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Department of Public Works
1050 Monterey Street
San Luis Obispo CA 93408

January 25, 2008

Subject: San Luis Obispo Creek Watershed Hydrology and Hydraulic Model Calibration Study

Dear Mr. Werst,

This letter report summarizes the results of the calibration study for the San Luis Obispo Creek watershed models. The objectives of the study were to:

- Examine County stage and rain gage data from water years 2003-2005
- Produce stage-discharge curves for the County gage locations
- Calibrate existing watershed models with County gage data
- Produce hydrographs for the County gage locations as predicted by the HEC-HMS rainfall-runoff model
- Compare model hydrographs to County gage hydrographs

San Luis Obispo Creek Watershed Hydrologic Model Inputs

The San Luis Obispo Creek watershed runoff model uses the U.S. Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) computer modeling package. The model is composed of three components: watershed sub-basins, stream flow routing reaches, and modeled precipitation events. The watershed sub-basin component mimics the physical characteristics of the watershed including the relationship between precipitation and runoff. The flow routing component describes how flow moves from the upper reaches of the watershed to the mouth and determines the relative timing of this runoff. The precipitation component describes precisely how much rainfall occurs on each watershed sub-basin at each model time step.

The San Luis Obispo Creek Watershed above the mouth is approximately 84 square miles in area. Elevations vary from sea level to over 2600 feet along the crest of the Cuesta Ridge, in the Santa Lucia Mountains. No point in the watershed is more than 14 miles from the coast. Storms coming off the Pacific Ocean are pushed over the mountains, tending to create widely varying rainfall patterns within the watershed. Precipitation in the lower Southeastern portions of the watershed can be less than half of that in the higher Northern portions. Flow in San Luis Obispo Creek can respond very quickly to short high intensity rainfall bursts. Floods in San Luis Obispo Creek tend to be of high magnitude and relatively short duration.

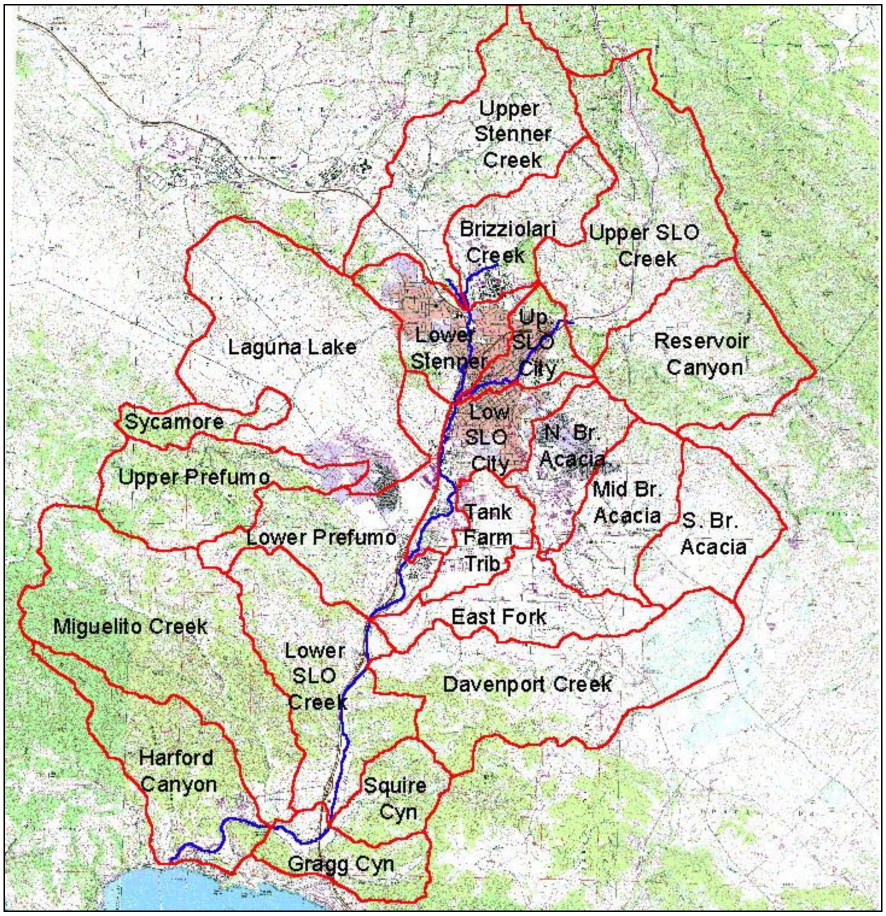


Figure 1. Hydrology model sub-basin delineation

Watershed Model

The watershed model was formed by splitting the watershed into 22 individual sub-basins (**Figure 1**). The SCS (Soil Conservation Service, now Natural Resources Conservation Service) loss-rate and the SCS unit hydrograph methods were used to determine runoff hydrographs from each of the sub-basins, based on a set of 24-hour design storms.

In the SCS loss-rate method, infiltration properties of a basin are described by a runoff curve number. Curve numbers (CN) range from 1 to 100, with lower values denoting less runoff for a given precipitation total than higher values. The SCS curve number was typically calculated as a function of land use and soil hydrologic characteristics, according to Natural Resources Conservation Service (NRCS) recommendations outlined in Technical Report 55 (TR55) (Soil Conservation Service, 1975).

Flow Routing

Runoff from individual sub-basins is routed through the system using the Muskingum-Cunge 8-point routing technique. This technique uses a rough approximation of a channel cross section, including the floodplain, along with representative roughness values, to evaluate the effects of channel and floodplain storage on the flood hydrograph as it passes downstream through the reach.

Precipitation

One of the challenges of modeling the rainfall along California's Central Coast is the strong orographic (i.e. changes in gradient causing air cooling and precipitation) influence the Coast Ranges have on precipitation totals. **Figure 2** shows the location of the County gages used for this calibration study.

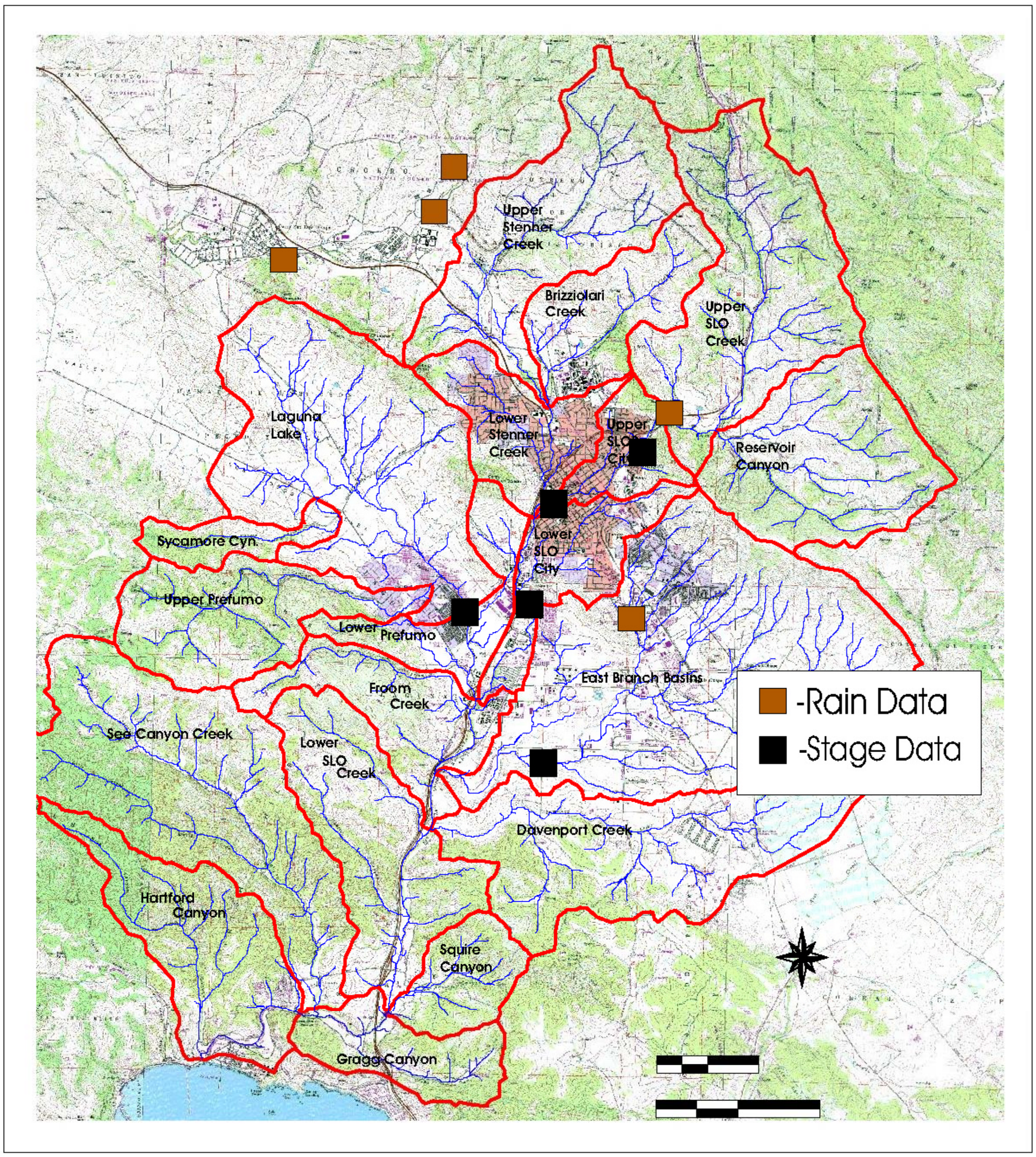


Figure 2. SLO County rain and stage gage locations.

