows.

Definitions

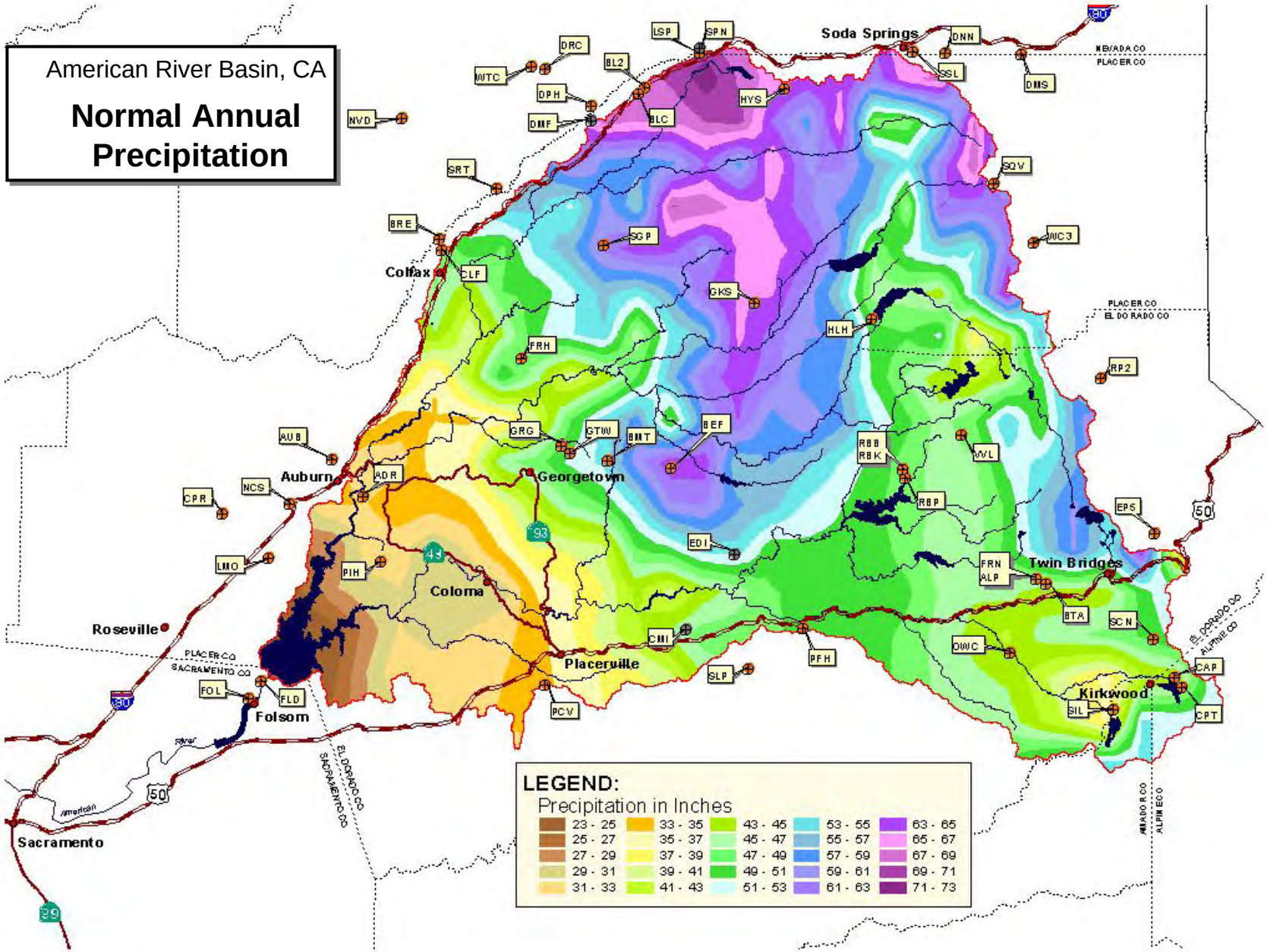
- PMP is defined as the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location and time of year. The criteria is presented in Hydrometeorological Report No. 59, “Probable Maximum Precipitation for California”

- PMS is the result of distributing the PMP aerially and temporally, based on studies of historic major storms.

Location Map



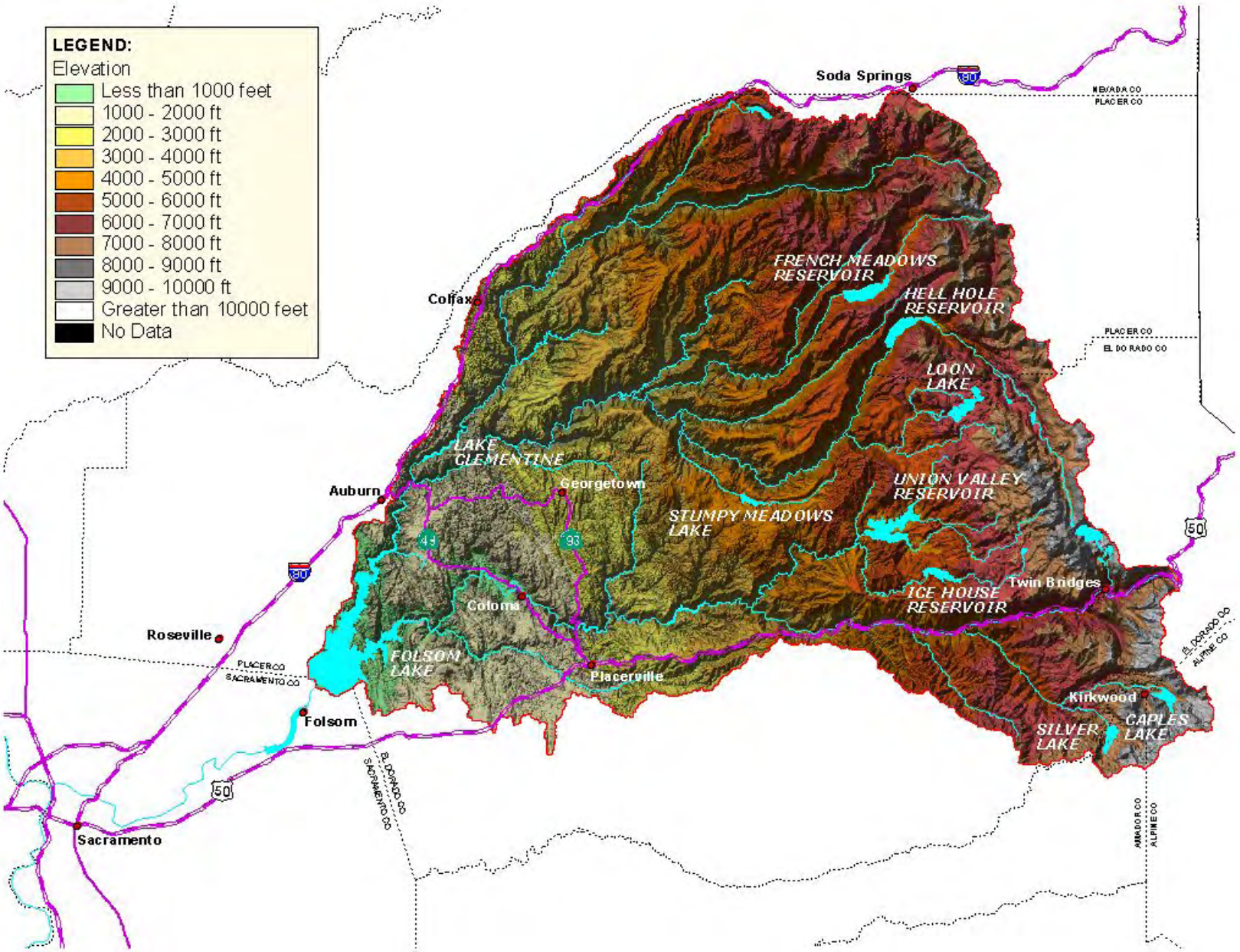
Normal Annual Precipitation Map



Descriptive Information

- American River Basin is second largest tributary to the Sacramento River below Shasta Dam
- Drainage Area 1,862 square miles and is located on the westward face of the Sierra Nevada Mtns.
- Three main Forks – North (342sq mi), Middle (631 sq mi), and South Forks (889 sq mi) of the American River
- Length of each tributary of 80 to 85 miles long
- Vegetation cover, lower 30% light to medium density, middle 40% heavy forest, upper 30% severely glaciated little or none

American River Basin Topography



Elevation Band Drainage Areas

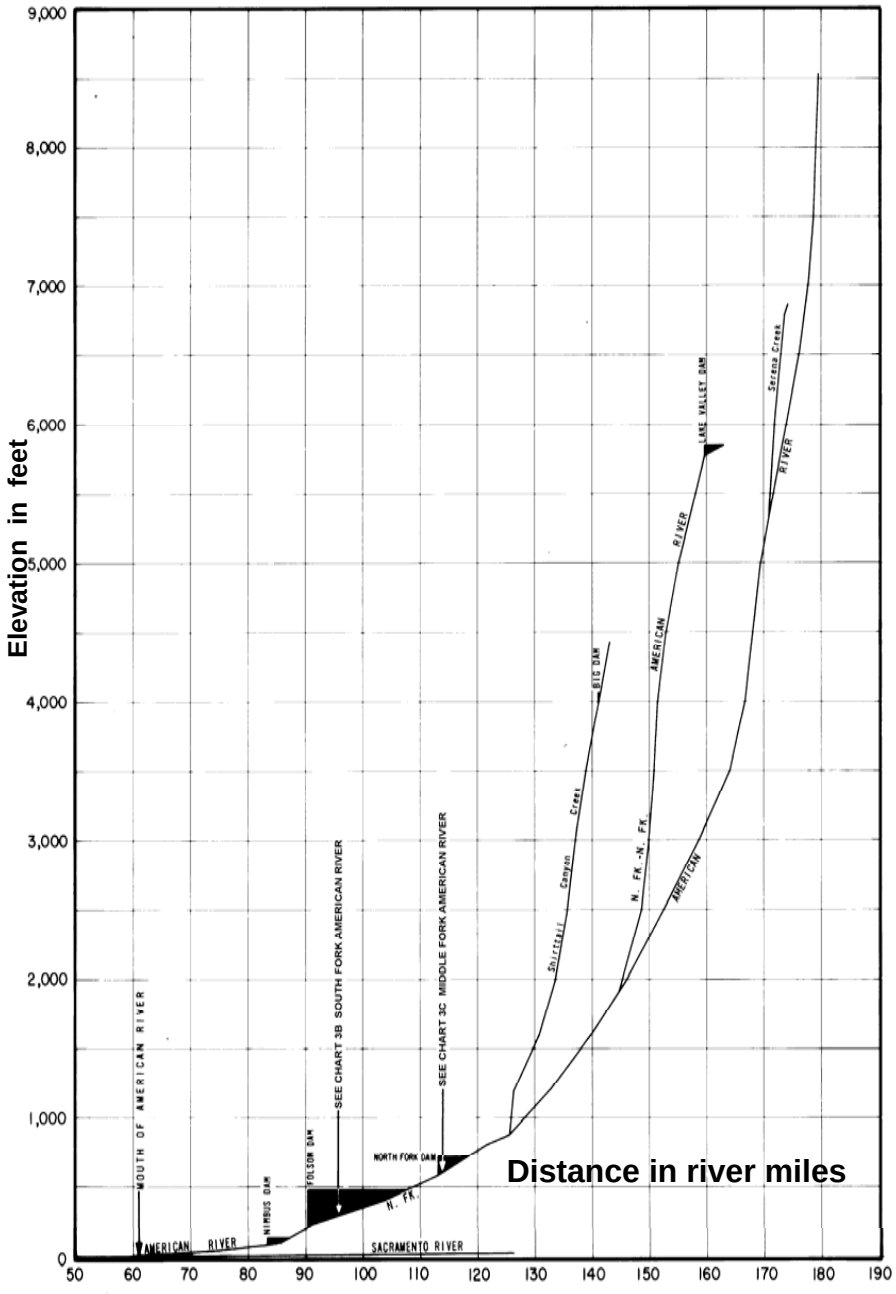
Elevation Band Drainage Area Relationships

Elevation Band	Drainage Area		Percent Drain Area			
			Above		Below	
Range	D.A.	Percent	Elev.		Elev.	
(ft)	(sq mi)	(%)	(ft)	(%)	(ft)	(%)
415-1,000	93	5.0%	415	100.0%	1,000	5.0%
1,001-2,000	261	14.0%	1,000	95.0%	2,000	19.0%
2,001-3,000	251	13.5%	2,000	81.0%	3,000	32.5%
3,001-4,000	217	11.6%	3,000	67.5%	4,000	44.2%
4,001-5,000	264	14.2%	4,000	55.8%	5,000	58.3%
5,001-6,000	283	15.2%	5,000	41.7%	6,000	73.5%
6,001-7,000	257	13.8%	6,000	26.5%	7,000	87.3%
7,001-8,000	158	8.5%	7,000	12.7%	8,000	95.8%
8,001-9,000+	78	4.2%	8,000	4.2%	9,000+	100.0%
TOTAL	1,862	100.0%				

Topography and Geology

- Topography, 200-10,000 Ft. MSL
- 50% drainage area above 4,700 Ft. MSL
- V- shaped canyons with slopes almost 80 to 100 feet per mile along their entire reaches above Folsom dam
- geology and soils
  - Upper Third of basin granitic, metamorphic, and some volcanic. Many massive granitic outcropping
  - Middle third of basin's canyon walls and ridges is covered with a heavy conifer forest on shallow soils cover.
  - Lower third consists of rolling hills with moderate depth soils.