The largest rainfall event that was captured by four out of five County gages occurred between December 27, 2004 through December 31, 2004, with the largest rainfall intensities the mornings of December 30th and 31st. This 5-day rainfall event was used as the calibration rainfall event for the study. Because rainfall at 15-minute intervals was required as input to the hydrology model for each of the 22 sub-basins, these gauges were deemed insufficient to fully characterize the magnitude of the storm in certain parts of the watershed, especially where orographic effects would have acted to increase precipitation beyond what the valley floor experienced. **Figure 3** shows how the rainfall distribution varies with gage location, as evidenced by much smaller rainfall totals for the Camp SLO gage as compared to the other gages, though this discrepancy also may have been due to equipment problems with the Camp SLO gage.

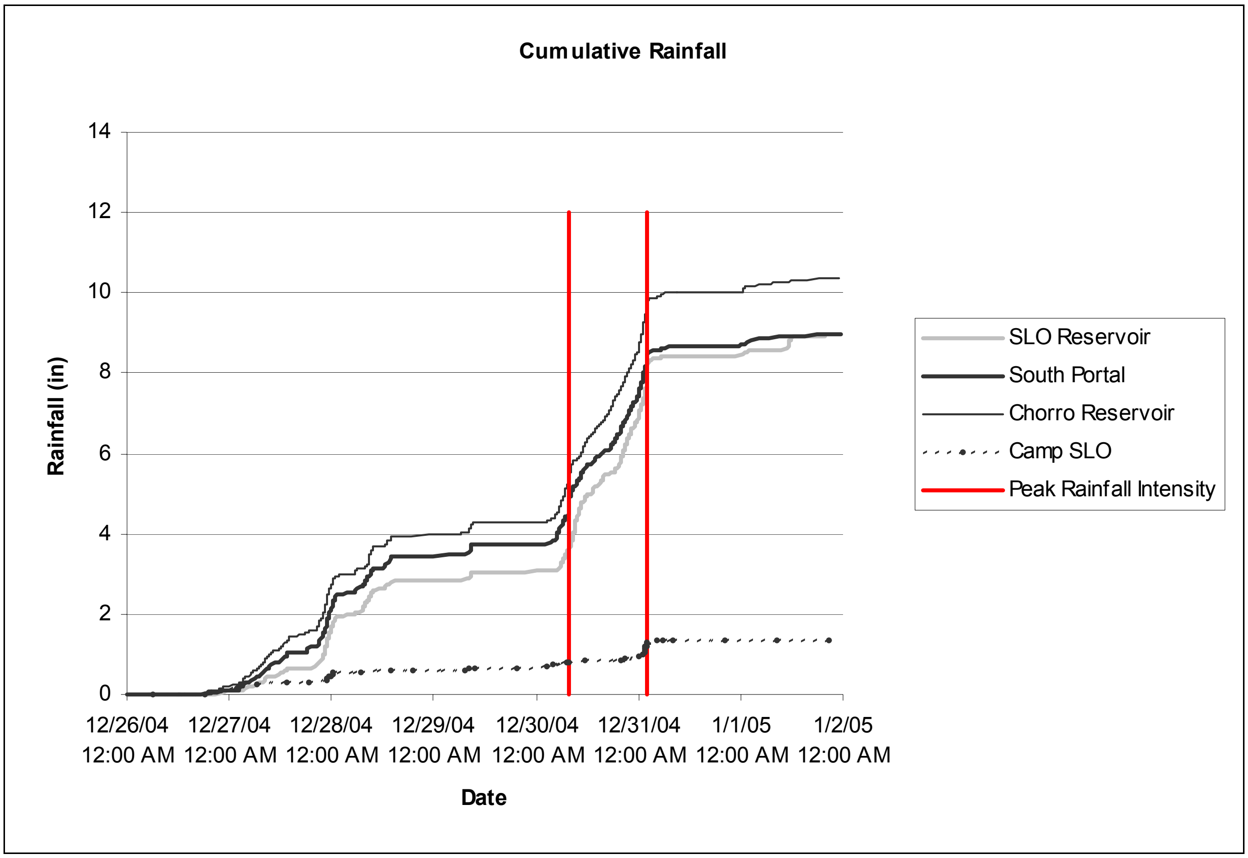


Figure 3. Cumulative rainfall amounts for rainfall event 12/27/04 to 12/31/04, measured at four County rain gages.

Peak recorded event totals ranged from 10.14 in at the Chorro Reservoir gage to 1.37 in at the Camp SLO gage. The rainfall totals at the Camp SLO gage were significantly lower than at any of the other gauges and are likely in error–especially considering the much higher totals recorded a few miles away at other gages. Though there was wide variability in precipitation totals from gage to gage and uncertainty in the reliability of the Camp SLO gage, a more detailed method of modeling rainfall for the December 2004 storm was required mostly due to lack of adequate density of watershed area gage coverage.

To provide a more complete picture of rainfall for the storm, archival NEXRAD meteorologic radar information for the time period in question was used to develop a detailed set of rainfall information, on 15-minute time steps, for each basin in the watershed model. The meteorologic analysis, performed by OneRain Corporation, involved calibrating radar return information with gaged rainfall intensities so that the OneRain dataset was consistent with gaged information. Gages outside the San Luis Obispo Creek watershed were used for this rainfall calibration process. Data was first computed on a 2-km by 2-km grid, and then averaged by sub-basin. Totals for the peak 5-day period ranged from 5.87 in for the Gragg Creek sub-basin to 13.06 in for the Sycamore Canyon sub-basin.

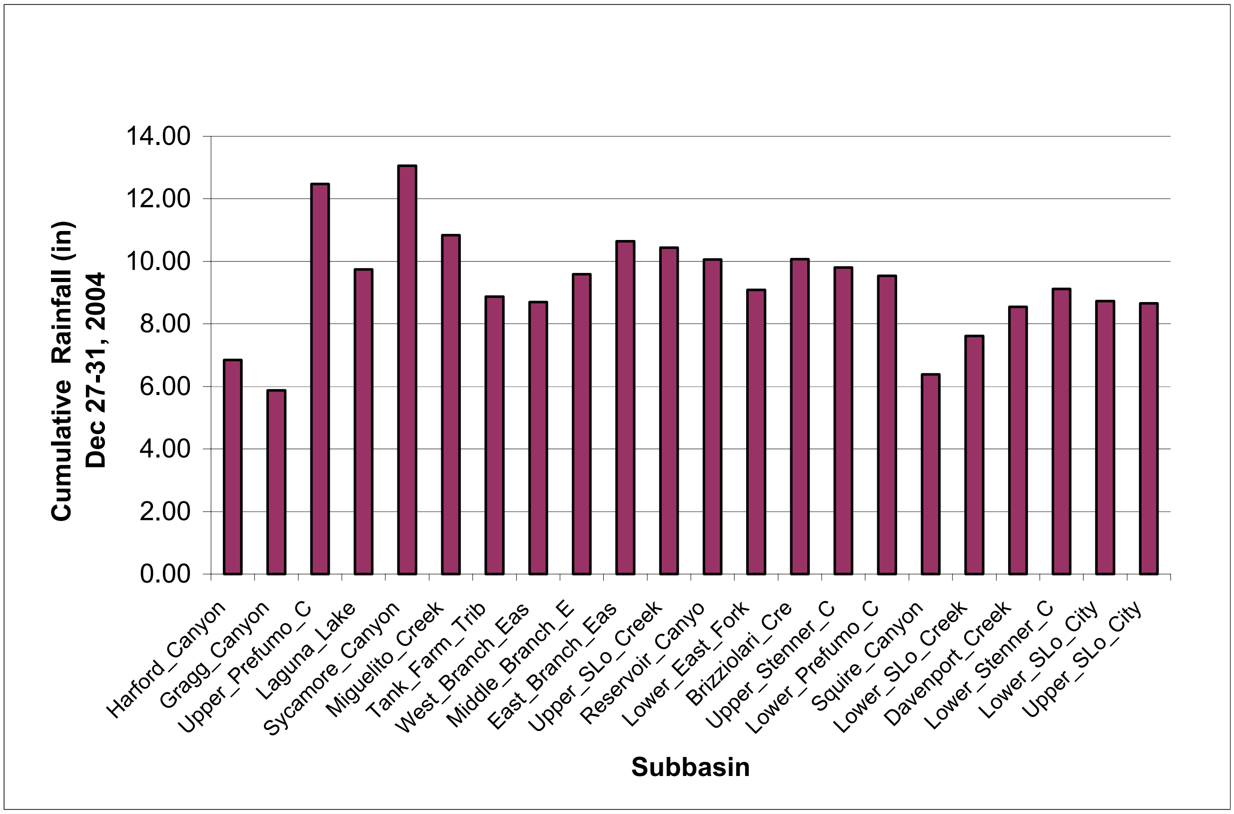


Figure 4. Cumulative Rainfall by Sub-basin OneRain data

Thus, the incremental rainfall on 15-minute intervals for each sub-basin was input to the hydrology model for the precipitation component, as provided by the archival NEXRAD meteorologic radar information.