River and Stream Profiles

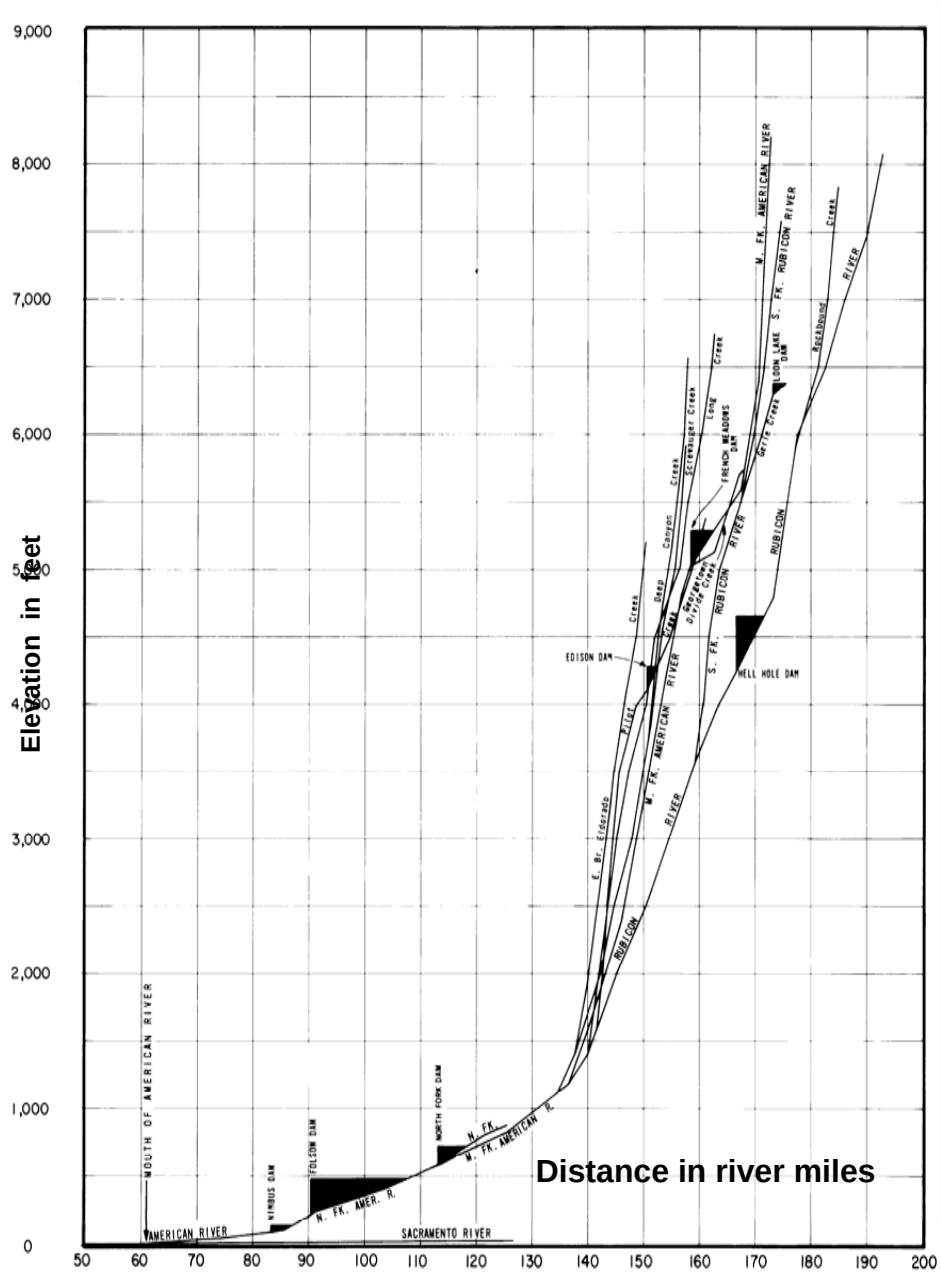


American River Basin, CA

Stream Profile: North Fork American River

NOTE: MILE 0.0 ON SACRAMENTO RIVER AT COLLINSVILLE

River and Stream Profiles

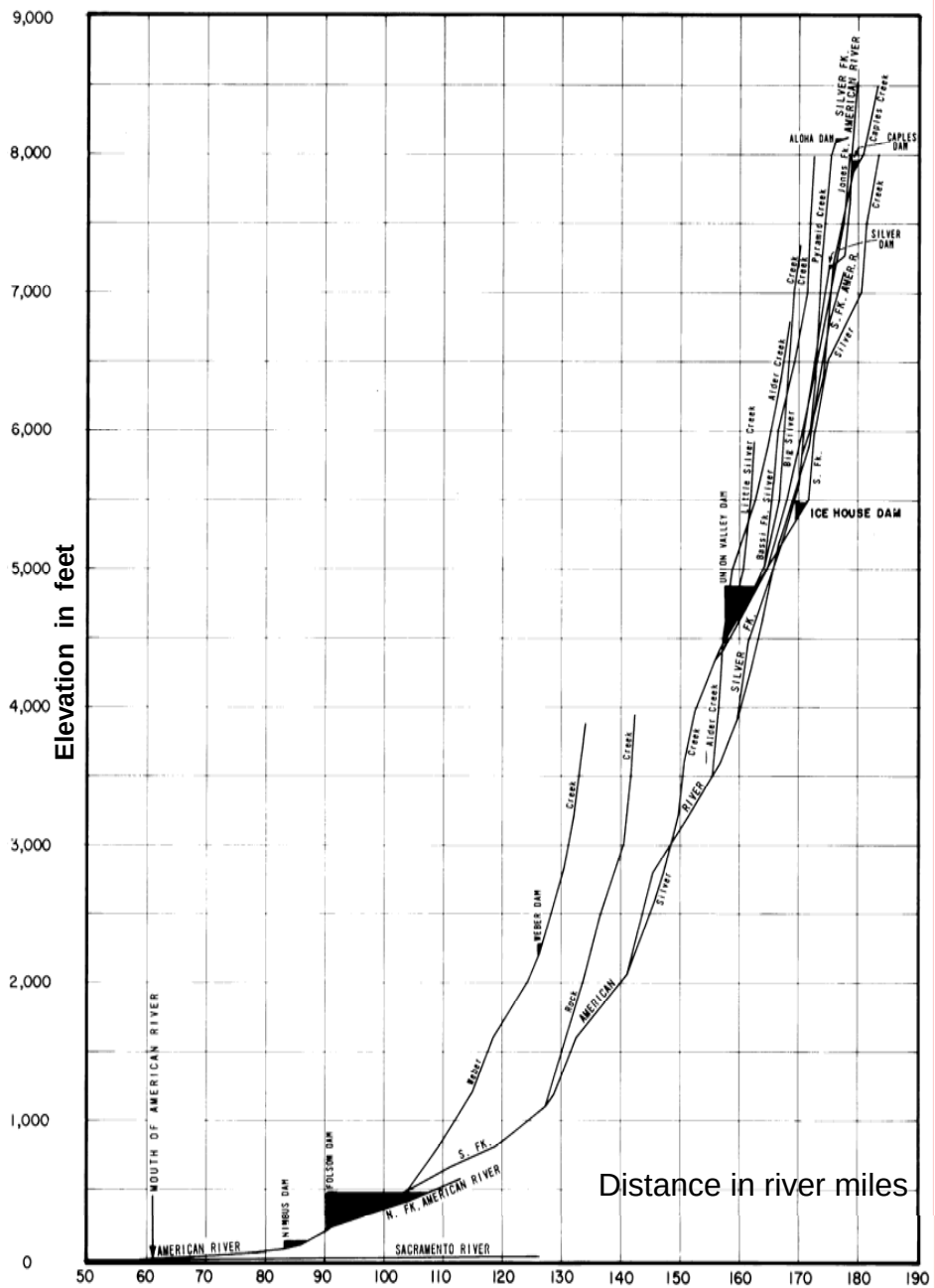


American River Basin, CA

Stream Profile: Middle Fork American River

NOTE: MILE 0.0 ON SACRAMENTO RIVER AT COLLINSVILLE

River and Stream Profiles



American River Basin, CA

Stream Profile: South Fork American River

NOTE: MILE 0.0 ON SACRAMENTO RIVER AT COLLINSVILLE

American River Rain Fall Runoff Model

- Subbasins: 29
- Upstream Reservoirs: 16
- Routing Reaches: 26
- Diversions: 8
- Created & Calibrated with 4 floods: January, 1963; December, 1964; January, 1969; and January, 1980
- Checked with two floods: February, 1986 and January, 1997

Descriptive Information

- Precipitation - 23 inches at Folsom to 80 inches in the higher elevations
- Historical average basin constant loss rates varied between 0.18 in. to 0.06 in. per hour
- Loss rates during saturated conditions from 0.10 inches to no losses at the highest elevation
- Time of concentration for the three basins is about 16 to 18 hours
- All major Forks peak concurrently

January 1963 And December 1964 Floods

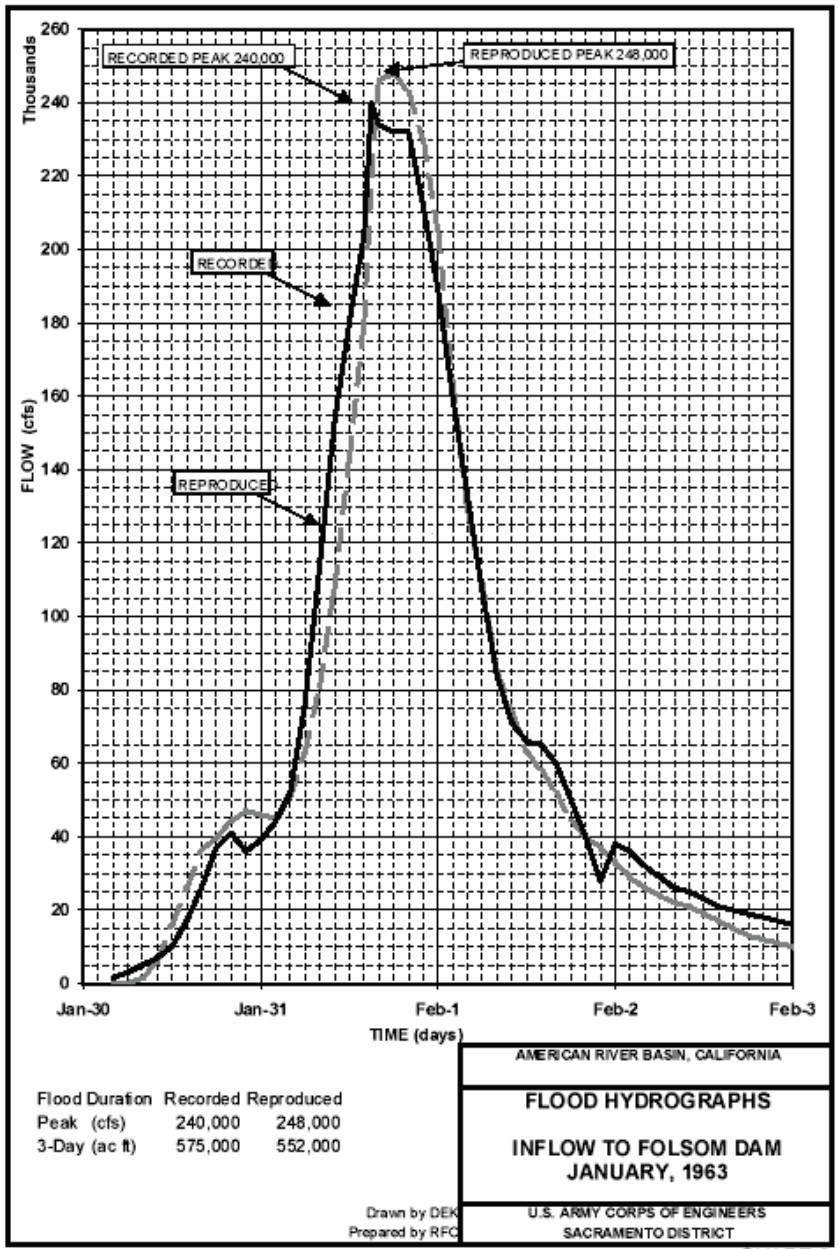


CHART 9

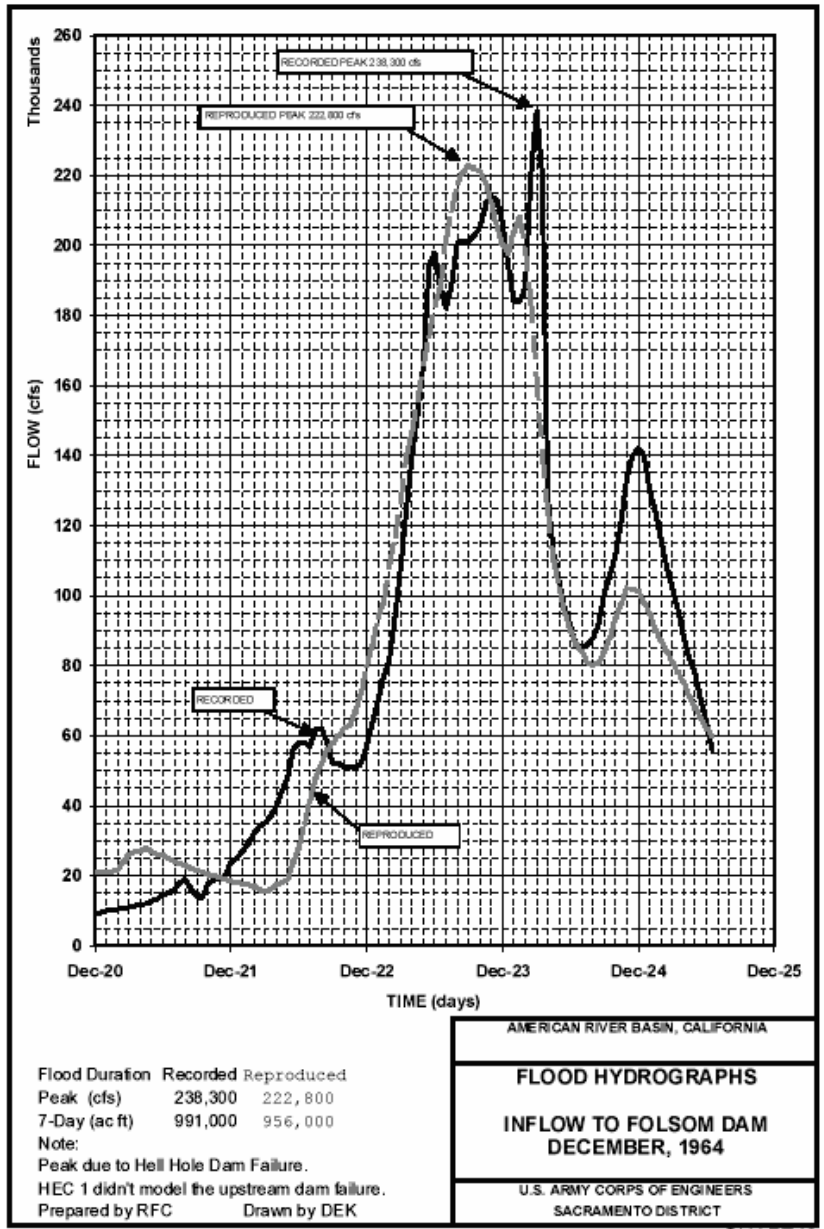
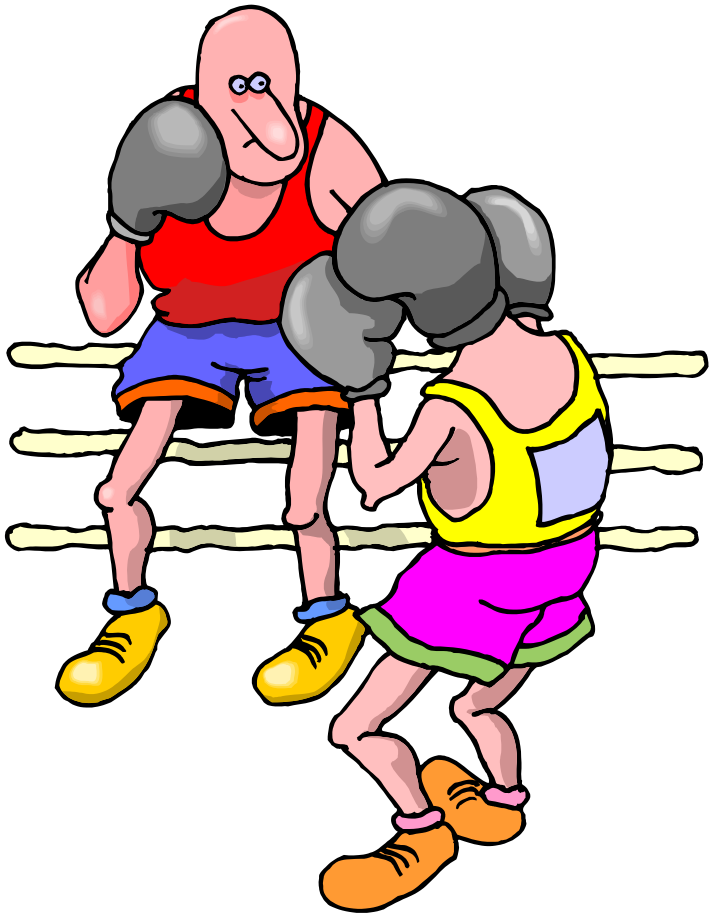


CHART 10

USACE Verses USBR



- What Could have happened

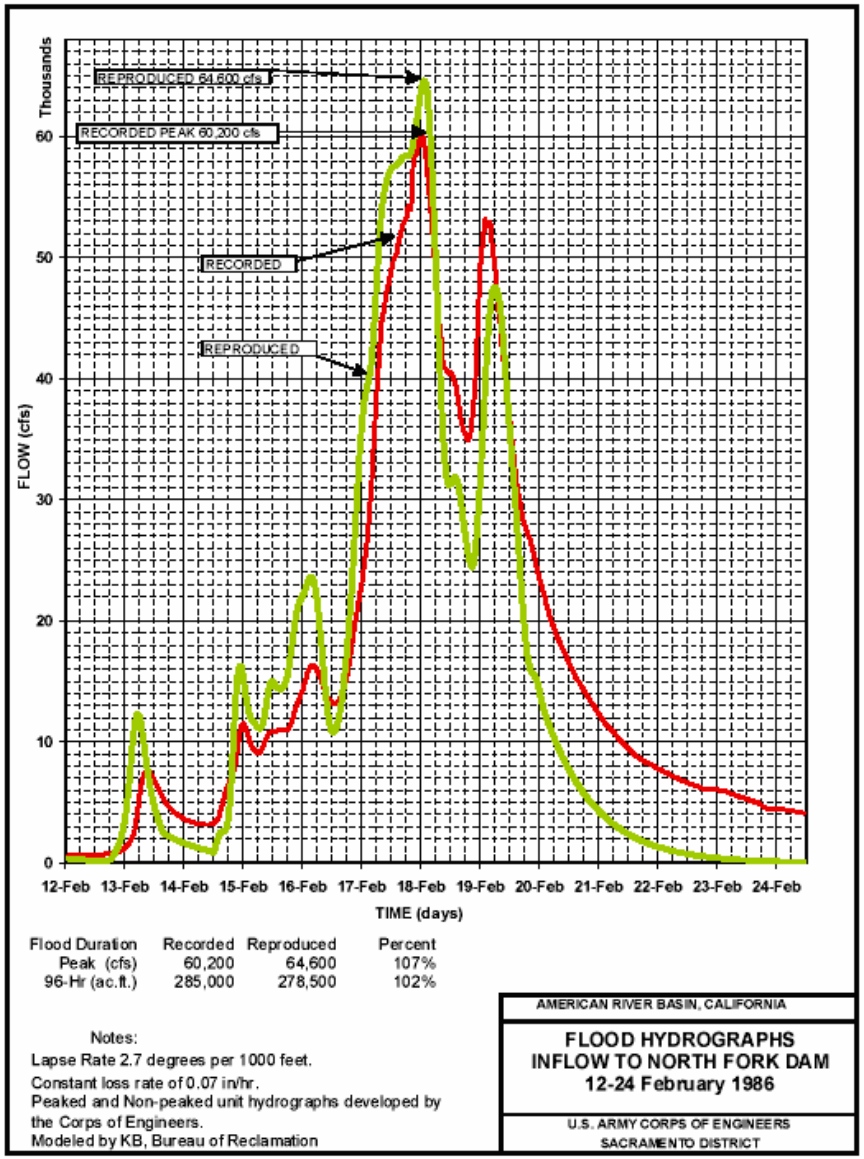
USACE Partners With USBR

- Our preliminary estimation of HMR No. 58 showed us we would come up with a PMF of similar in magnitude to the HMR No. 36 derived PMF
- BOR's study using criteria developed from hydrologic studies in the north west and our routing model resulted in a reduced peak PMF that could be be passed by the the present spillway design
- The BOR didn't calibrate their model with any floods that occurred over the American Basin
- We asked them to use our model with storm and runoff data from the February 1986 Flood
- BOR's results showed no changes in the 1980 HEC-1 Model were necessary
- SPK's 1997 flood calibration further verified no changes were needed

February 12-21 1986 Flood

- Precipitation from 74 Stations
- Winds from the River forecast Center
- Temperatures from the Blue Canyon Station
- Snow depth and SWE from several stations in and around the basin
- Runoff from BOR, CDEC, USGS, SMUD, and PG&E

1986 Flood



Flood Duration	Recorded	Reproduced	Percent
Peak (cfs)	60,200	64,600	107%
96-Hr (ac.ft.)	285,000	278,500	102%

Notes:
Lapse Rate 2.7 degrees per 1000 feet.
Constant loss rate of 0.07 in/hr.
Peaked and Non-peaked unit hydrographs developed by the Corps of Engineers.
Modeled by KB, Bureau of Reclamation