San Luis Obispo Creek Watershed 1-D Hydraulic Model Inputs

Project flood management alternatives were analyzed using the U.S. Army Corps of Engineers Hydraulic Engineering Center–River Analysis System (HEC-RAS) version 3.0. HEC-RAS is a one-dimensional hydraulic computer modeling system that is used to predict flood water surface elevations at approximately evenly spaced cross-sections, oriented perpendicular to the predominate flow direction and distributed throughout the modeled reach. The predicted water surface elevations are then compared to the elevation of the top of channel banks and of the floodplain (and buildings) to determine flood break-out points and outline the extent and depth of flood water for various flood flow recurrence intervals (i.e. 10-year, 100-year flows).

San Luis Obispo Creek Stage Gages and Updated Cross-Sections

In November 2001, five stage gages were installed by the County within the SLO Creek watershed.
New cross-section surveys were conducted in July 2006 at the five County stage gage locations. The cross-sections were taken in the same vertical plane as the gage sensor attached to the bridge on the downstream side at each location. **Figure 5** shows a comparison of cross-sections from the original LIDAR 2001 aerial topographic data with the 2006 field surveys.

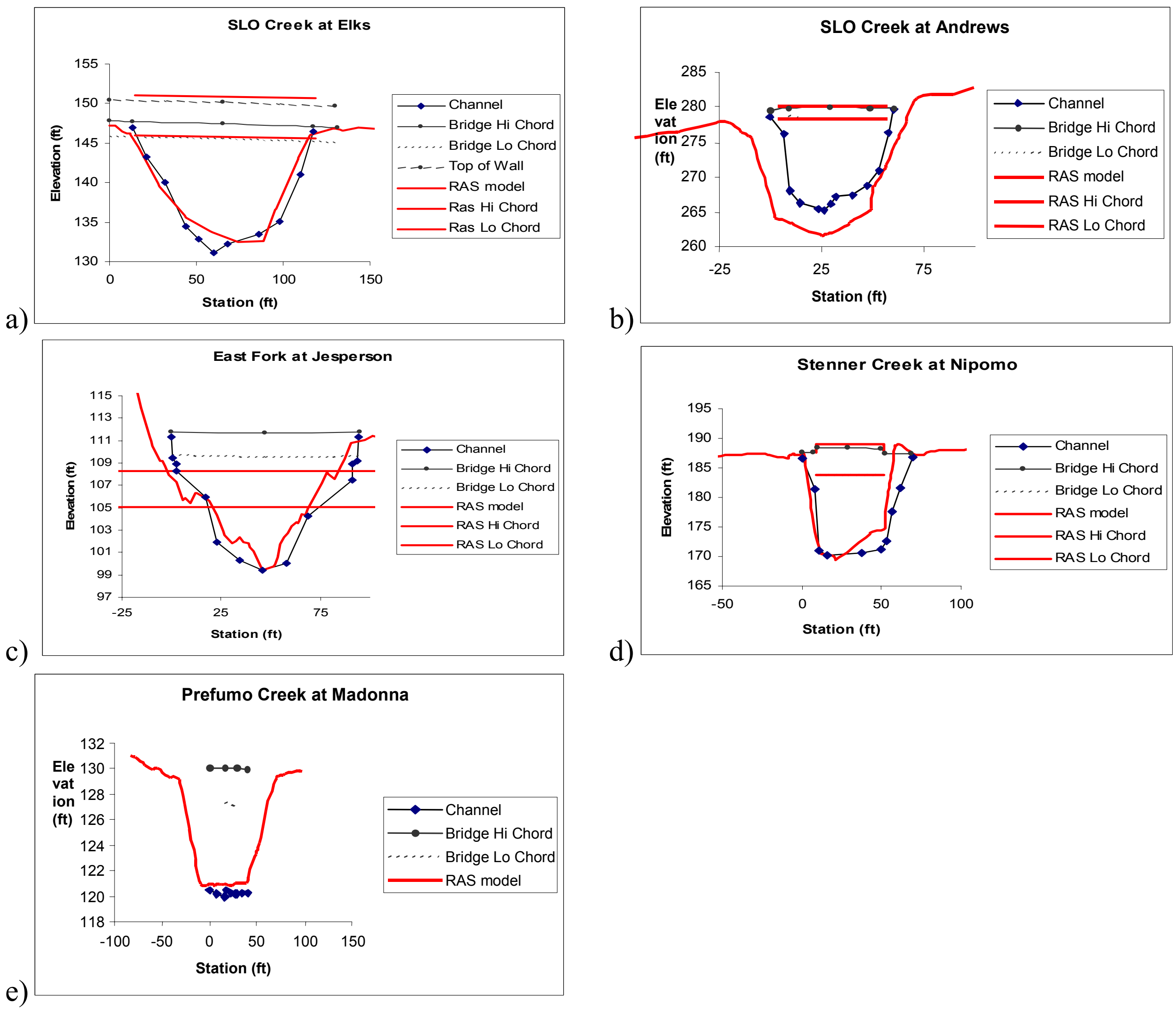


Figure 5. Cross-sections at County stage gage locations with red lines showing LIDAR data used for the existing hydraulic model and blue lines showing 2006 survey data, which was used to update the hydraulic model: a) Elks Lane Bridge over SLO Creek b) Andrews Street Bridge over SLO Creek c) Jesperson Road Bridge over East Fork of SLO Creek d) Nipomo Street Bridge over Stenner Creek e) Madonna Road Bridge over Prefumo Creek.

At Elks Lane, Nipomo Street and Madonna Road, LIDAR and surveyed cross-section thalweg elevations generally matched. At Andrews Street Bridge, while the high and low chords of the bridge matched, the channel bottom was higher for the surveyed cross-section. This may be due to the cross-section cut from LIDAR data being situated further downstream than the surveyed cross-section, i.e., the 2006 survey mapped a smaller cross-sectional area since it was taken closer to the bridge outlet.

In the Jesperson Road graph, the LIDAR cross-section shows a much lower bridge deck than the more recent surveys. This was likely due to datum uncertainty; all crossing data for the East Fork of SLO Creek was originally taken from a Boyle Engineering hydraulic model with an unknown vertical datum.

The updated survey information was input to provide better cross-section data to the hydraulic model for the development of stage-discharge curves at each County gage.

Stage-Discharge Curves

Stage-discharge curves provide a method of converting stage gage water depth readings to channel flow quantities. A large range of flows (up to 12,000 cfs) was run through the hydraulic model to generate stage-discharge curves at each of the County gage locations.

A sensitivity analysis on the modeled roughness coefficients for each gage location was performed. Varying roughness coefficients by a value of 0.02 changed water surface elevations less than 0.3 ft. Original roughness coefficients for gage locations upstream and downstream of waterway crossings were retained to maintain consistency with roughness coefficients reported in the Waterway Management Plan. The sensitivity analysis showed that adjusting roughness coefficients would not have a significant impact on model calibration results.

These stage-discharge curves were converted to water surface elevation (WSE)-discharge curves to avoid any confusion between vertical datums. The water surface elevations are given in NAVD 88 feet vertical datum. **Figure 6** shows the WSE-discharge curves for the County gages. The curves and associated data are also included in **Appendix A**.

Regression equations were developed for each WSE-discharge curve, and stage gage readings could be readily converted to discharge quantities.

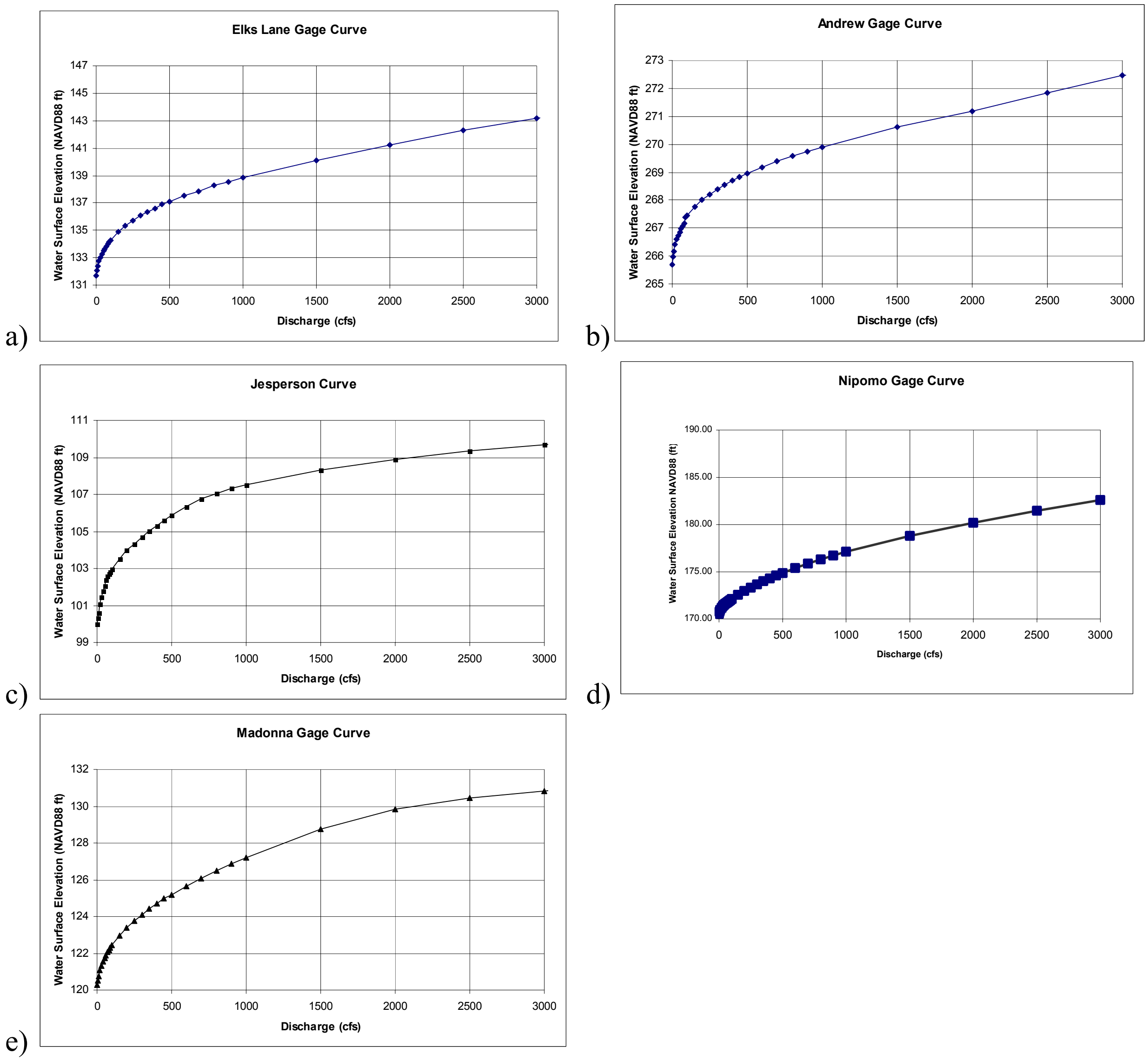


Figure 6. WSE-discharge curves for County stage gages: a) Elks Lane Bridge over SLO Creek b) Andrews Street Bridge over SLO Creek c) Jesperson Road Bridge over East Fork of SLO Creek d) Nipomo Street Bridge over Stenner Creek e) Madonna Road Bridge over Prefumo Creek.

Model Calibration

To calibrate the model, outflow hydrographs from the hydrology model were compared to stage gage hydrographs. Both sets of hydrographs covered the 5-day rain event from December 27, 2004 to December 31, 2004, with the hydrology model incorporating the December 2004 storm as a precipitation component employing OneRain historical radar rainfall data, and the County stage gage hydrographs reflecting discharge conversions from actual stage heights measured in-stream during the December 2004 storm event.

County High Water Marks

During the December 2004 storm event, County staff measured high water levels just following peak rainfall intensities on December 30. These high water marks serve as a check on the accuracy of the stage gages at this specific "snapshot" in time. **Figure 7** shows the high water marks in red at the time they were taken.

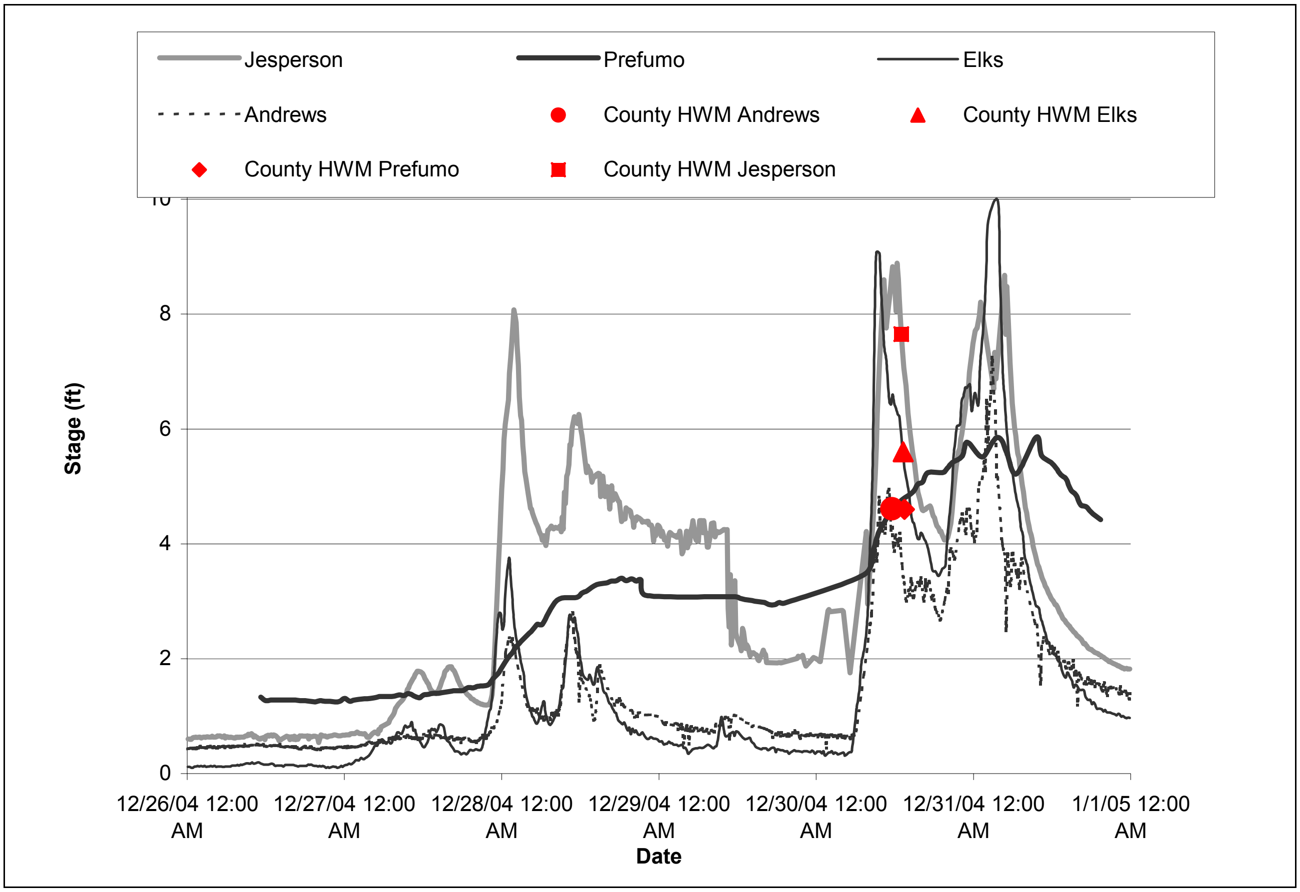


Figure 7. Stage gage output and corresponding County high water marks during the December 2004 storm.

The measured high water marks correspond well to the recorded stage gage hydrographs, with high water marks matching the stage heights measured by the gages on December 30th, 2004. Thus, stage gage readings during the December 2004 storm event were used as calibration data for the SLO Creek Watershed models. No stage gage data was available at the Nipomo Street gage on Stenner Creek for the December 2004 storm event.

Calibration Technique and Results

In the hydrology model, the SCS loss-rate method requires input of infiltration properties of a basin as described by a runoff curve number and initial abstraction number. Initial abstraction defines the amount of precipitation that must fall before surface excess results. Without any calibration, the rainfall-runoff model gave fairly high runoff results. To achieve the best fit possible, the SCS curve number parameter was reduced by 30% across the entire model, and the initial abstraction parameter was increased by 30% across the entire model. These reductions are justified by the fact the original model assumed a saturated watershed before the design 24-hr storm event in March 1995 where the storm event followed several storm events (i.e. the watershed was already saturated). To mimic watershed conditions before the December 2004 storm, the watershed had to be assumed to be relatively dry (unsaturated); thus, reducing curve numbers and increasing initial abstraction numbers resulted in drier initial watershed conditions.

However, even after altering hydrology model input parameters, peak flow quantities predicted from the hydrology model were larger than those predicted by stage data. **Figures 8 through 11** show graphical comparisons of hydrographs predicted by the stage gage data and the hydrology model. Each figure shows a) discharge rates for the gage location over the 5-day storm event and b) water surface elevations for the gage location. For reference, the water surface elevation hydrographs also show the elevation of the bridge low chord.