AMERICAN RIVER BASIN, CALIFORNIA

FLOOD HYDROGRAPHS
INFLOW TO NORTH FORK DAM
12-24 February 1986

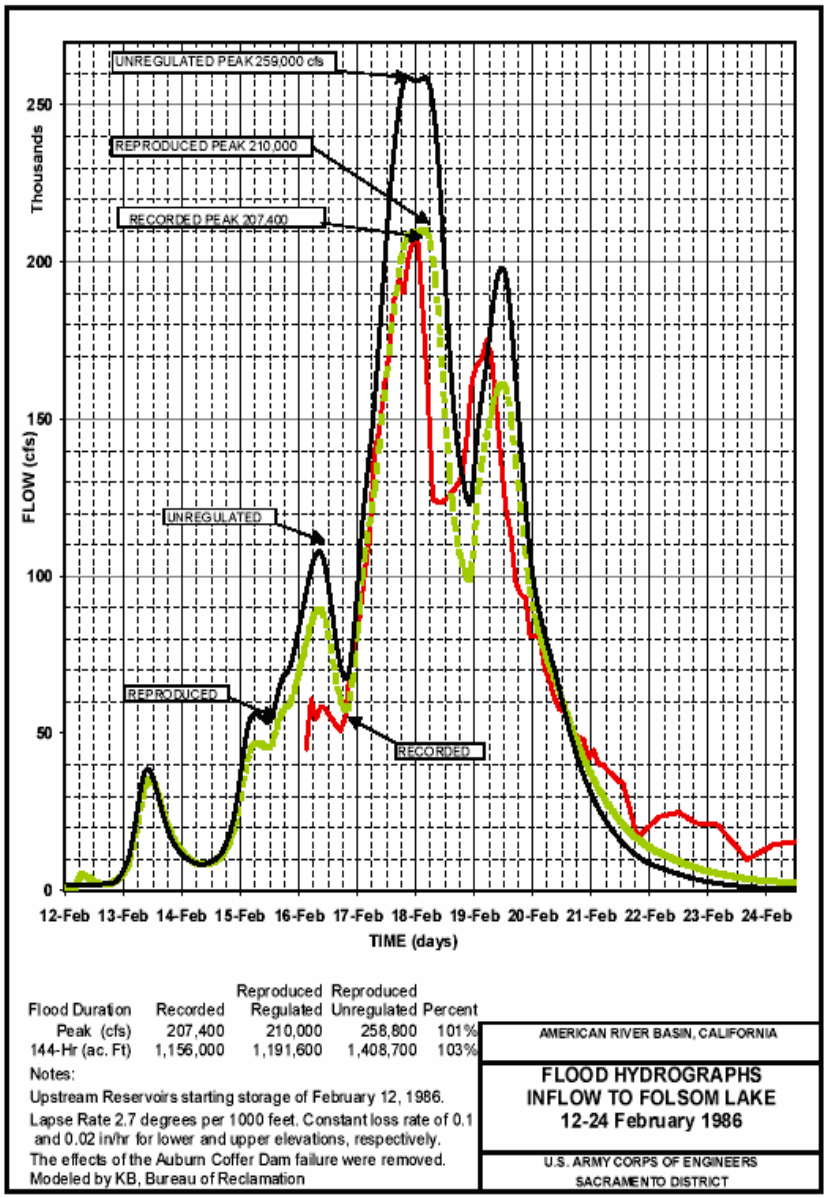
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

CHART 11

Feb. 12-24 1986 Flood

Effects of the coffer dam failure removed.

American River 1986 Flood



Flood Duration	Recorded	Reproduced Regulated	Reproduced Unregulated	Percent
Peak (cfs)	207,400	210,000	258,800	101%
144-Hr (ac. Ft)	1,156,000	1,191,600	1,408,700	103%

Notes:
Upstream Reservoirs starting storage of February 12, 1986.
Lapse Rate 2.7 degrees per 1000 feet. Constant loss rate of 0.1 and 0.02 in/hr for lower and upper elevations, respectively.
The effects of the Auburn Coffer Dam failure were removed.
Modeled by KB, Bureau of Reclamation

AMERICAN RIVER BASIN, CALIFORNIA

FLOOD HYDROGRAPHS
INFLOW TO FOLSOM LAKE
12-24 February 1986

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

CHART 12

February 12-24 1986

Effects of the Auburn coffer Dam failure removed

12-24 February 1986

INFLOW TO FOLSOM LAKE				
		Reproduced	Reproduced	
Flood Duration	Recorded	Regulated	Unregulated	Percent
Peak (cfs)	207,400	210,000	258,800	101%
144-Hr (ac. Ft)	1,156,000	1,191,600	1,408,700	103%
Notes:				
Upstream Reservoirs starting storage of February 12, 1986.				
Lapse Rate 2.7 degrees per 1000 feet. Constant loss rate of 0.1				
and 0.02 in/hr for lower and upper elevations, respectively.				
The effects of the Auburn Coffer Dam failure were removed.				

Dec 25 - Jan 4, 1997 Flood Data

- Precipitation from 45 CDEC Stations
- Winds from the River forecast Center
- Temperatures from 10 CDEC stations
- Snow cover from CRREL's satellite analysis
- Snow depths and SWE from 11 CDEC stations
- Runoff from BOR, CDEC, USGS, SMUD, and PG&E

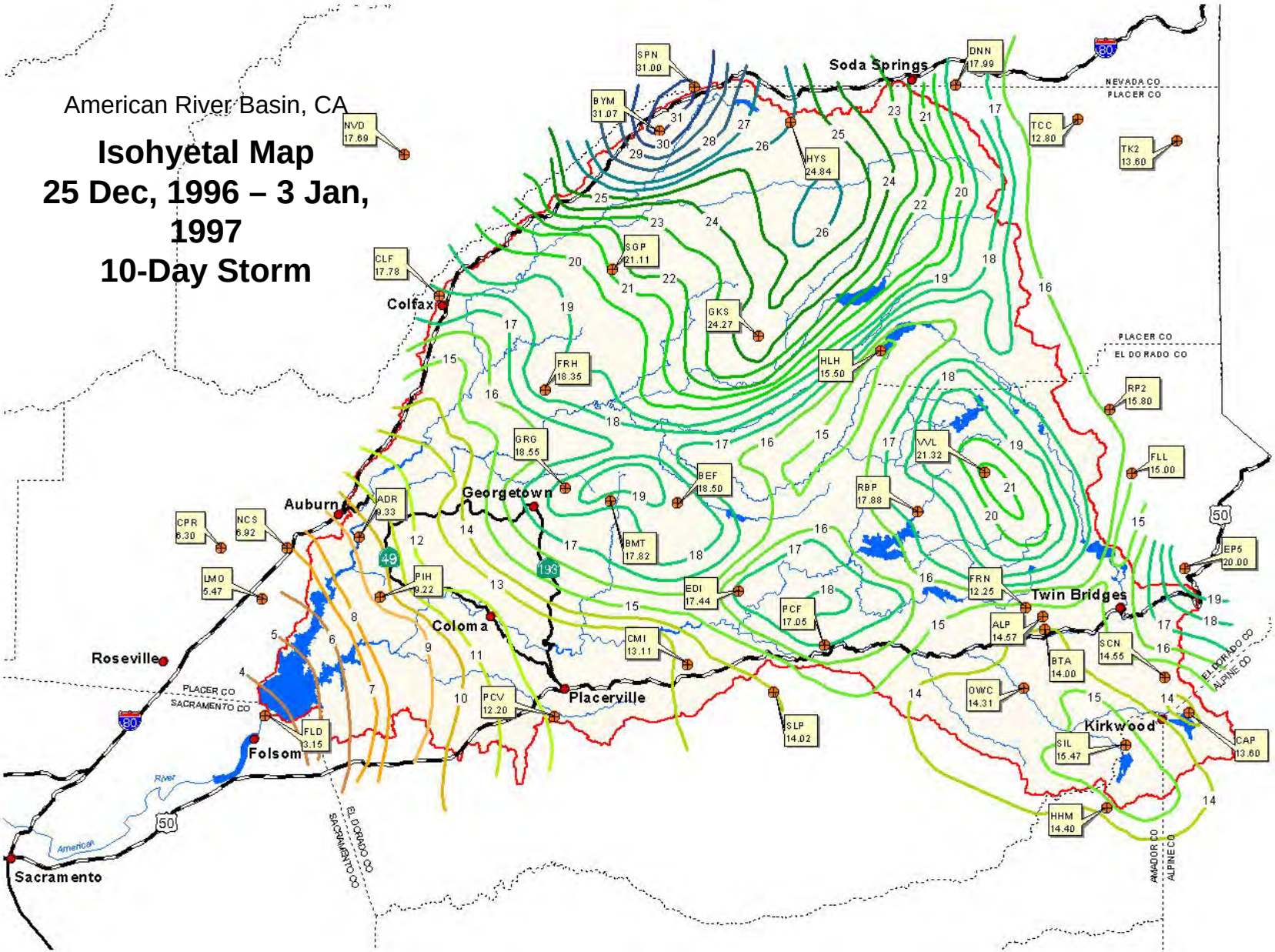
January 1997 Flood

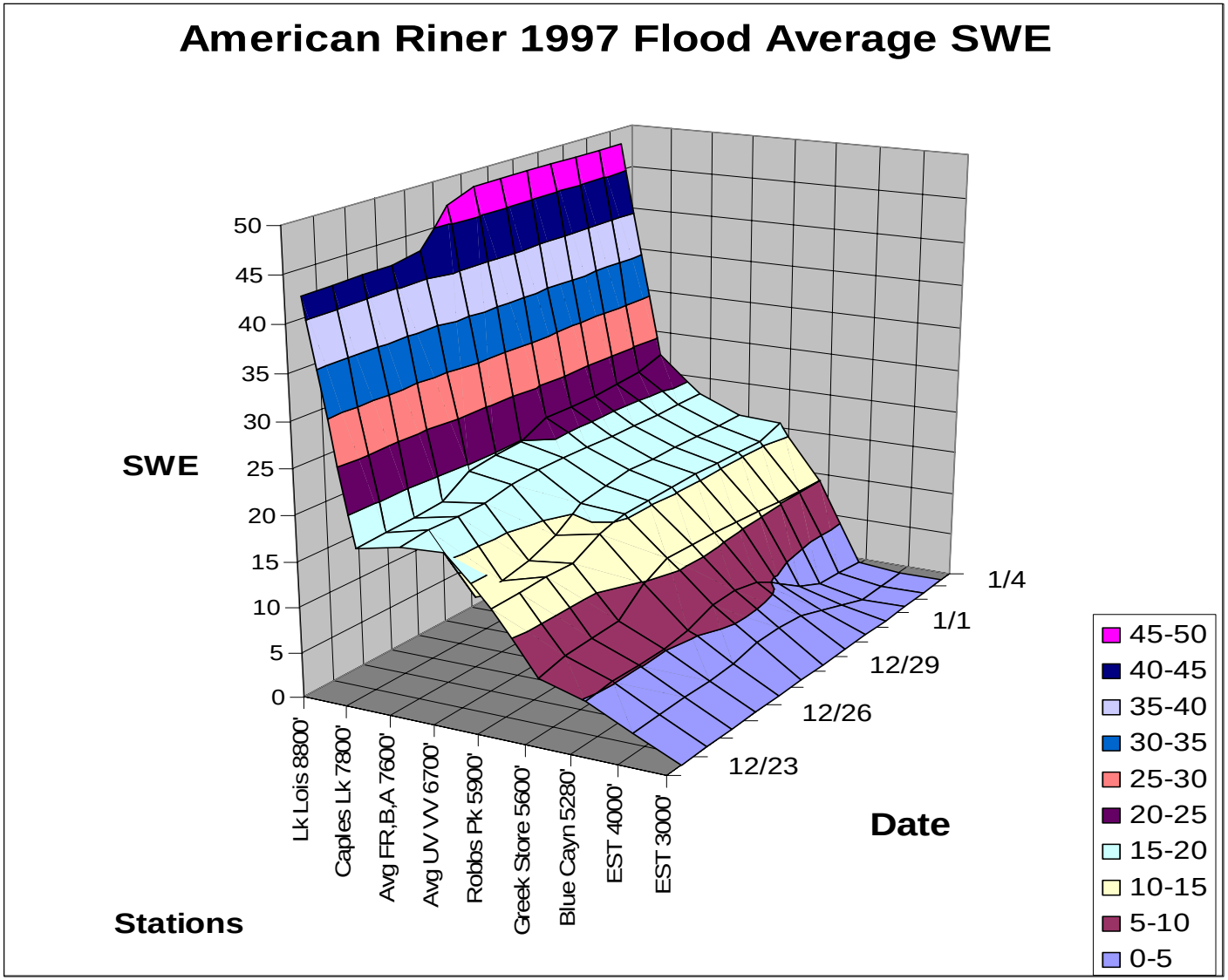
- Antecedent conditions
  -Rained and snowed for the first 3 weeks in Dec.
  - Snow covered close to 70% of the American R. Basin
- 30 December 1996 - 2 January 1997
  - Heaviest precipitation period American river basin
  - Freezing levels above 10,000 feet for most of this storm period
  - Record rainfall produced snowmelt and runoff.
  -Average 4-day rainfall depth over the basin of 11.8 inches. -
  -Unregulated runoff estimated at 11.1 inches
  -Net loss was only 0.7 inches.
- Study period 25 Dec. 1996 – 4 Jan. 1997 results were:
  - 10-day average basin depth 17.2 inches
  - 10-day average basin snowmelt runoff of 2.9 inches of water