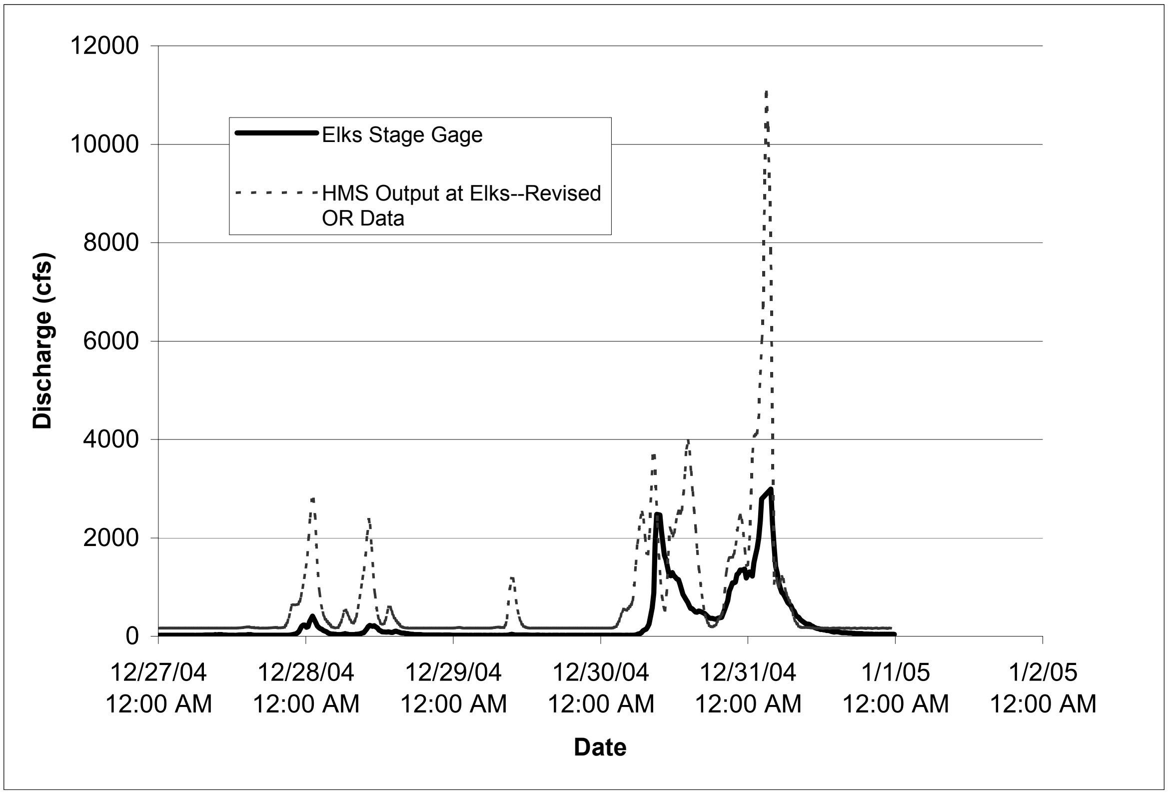
While peak flow rates predicted by the model tend to be greater than stage gage results, it is important to note that the hydrograph peaks generally coincided well with each other, i.e. though peak flow rates are different, the peaks occurred at the same times during the storm event. This demonstrates that routing and time lag input parameters for the model are matching real-world flow routing and timing as measured by the gages.

Also, discharge rates predicted by the hydrology model were all greater than the 20-year peak runoff events as categorized in the Waterway Management Plan, while discharge rates converted from stage gage data were all less than the 5-year event. This demonstrates that the existing hydrology model may have some limitations during smaller storm events. The calibration done for the Waterway Management Plan was to the March 1995 storm, a nearly 100-year event—modeled with all subbasins saturated before the major 24-hr rainfall event.

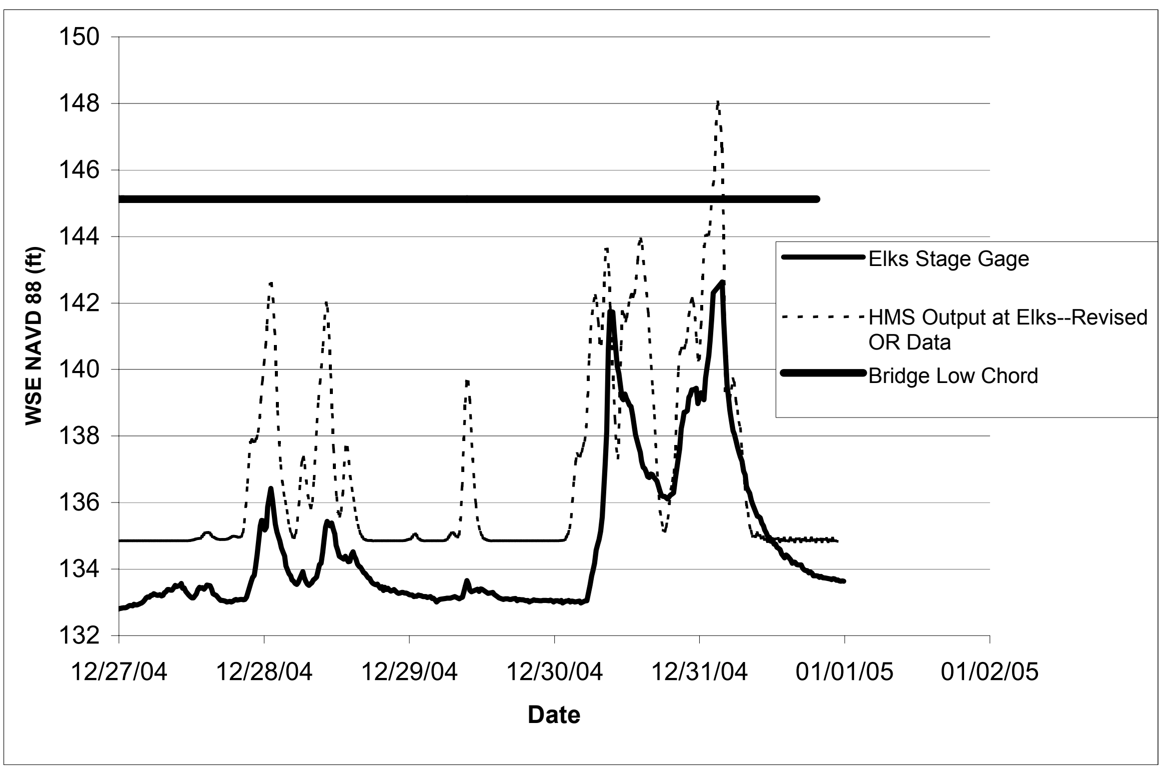
Thus, a more sophisticated subbasin infiltration scheme may be needed for smaller storm events, below 50- or even 20-year peak flow events, to more accurately describe un-saturated conditions before smaller storms. The HEC-HMS rainfall-runoff software does incorporate loss models that require variables specifying canopy interception, surface depression storage, groundwater, soil, conductivity. Also, a gridded subbasin scheme may allow for sub-basins to be further divided into smaller areas with individual infiltration properties per grid (CN or soil moisture accounting variables).

It should be noted that this current modeling effort was intended to compare field gage and model results for a specific storm event and to calibrate the watershed models based on that given storm event, not to fully update the existing hydrologic and hydraulic models. A full-scale effort to update the existing models would involve obtaining topographic data to ensure that current channel cross-sections, bridge chord elevations, and new development in the floodplain were accurately represented. Also, a review of sub-basin delineation, impervious area, infiltration parameters and baseflows would also be required to update watershed area characterization for the rainfall-runoff model.

In general, the existing hydrology and hydraulic models can be applied for planning purposes throughout the watershed, as the model would provide conservative design flows.

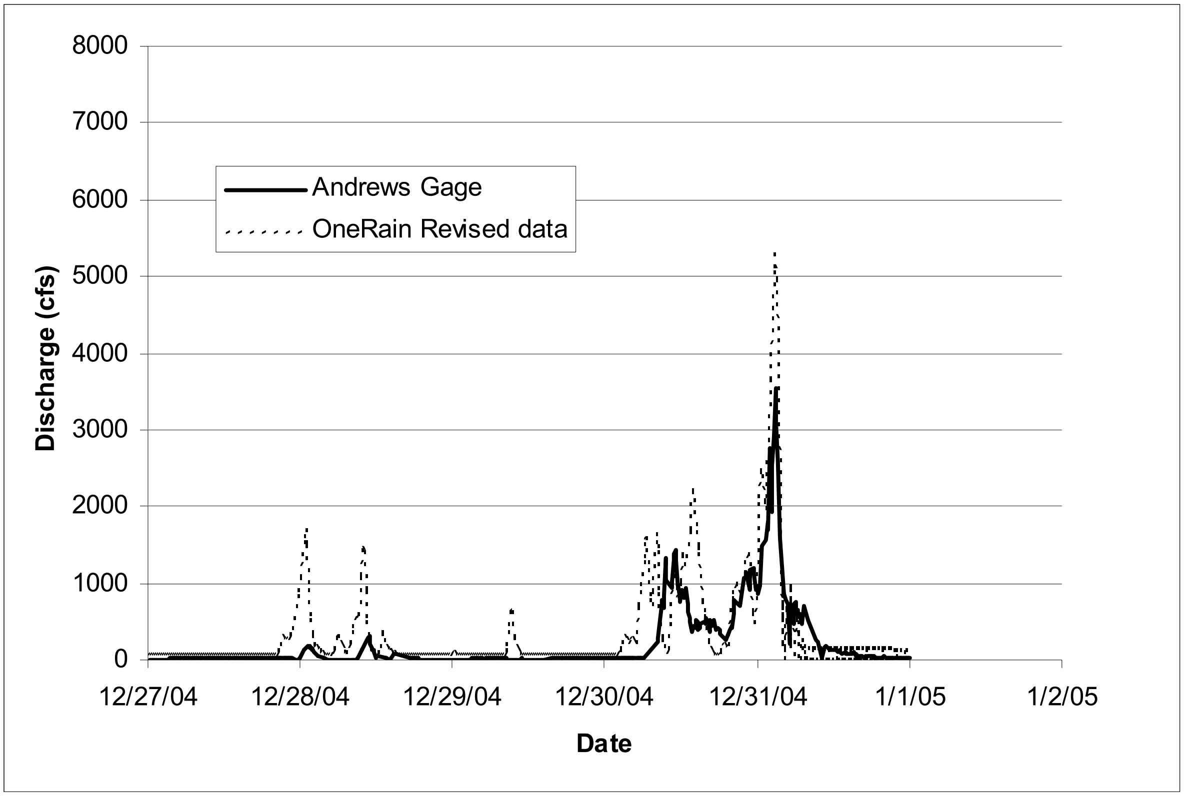


a)