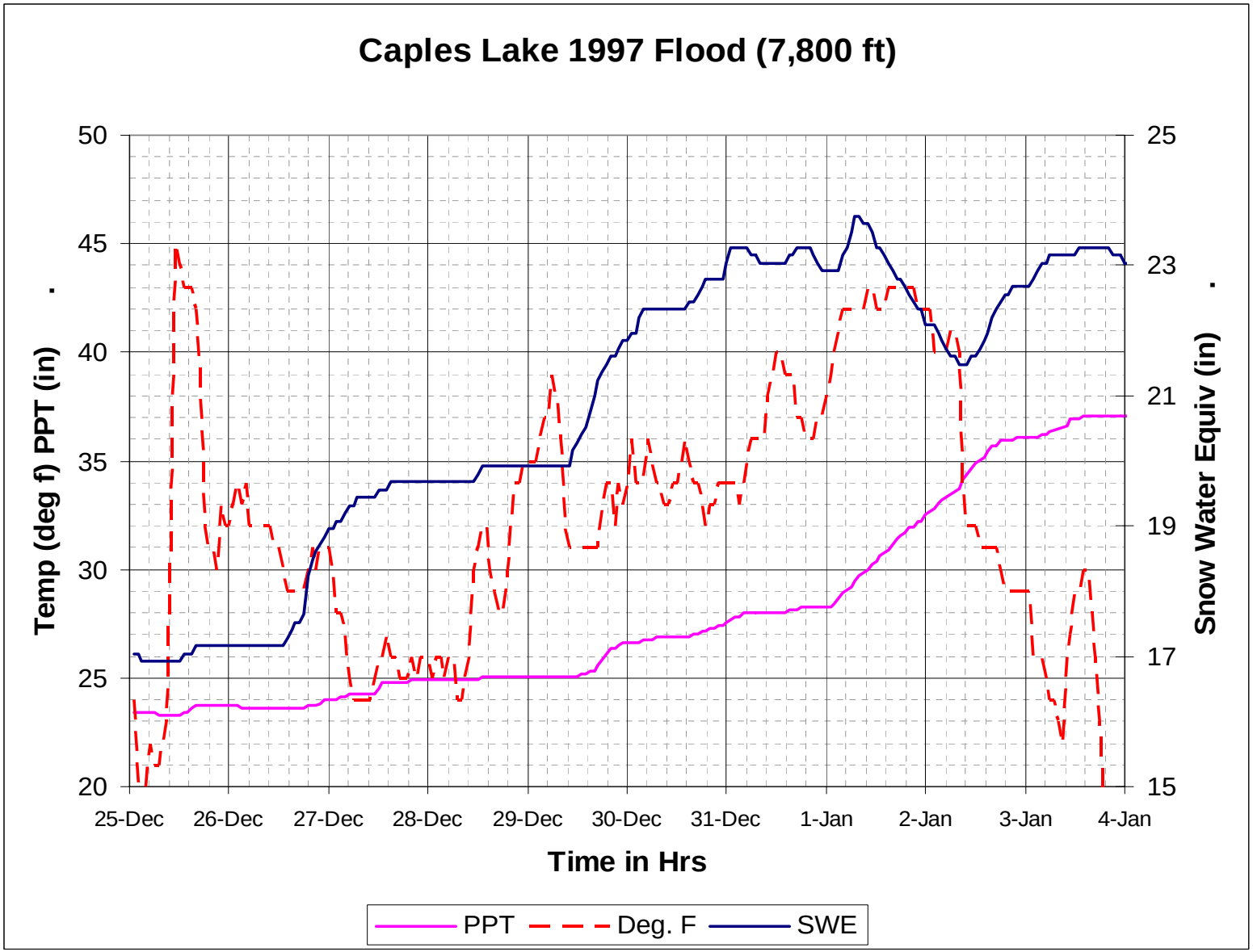
Dec 25-Jan 4, 1997 Flood, HEC-1 Model Input

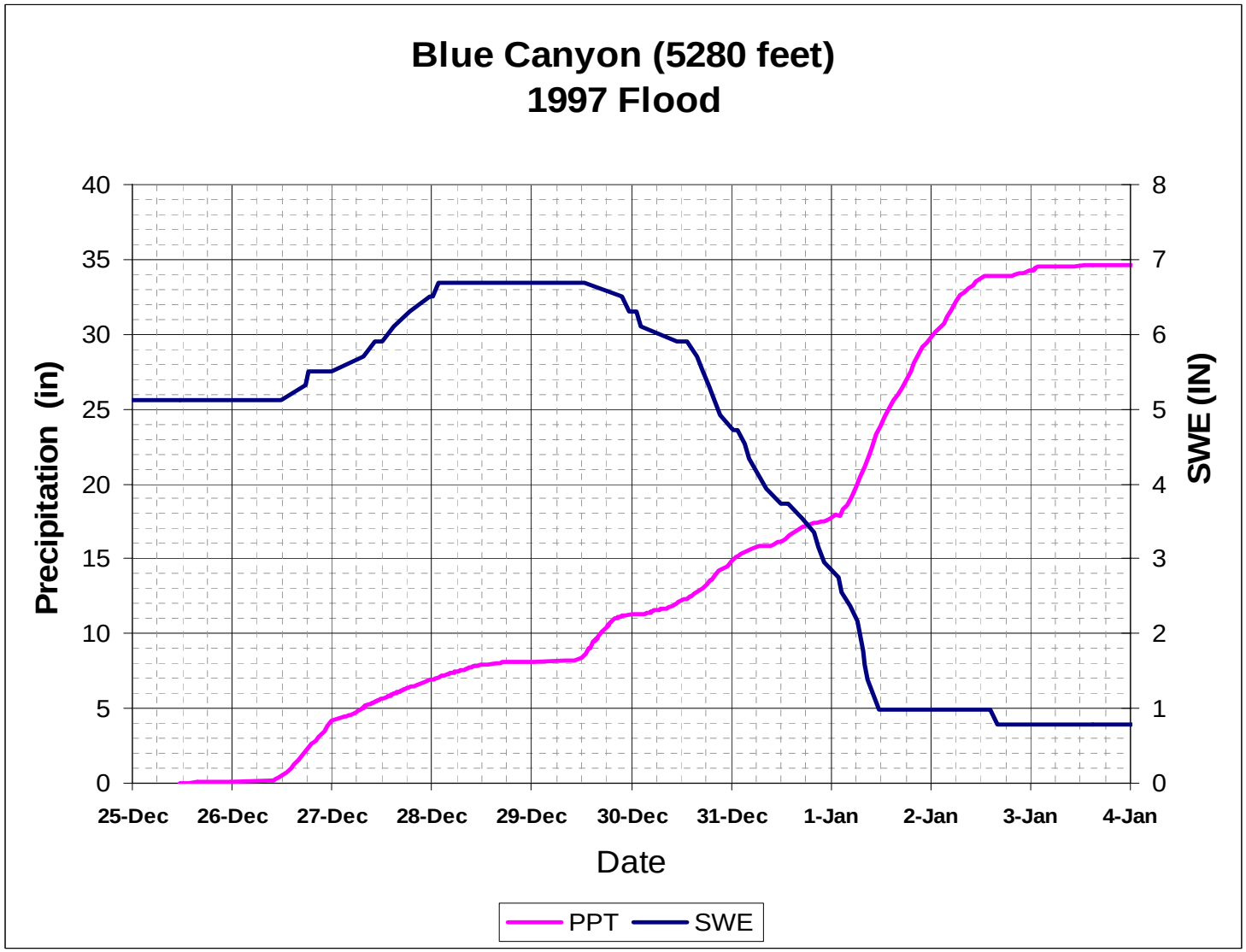
- Model precipitation
  - -Isohyetal Map from storm totals & sub-basin depth
  - -Basin precipitation temporal distributions from selected stations
- Water available for runoff from a snowmelt program
  - -Winds from the River forecast Center
  - -lapse rates averaged from 10 stations
  - -Snow Cover verified from station and satellite data
  - -SWE and snow depths averaged from 11 stations
- Runoff from BOR, CDEC, USGS, SMUD, and PG&E
  - -Many gages with daily flow
  - - Limited gages with complete hourly data

Isohyetal Map 1997 Storm

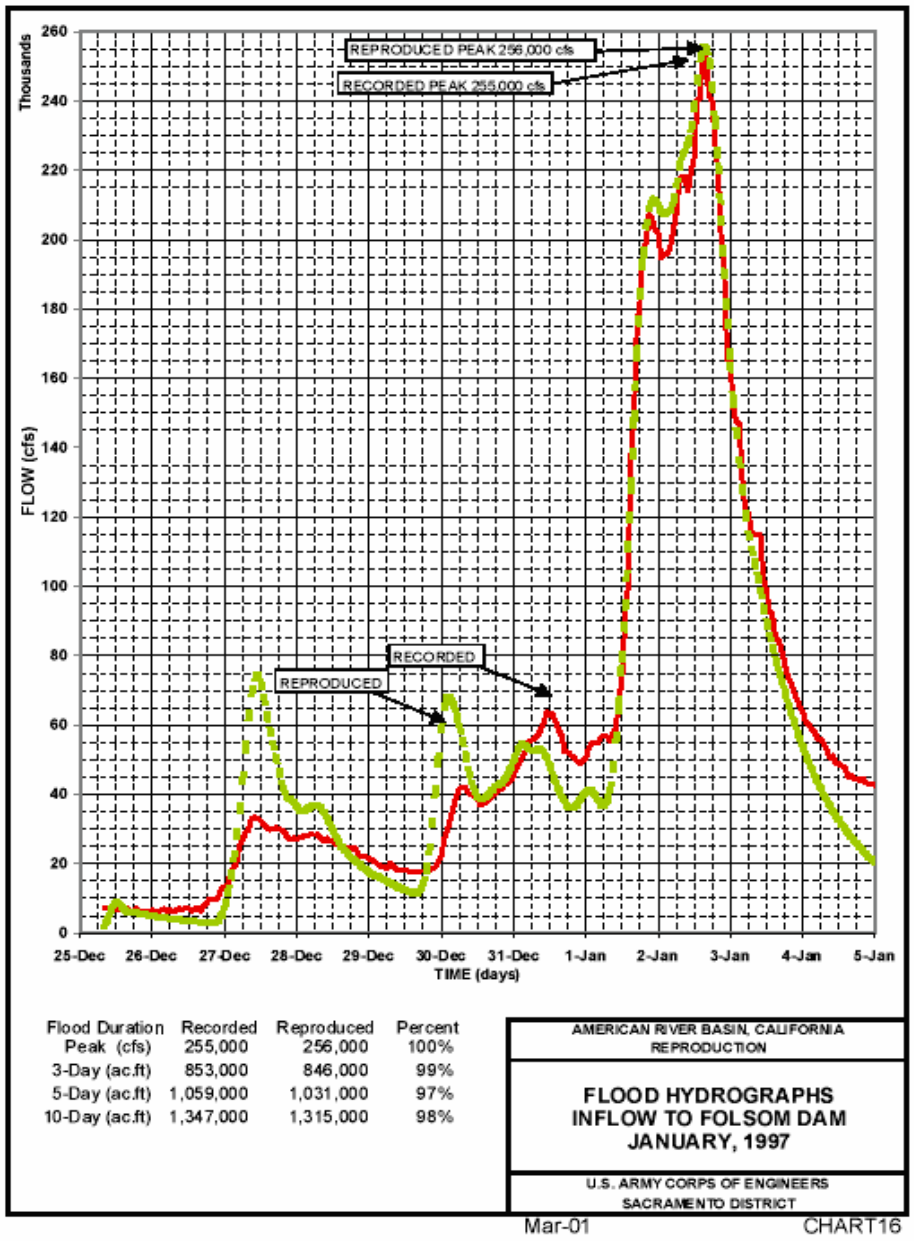



American Riner 1997 Flood Average SWE
SWE
50
45
40
35
30
25
20
15
10
5
0
Lk Lois 8800'
Caples Lk 7800'
Avg FR,B,A 7600'
Avg UV VV 6700'
Robbs Pk 5900'
Greek Store 5600'
Blue Cayn 5280'
EST 4000'
EST 3000'
Stations
12/23
12/26
12/29
1/1
1/4
Date
45-50
40-45
35-40
30-35
25-30
20-25
15-20
10-15
5-10
0-5


Caples Lake 1997 Flood (7,800 ft)
Temp (deg f) PPT (in)
Snow Water Equiv (in)
50
45
40
35
30
25
20
25
23
21
19
17
15
25-Dec
26-Dec
27-Dec
28-Dec
29-Dec
30-Dec
31-Dec
1-Jan
2-Jan
3-Jan
4-Jan
Time in Hrs
PPT
Deg. F
SWE