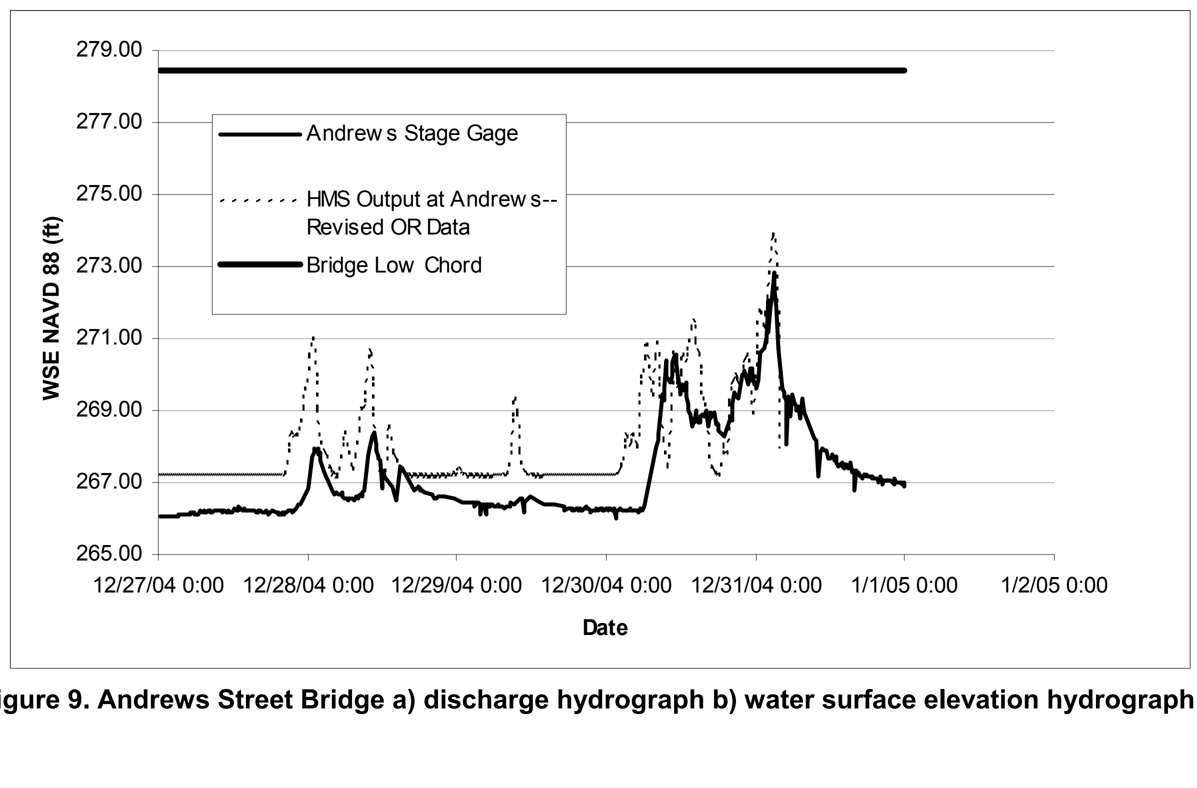


b)

Figure 8. Elks Lane Bridge Hydrographs. a) discharge hydrograph b) water surface elevation hydrograph



a)



b)

Figure 9. Andrews Street Bridge a) discharge hydrograph b) water surface elevation hydrograph

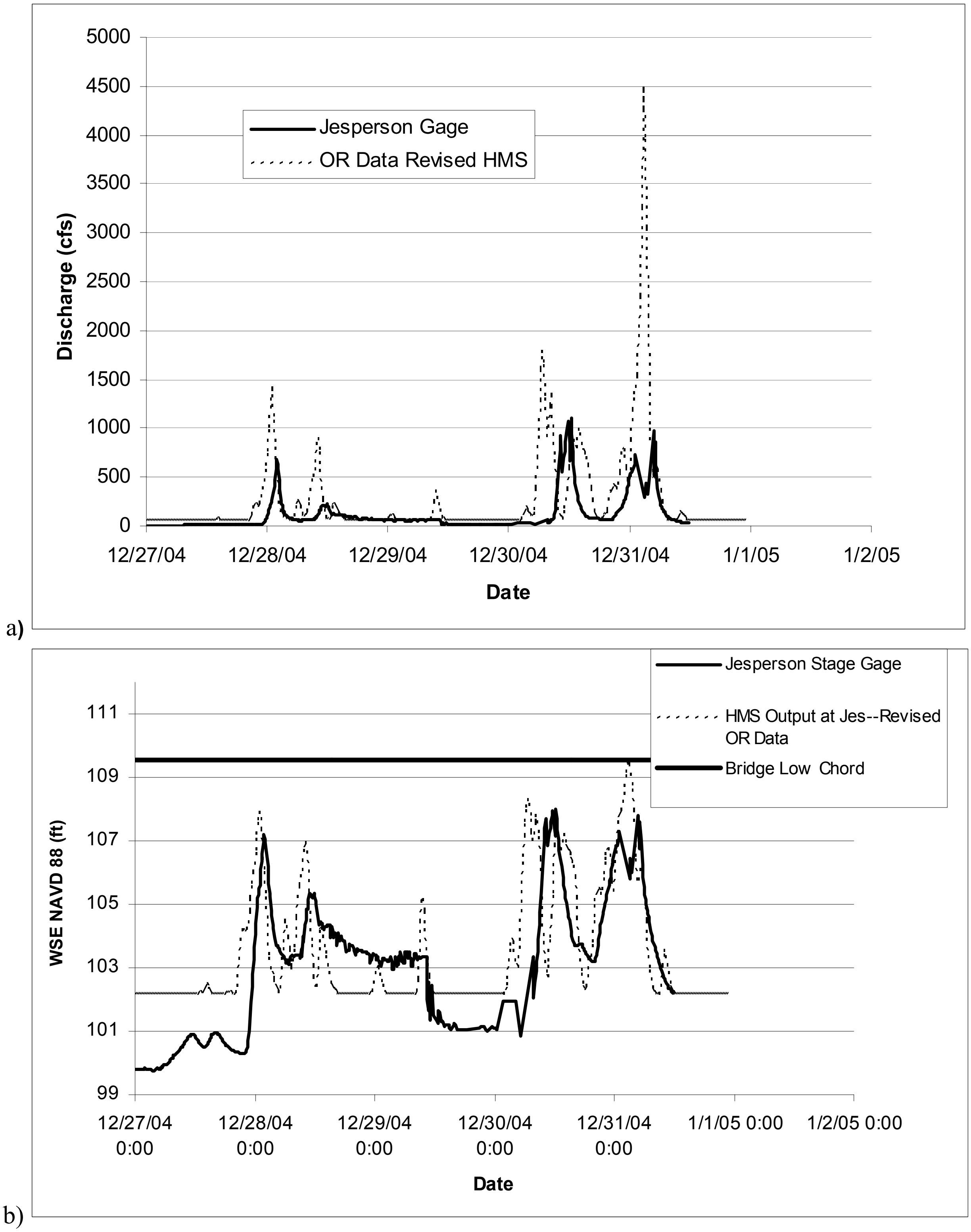
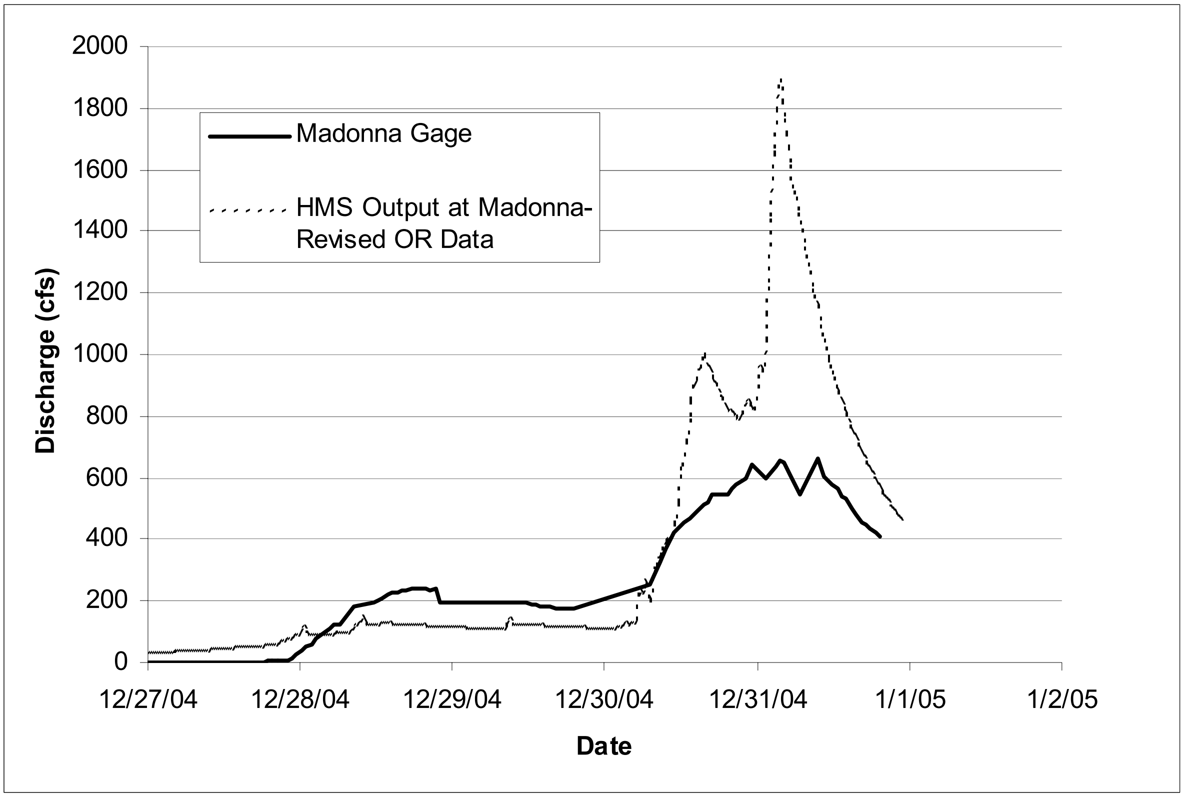