Blue Canyon (5280 feet)
1997 Flood
Precipitation (in)
SWE (IN)
40
35
30
25
20
15
10
5
0
8
7
6
5
4
3
2
1
0
25-Dec
26-Dec
27-Dec
28-Dec
29-Dec
30-Dec
31-Dec
1-Jan
2-Jan
3-Jan
4-Jan
Date
PPT
SWE

1997 Flood Hydrographs



Flood Duration Peak (cfs)	Recorded 255,000	Reproduced 256,000	Percent 100%
3-Day (ac.ft)	853,000	846,000	99%
5-Day (ac.ft)	1,059,000	1,031,000	97%
10-Day (ac.ft)	1,347,000	1,315,000	98%

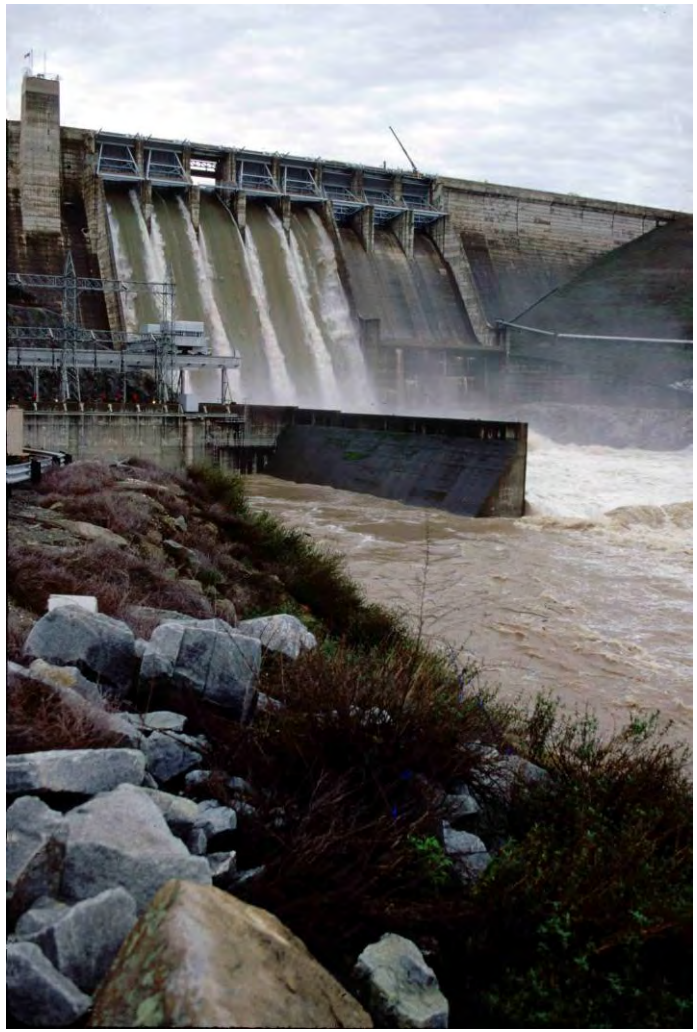
AMERICAN RIVER BASIN, CALIFORNIA
REPRODUCTION

FLOOD HYDROGRAPHS
INFLOW TO FOLSOM DAM
JANUARY, 1997

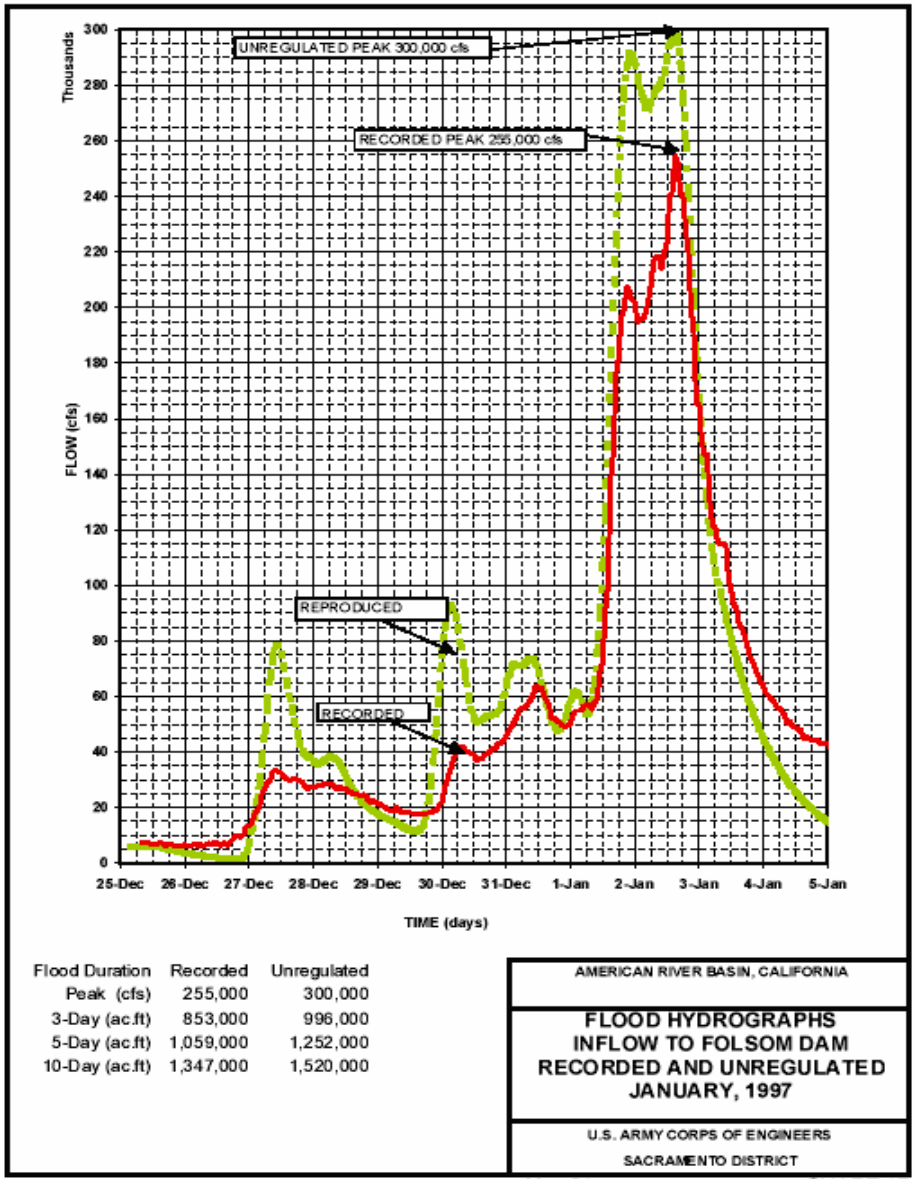
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Mar-01 CHART16

Dec 25 –Jan 5 1997 Flood Recorded and computed with Up stream regulation.



Dec 25 - Jan 5 1997 Flood



Flood Duration	Recorded	Unregulated
Peak (cfs)	255,000	300,000
3-Day (ac.ft)	853,000	996,000
5-Day (ac.ft)	1,059,000	1,252,000
10-Day (ac.ft)	1,347,000	1,520,000

AMERICAN RIVER BASIN, CALIFORNIA

FLOOD HYDROGRAPHS
INFLOW TO FOLSOM DAM
RECORDED AND UNREGULATED
JANUARY, 1997

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Mar-01 CHART 17

Dec 25 –Jan 5 1997 Flood

With and without Up stream regulation.

Dec 25-Jan 4, 1997 Flood

INFLOW TO FOLSOM DAM

Flood Duration	Recorded	Reproduced	Percent
Peak (cfs)	255,000	256,000	100%
3-Day (ac.ft.)	853,000	846,000	99%
5-Day (ac.ft.)	1,099,000	1,031,000	97%
10-Day (ac.ft.)	1,347,000	1,315,000	98%

NOTES:

Upstream Reservoirs starting storage as of Jan.30 1997
Laps Rate 2.7 degrees per 1,000 feet.
Constant loss rate of 0.1 and 0.0 in/hr for lower and upper elevations respectively.

American River Floods: January 1862

Antecedent Conditions

- Warm rains from Nov. 9 to Dec 7, 1861 saturated the basin.
- Record storm Dec. 9-10 1861 caused levees to fail and flood Sacramento.
- Last week in December 1861 Second record storm floods Sacramento 2nd time produce higher stages than
- First Week January 1862 an extremely cold storm causes snow accumulations below 1,000 feet. Temperatures in San Francisco hit 23 ^{o}F with 10-15 feet of snow accumulating in the lower Sierra Nevada Mountains.

Flood January 9-12 1862

- Warm and heavy rains from Jan. 9-11 storm produced highest flood stages in Sacramento.
- Large post storm Jan 15-17 prolonged severe flooding of the lower portion of the basin.

Jan 9-11, 1862 Flood

American River 1862 3-Day Flows				
1986 Flood 3-Day Flow	Additional Runoff 931 sq.mi.	3-Day cfs	3-Day cfs	3-Day Volume
(day-cfs)	(in)	(day-cfs)	(day-cfs)	(ac.ft.)
166,000	1	8,400	174,400	49,700
166,000	2	16,800	182,800	99,400
166,000	3	25,200	191,200	149,100

American River Floods: Historic to Theoretical

American River at Fair Oaks

PMF and Maximum Unregulated Historic Rain Floods

Ordered by Maximum 3-day Flow				
Water Year	Date of Peak	Peak cfs	1-day cfs	3-day cfs
PMF	Dec-Jan	906,000	698,000	472,000
1862	9-Jan	300,000 est.	208,000 est.	180,000est
1986	9-Jan	265,000	160,000	166,000
1997 [1]	2-Feb	302,000 [2]	252,500 [1]	165,000
1997 [3]	2-Feb	300,000 [2]	248,900 [3]	164,200 [3]
1965	23-Dec	260,000	183,200	140,300
1956	23-Dec	219,000	189,100	127,400

Notes:

[1] Derived from USGS Water-Data Report published in 1998.

[2] COE peak estimate for the 1997 flood.

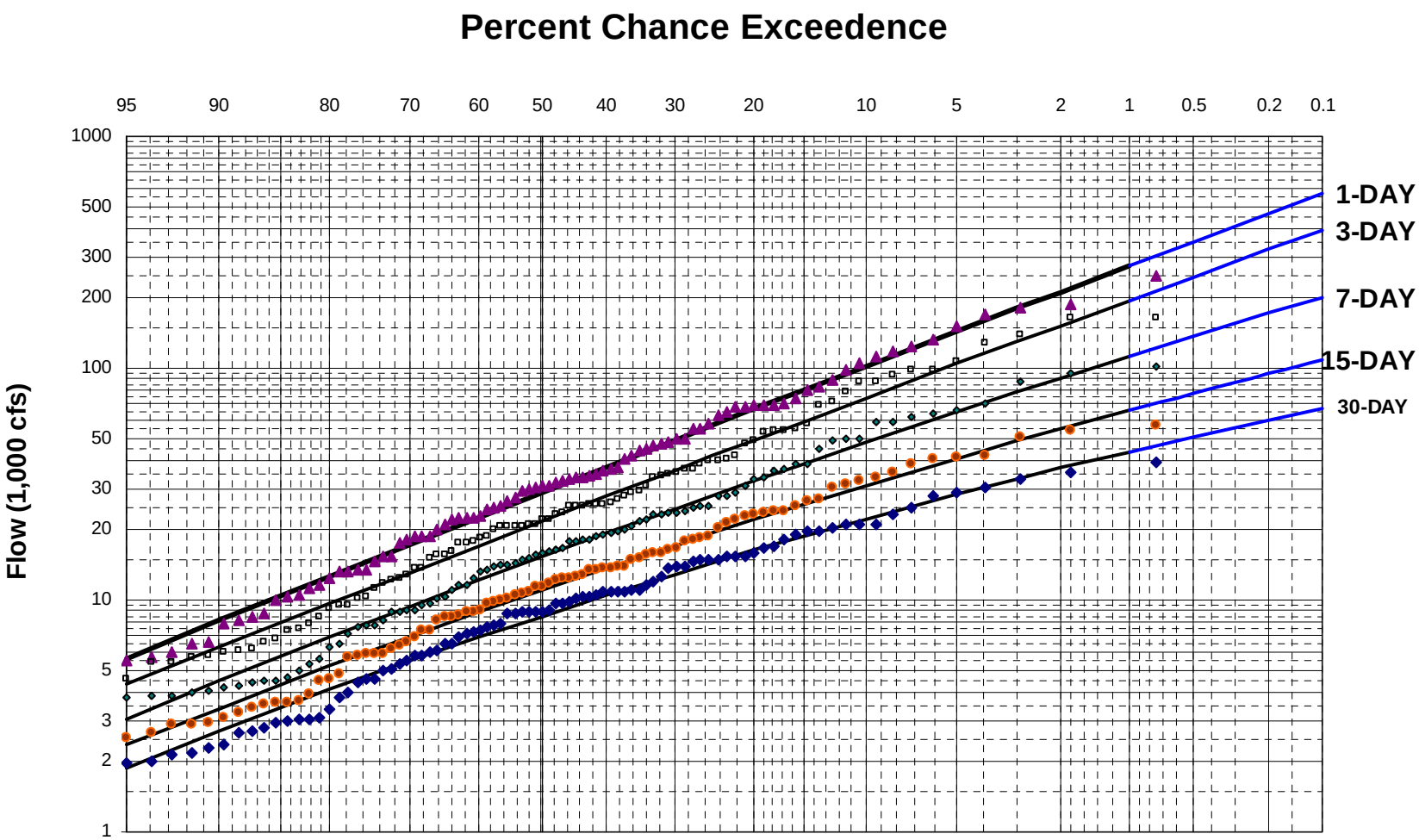
[3] Data provided by DWR's CDEC database used in the latest COE frequency analysis and results from 2001 Folsom PMF Report.