Figure 10. Jesperson Road Bridge a) discharge hydrograph b) water surface elevation hydrograph

a)


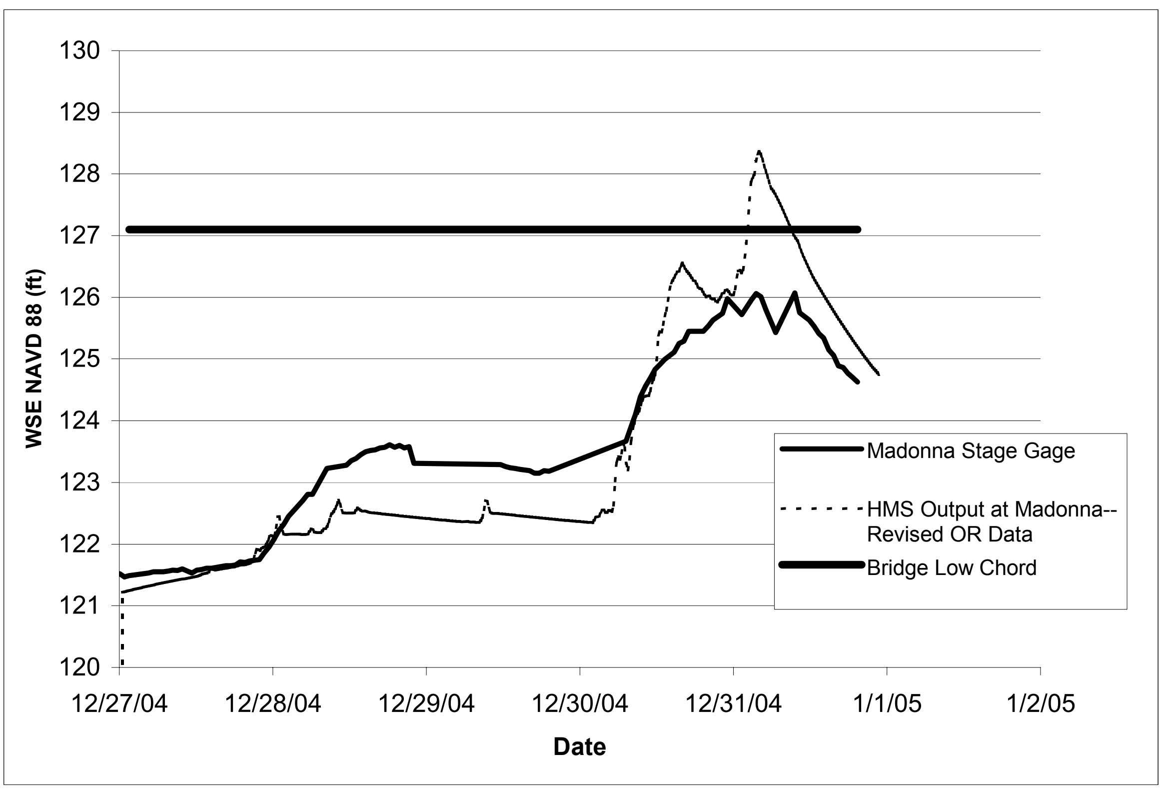
b)


Figure 11. Madonna Road Bridge a) discharge hydrograph b) water surface elevation hydrograph

Conclusions

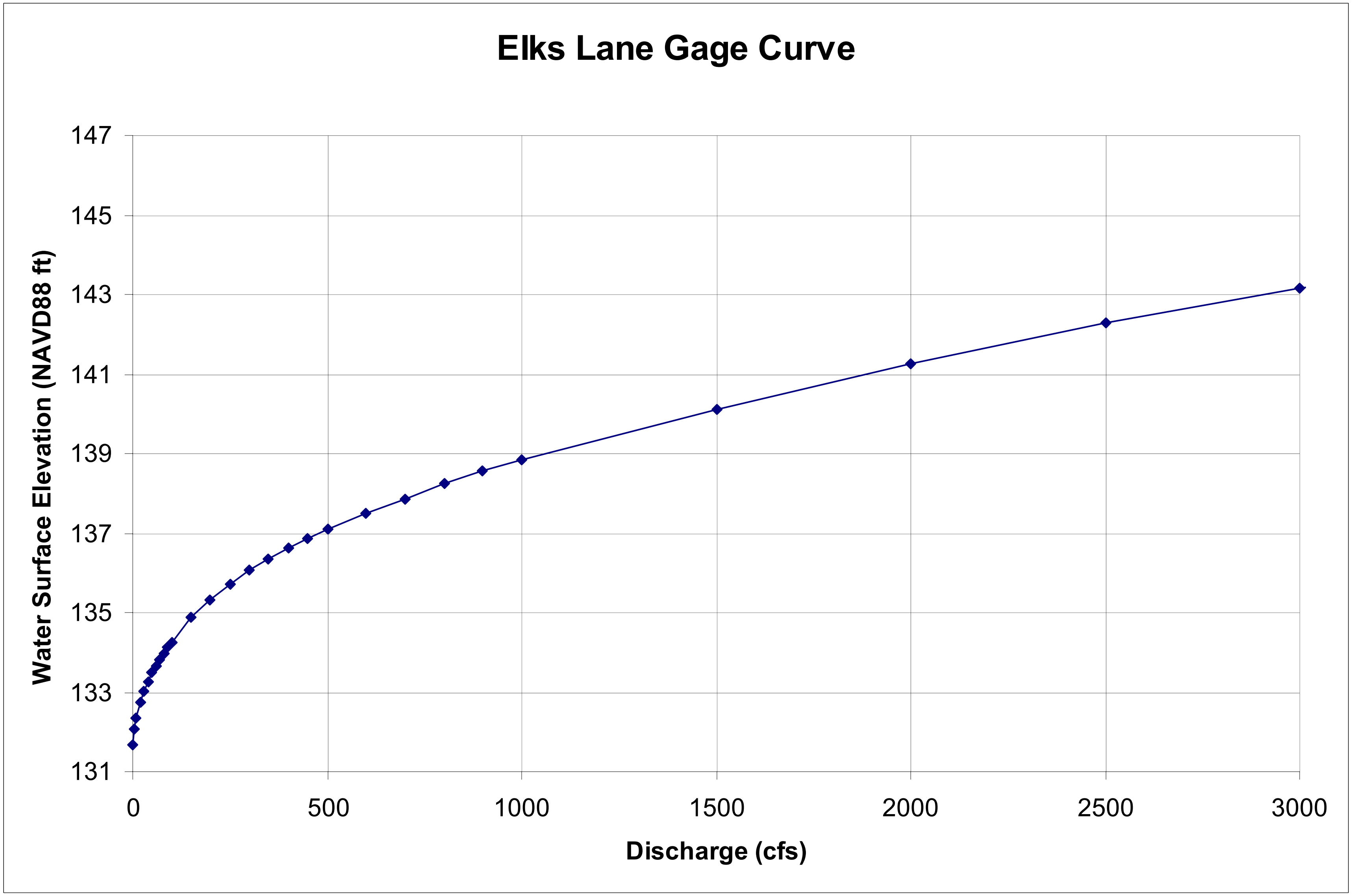
- The existing SLO Creek Watershed hydrology model may have some limitations during smaller storm events, as the hydrology model predicted greater peak flows rates than obtained from stage gage data;
- The first calibration was to the March 1995 storm, a nearly 100-year event—modeled with all subbasins saturated before the major 24-hr rainfall event, while this calibration study used stage gage data for a 2-year to 5-year peak flow event, with 50% more infiltration capacity in all sub-basins;
- A more sophisticated subbasin infiltration scheme may be needed for smaller storm events below the 50-year recurrence interval, to more accurately describe un-saturated conditions before smaller storms;
- Loss models should be considered that require more variables specifying canopy interception, surface depression storage, groundwater, soil, conductivity;
- A gridded subbasin scheme may allow for smaller areas with individual infiltration properties per grid (CN or soil moisture accounting variables) to provide more site-specific input parameter; and
- For planning purposes, the existing model provides conservative design flows.