❖Developing Hypothetical Floods

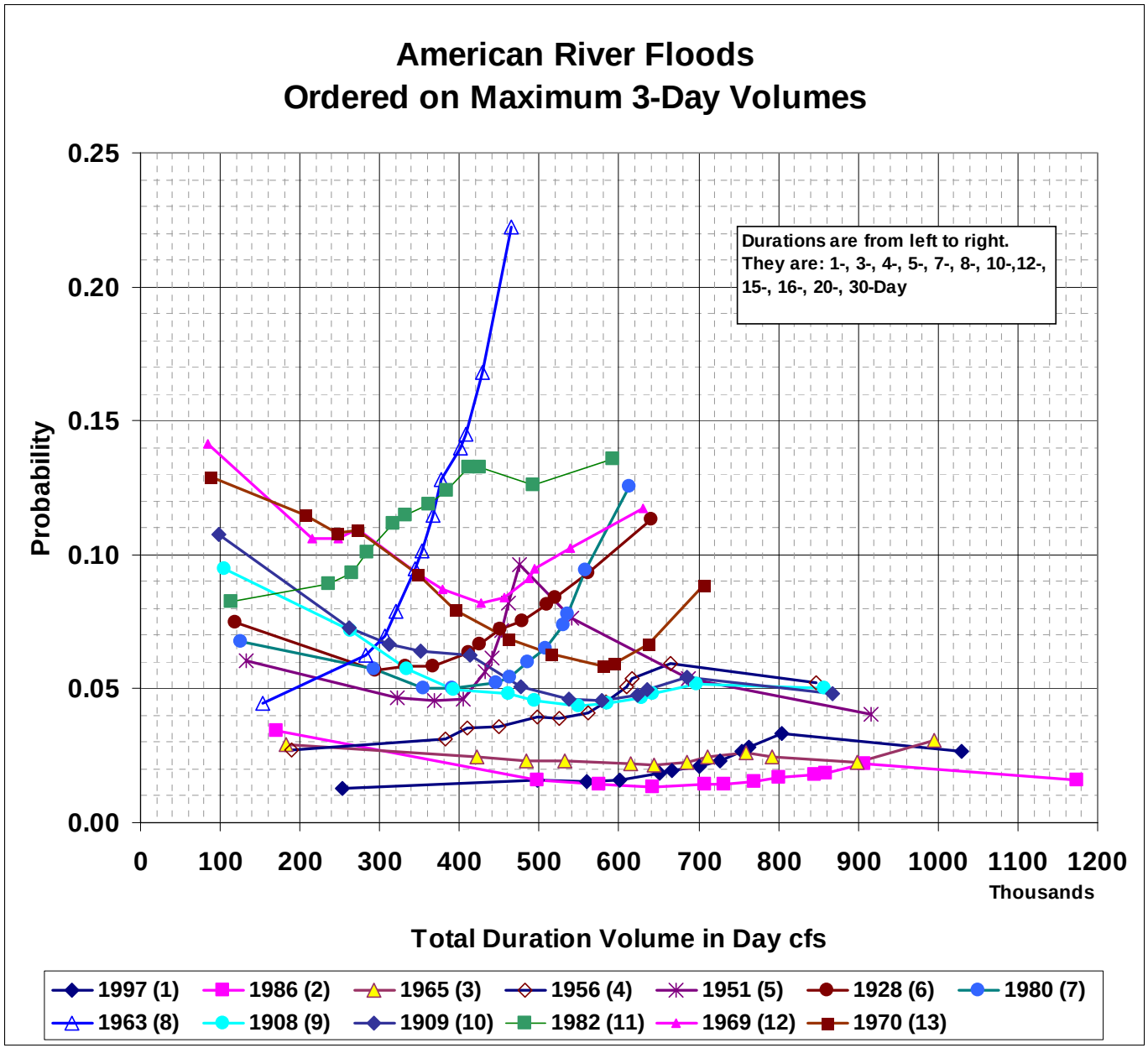
Increasing Historical Floods using different critical durations.

Balancing hydrographs from the peak and volume frequency curves.

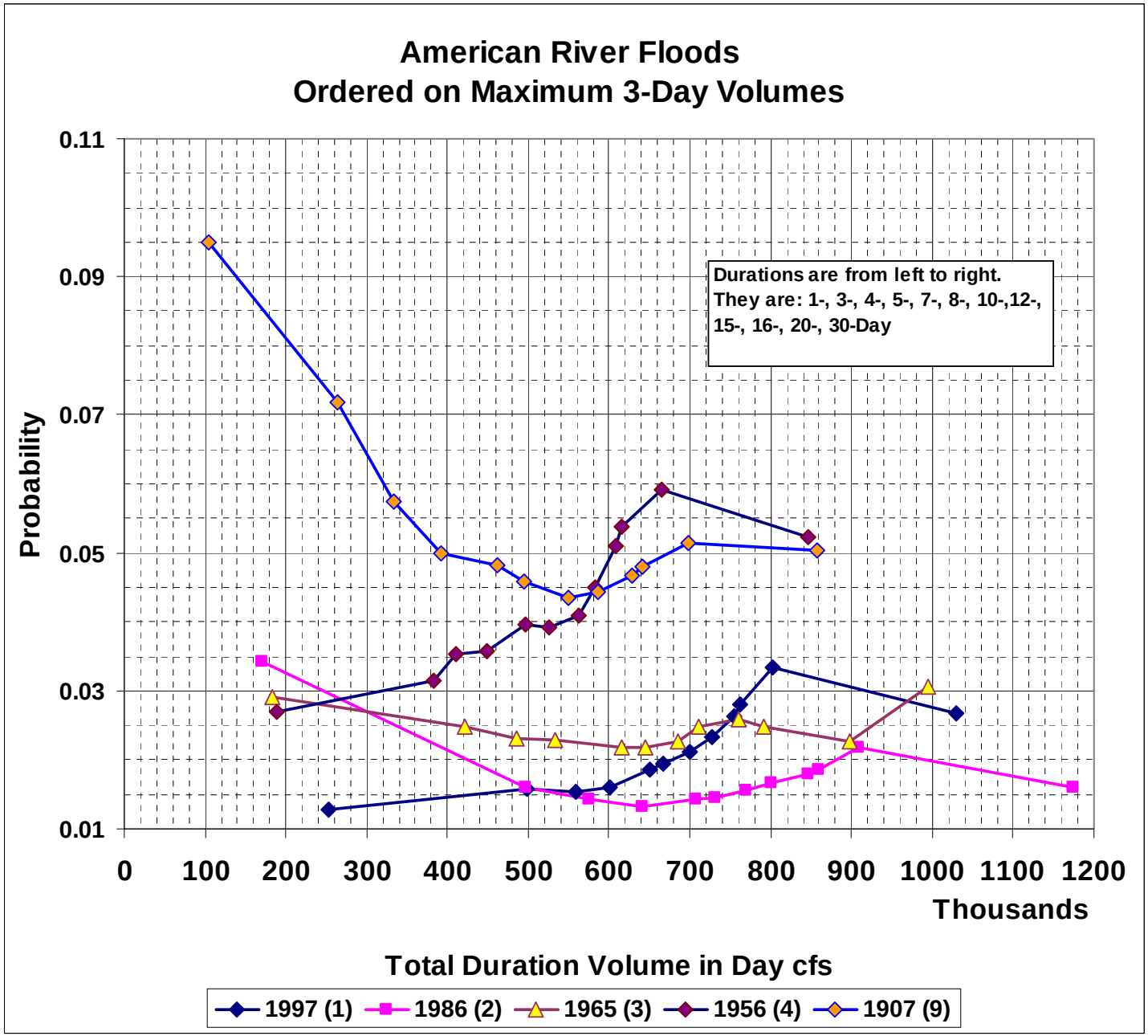
American River Largest Historic Floods



American River Largest Historic Floods



American River Largest Historic Floods



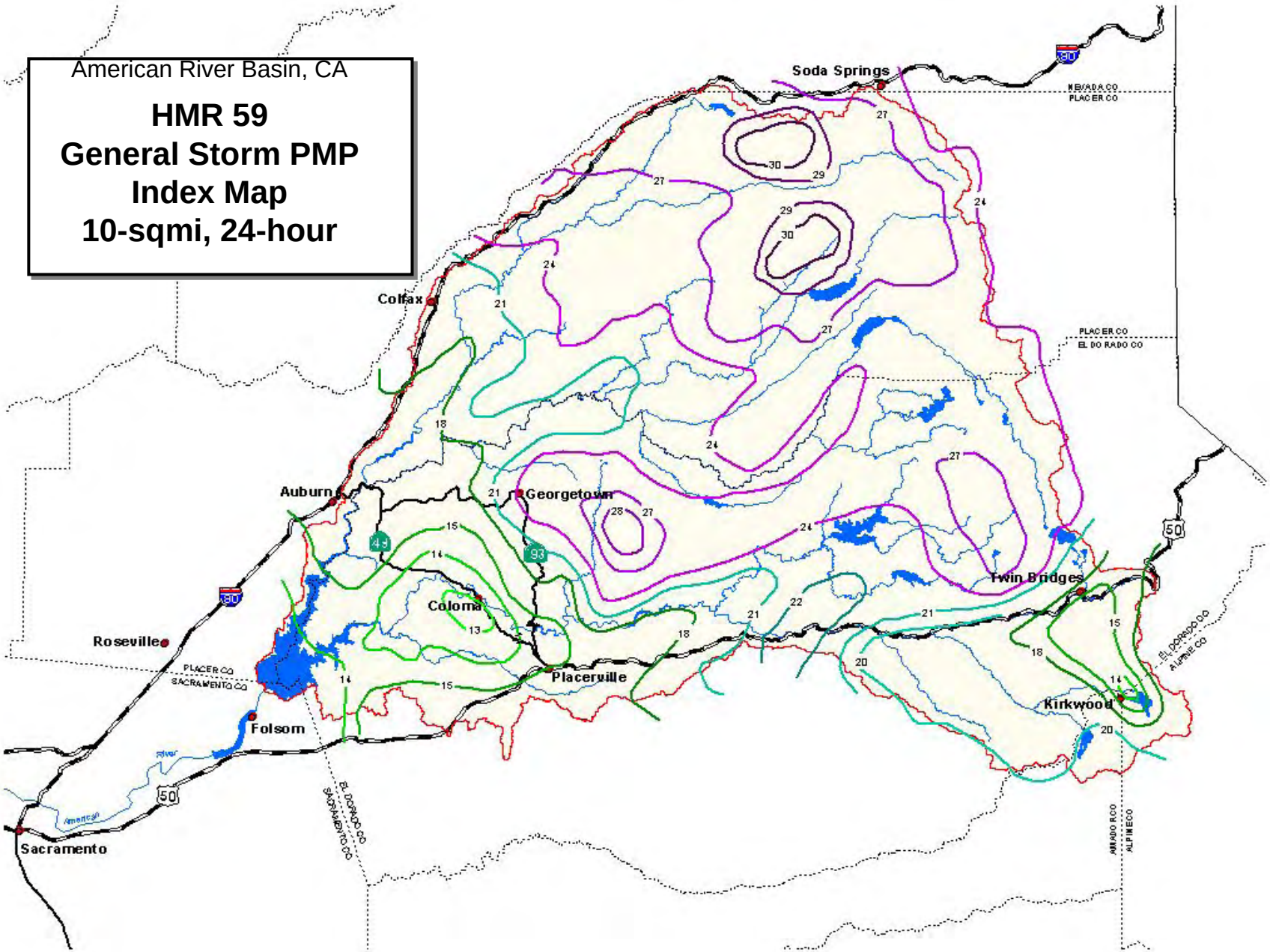
Modeling The PMF

- 1980 USACE American River Basin SPF Model
- 1986 and 1997 floods which were largest in 140 years
- Modeled 1986 and 1997 floods to test unit hydrographs, loss rates, or routing parameters
- Compute PMF

General Storm PMP from HMR No. 59

- Precipitation from the 10 sq. mi. 24 hr General Storm PMP Index Map for each subbasin and elevation band
- Seven regions PMP HMR58 Sierra Mountain Area 5
- All Season one
- Off Season + or – 5 months
- Depth Area Duration curves for 1-, 6-, 12- , 24-, 48-, 72-hour periods

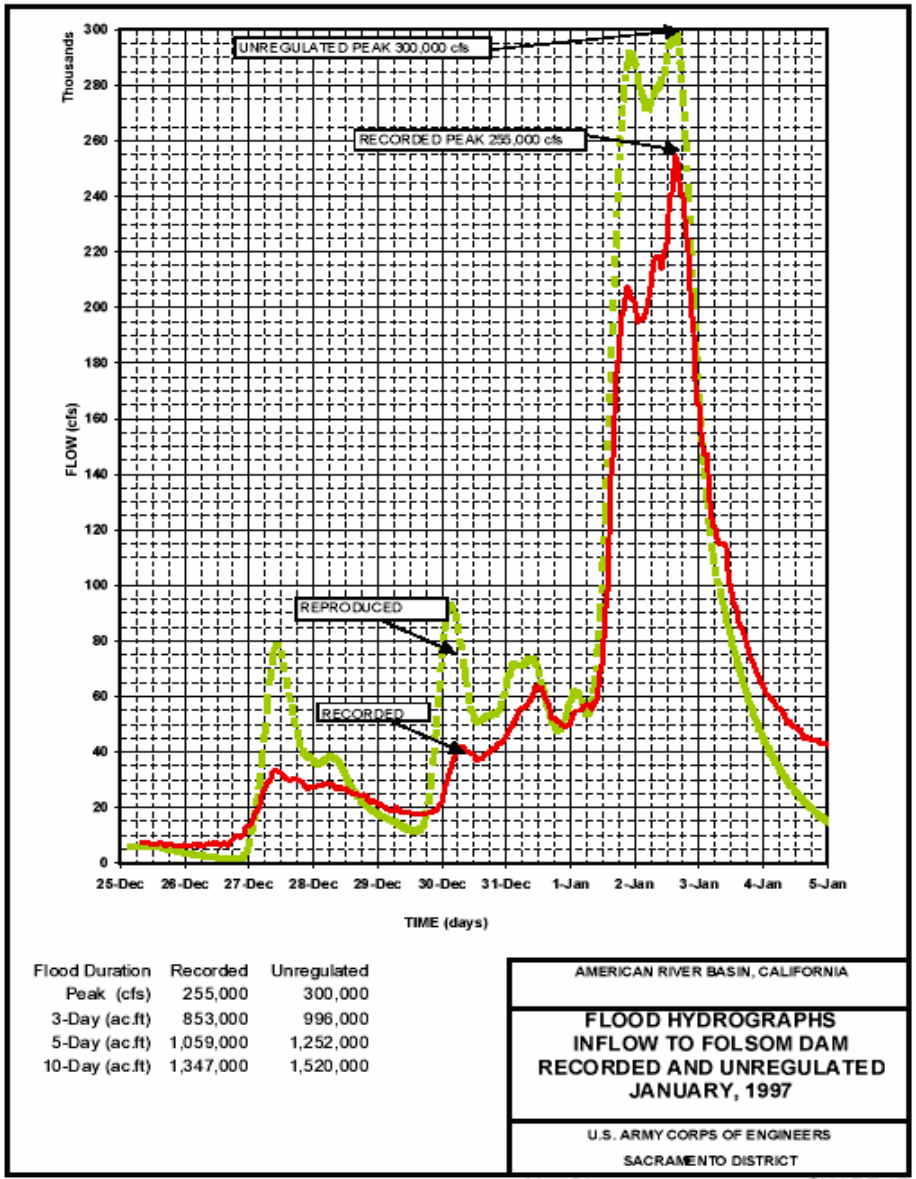
General Storm PMP Index Map



Snowmelt And Water Available for Runoff

- Potential snowmelt for each 1,000-foot elevation band EM 1102-2-1406
- Forested and partly- forested areas
- Dew points, freezing levels and winds for December from HMR No. 59
- Average lapse rate of 2.7 degrees Fahrenheit per 1,000-foot elevation
- Snow density and depth from the 1997 event

Dec 25 - Jan 5 1997 Flood



Flood Duration	Recorded	Unregulated
Peak (cfs)	255,000	300,000
3-Day (ac.ft)	853,000	996,000
5-Day (ac.ft)	1,059,000	1,252,000
10-Day (ac.ft)	1,347,000	1,520,000

AMERICAN RIVER BASIN, CALIFORNIA

FLOOD HYDROGRAPHS
INFLOW TO FOLSOM DAM
RECORDED AND UNREGULATED
JANUARY, 1997

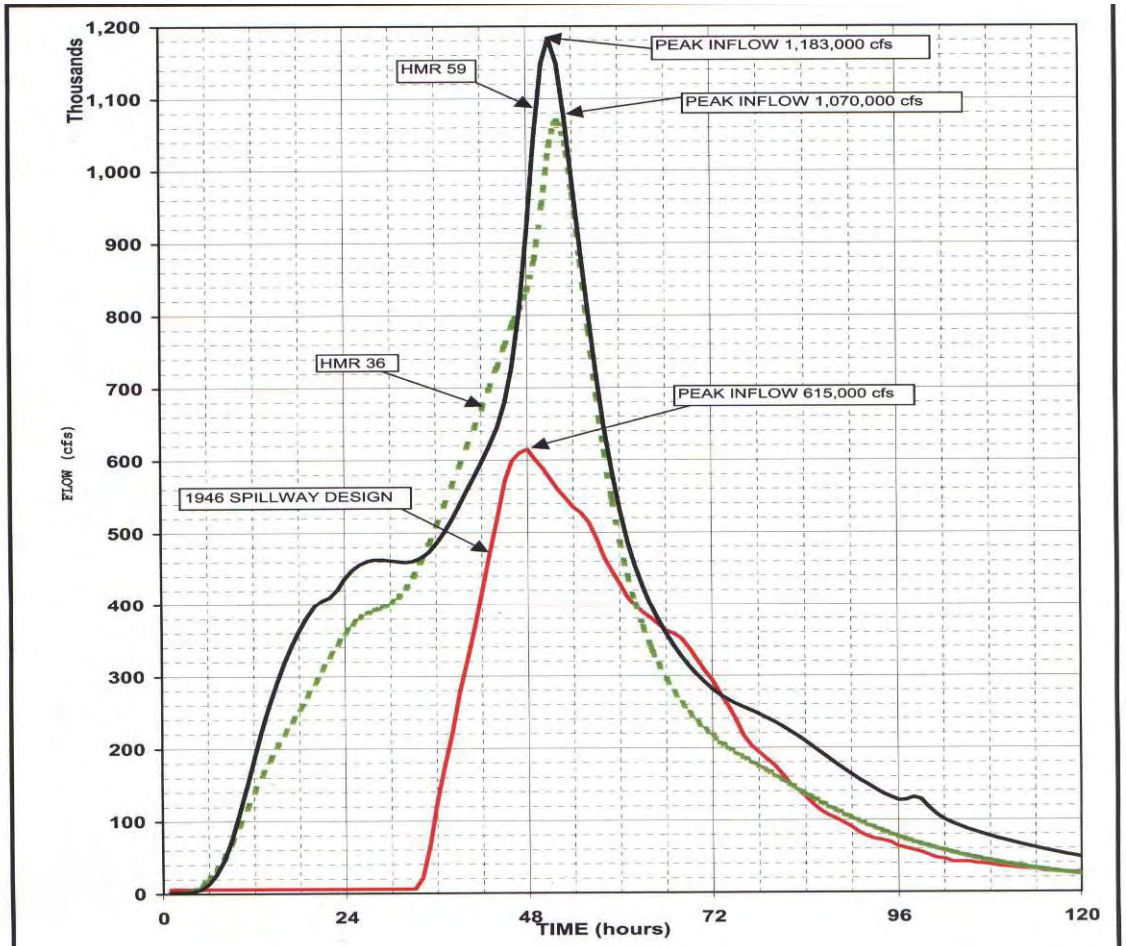
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Mar-01 CHART 17

Dec 25 –Jan 5 1997 Flood

With and without Up stream regulation.

Probable Maximum Floods



Flood Duration	Spillway Design Flood HMR No 3	HMR No 36	HMR No
Peak (cfs)	615,000	1,070,000	1,183,000
72-Hr (ac.ft.)	1,638,000	2,651,000	2,935,000
120-Hr (ac.ft.)	1,696,000	2,885,000	3,327,000

Note:
Floods computed from HMR No 36 and No 59
Hydrographs include French Meadows Dam failure

AMERICAN RIVER BASIN, CALIFORNIA

PROBABLE MAXIMUM FLOODS
HMR No. 3, No. 36, AND No. 59
INFLOW TO FOLSOM LAKE

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September, 2001 CHART 19

Hydrology Section
Sacramento District

PMF Determination - American River

PMF Summary

Folsom Lake: Drainage Area 1,862 Square Miles									
Storm Identification	Precipitation & Snow			Model Runoff					
	72-hr PMP	Snowmelt	Remaining in snow	Loss	Excess	Peak Flow		72 Hour Volume	
	(in)	(in)	(in)	(in)	(in)	(Tcfs)	(csm)	(TAF)	(in)
HMR No. 3, PMF U.S.C.E. D.P.R. Hydrology									
June 1946	21.20	5.00	1.70	8.40	16.10	615	330	1,638	16.5
HMR No. 36, Revised PMF with Upstream Dam Failures									
Revised 1980	32.83	2.10	1.64	7.12	26.17	1,037	557	2,657	26.9
Revised 1991	32.83	2.10	1.64	7.12	26.17	1,070	558	2,651	26.8
HMR No. 36, Revised PMF without Upstream Failures									
Revised 1980	32.83	2.10	1.64	7.12	26.17	848	456	2,495	25.3
Revised 1991	32.83	2.10	1.64	7.12	26.17	839	453	2,509	25.4
50% PMF 1991						413	223	1,244	12.6
HMR No. 59, PMF with Upstream Dam Failure									
Revised 2001	29.62	2.91	0.13	3.22	27.45	1,183	636	2,936	29.6
HMR No. 59, PMF without Upstream Dam Failure									
Revised 2001	29.62	2.91	0.13	3.22	27.45	906	486	2,811	28.3
50% 2001 PMF						441	237	1,397	14.1

PMF Determination - American River

American River Basin, California
Folsom Dam Spillway Routing Data Summary for HMR No. 59 PMF

Description of Flood Condition	PMF with Upstream Dam Failures[a./]	PMF w/o Upstream Dam Failures[b./]
Initial Loss	None	None
Uniform Loss	0.04 in/hr	0.04 in/hr
Peak Inflow	1,183,000 cfs	906,000 cfs
Initial Storage	977,000 ac-ft	Same
Maximum Storage	1,193,000 ac-ft	1,170,000 ac-ft
Height of Main Dam (El.)	484 ft	Same
Crest Length of Main Dam	1,400 ft	Same
Height of Other Structures (El.)[c./]	480.5 ft	Same
Crest Length of other Structures	25,275 ft	Same
Max. Flood Pool Elevation	483.9 ft	482.6 ft
Max. Overtopping	3.4 ft	2.1 ft
Duration of overtopping	11 hrs	9 hrs

Remarks
a./ Upstream dam failure at French Meadows Reservoir only.
b./ Both of these routings assume that Folsom Dam does not fail.
c./ Other structures include wing dams, dikes, and Mormon Island Dam.

THE END