Appendix A

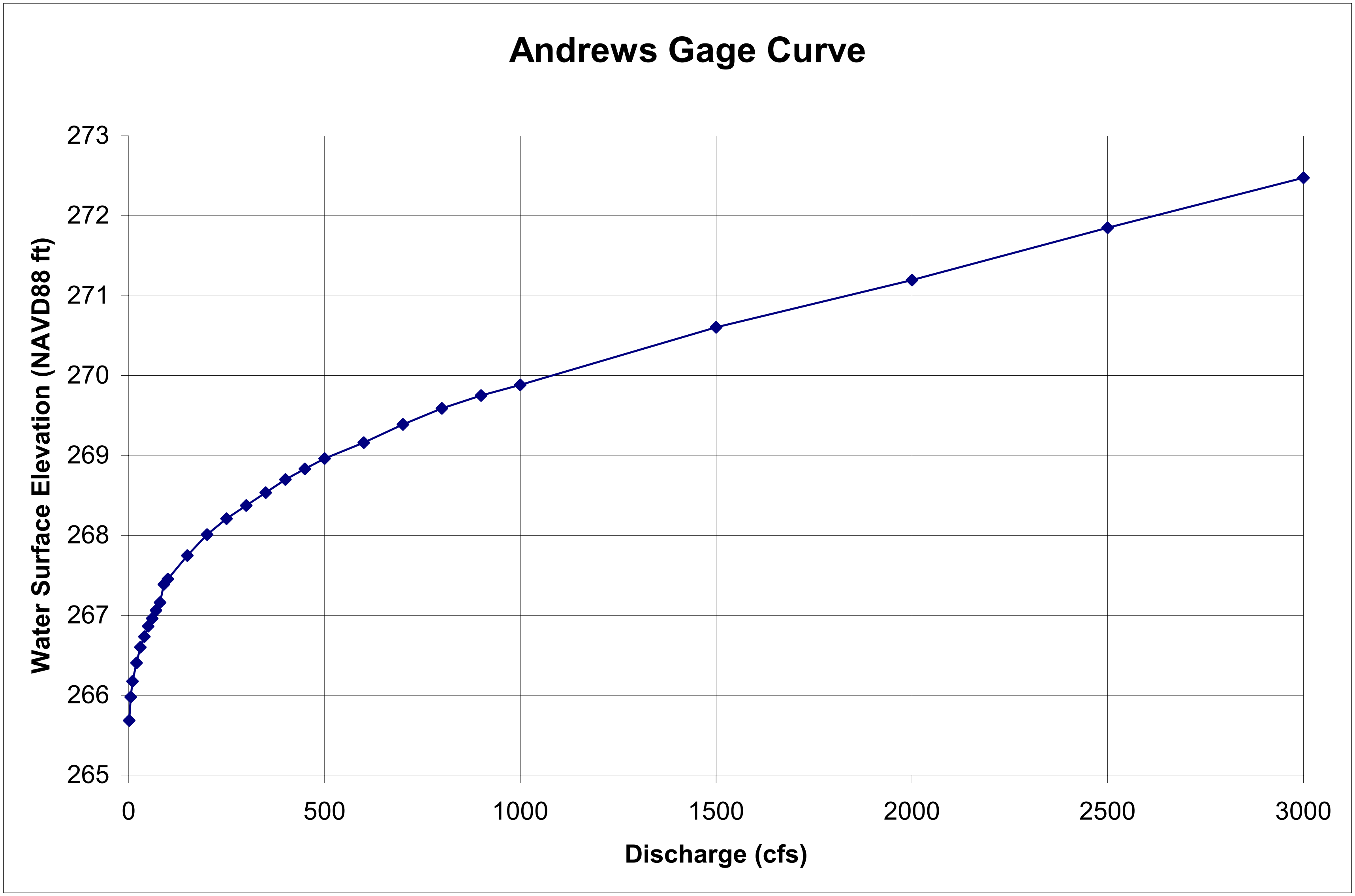
Water Surface Elevation-Discharge Curves for County Stage Gage Locations

Table A.1 WSE-Discharge Curve Data

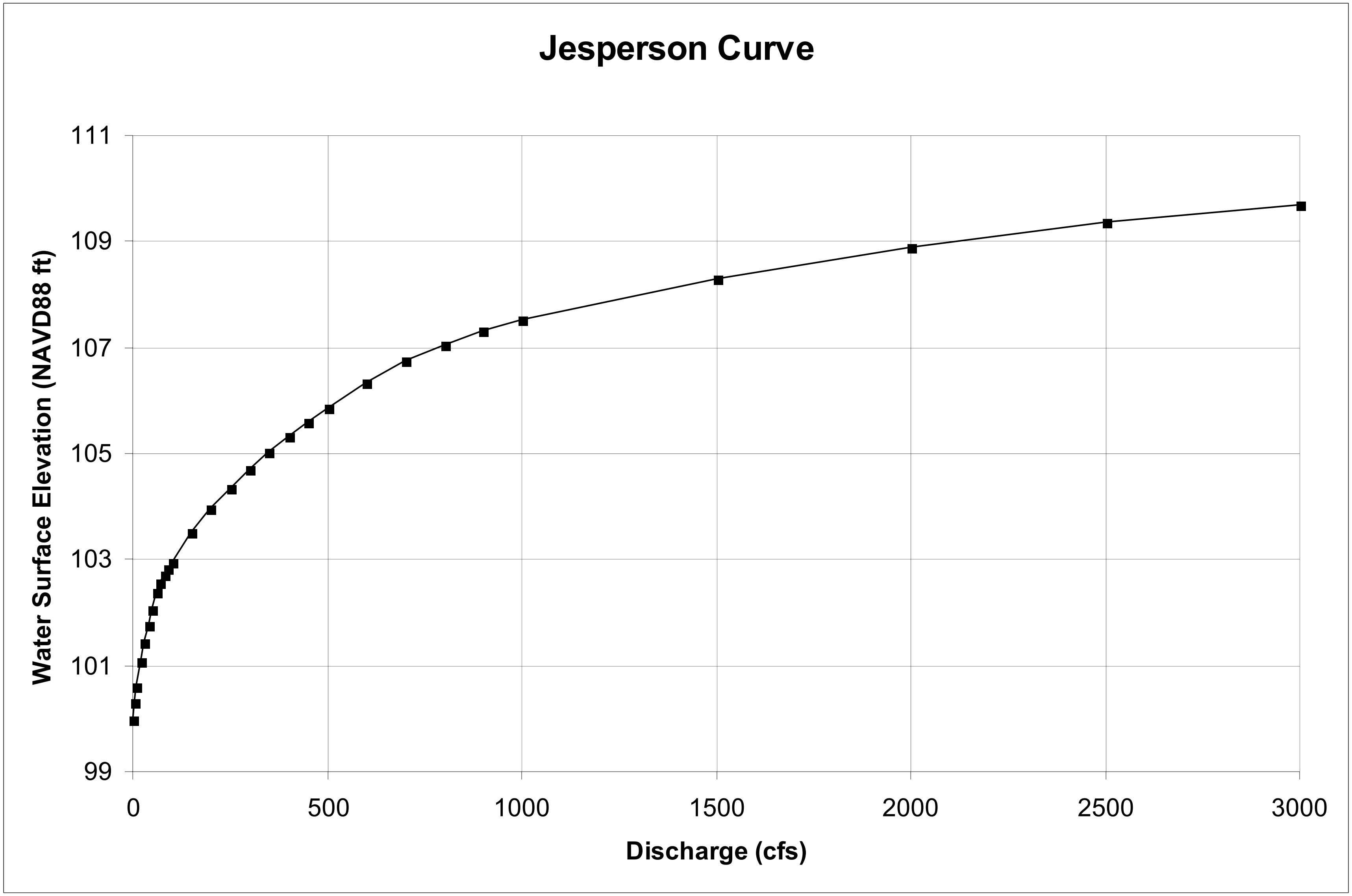
Discharge (cfs)	Water Surface Elevation (NAVD 88) feet				
	Elks Lane Gage	Andrews Street Gage	Jesperson Road Gage	Madonna Road Gage	Nipomo Street Gage
1	131.69	265.68	99.97	120.28	170.52
5	132.09	265.98	100.30	120.51	170.75
10	132.35	266.17	100.59	120.73	170.95
20	132.74	266.40	101.08	121.06	171.18
30	133.04	266.60	101.45	121.33	171.34
40	133.27	266.73	101.77	121.52	171.48
50	133.50	266.86	102.07	121.72	171.61
60	133.66	266.96	102.40	121.88	171.70
70	133.83	267.06	102.56	122.01	171.80
80	133.99	267.16	102.73	122.15	171.90
90	134.12	267.39	102.82	122.28	172.00
100	134.25	267.45	102.95	122.41	172.10
150	134.88	267.75	103.51	122.93	172.56
200	135.33	268.01	103.97	123.36	172.95
250	135.73	268.21	104.33	123.72	173.31
300	136.06	268.37	104.69	124.05	173.67
350	136.35	268.54	105.02	124.31	174.00
400	136.61	268.70	105.32	124.57	174.30
450	136.88	268.83	105.58	124.84	174.59
500	137.11	268.96	105.87	125.07	174.85
600	137.50	269.16	106.33	125.49	175.38
700	137.86	269.39	106.76	125.89	175.87
800	138.25	269.59	107.06	126.25	176.30
900	138.55	269.75	107.32	126.57	176.72
1000	138.85	269.88	107.52	126.87	177.12
1500	140.12	270.60	108.30	128.05	178.79
2000	141.24	271.19	108.89	128.71	180.20
2500	142.29	271.85	109.35	129.20	181.45
3000	143.14	272.47	109.68	129.63	182.60
3500	143.73	272.60	109.94	129.95	183.68
4000	144.26	273.13	110.21	130.28	184.43
4500	144.72	274.11	110.34	130.58	185.09
5000	145.11	274.61	110.47	130.84	185.68
5500	145.47	275.07	110.57	131.10	186.27
6000	145.73	275.52	110.70	131.33	186.67
6500	146.00	275.98	110.76	131.53	186.99
7000	146.19	276.41	110.80	131.76	187.32
8000	146.52	277.33	110.76	132.15	187.98
9000	146.85	278.90	110.66	132.51	188.77
10000	147.11	279.49	110.80	132.87	189.65

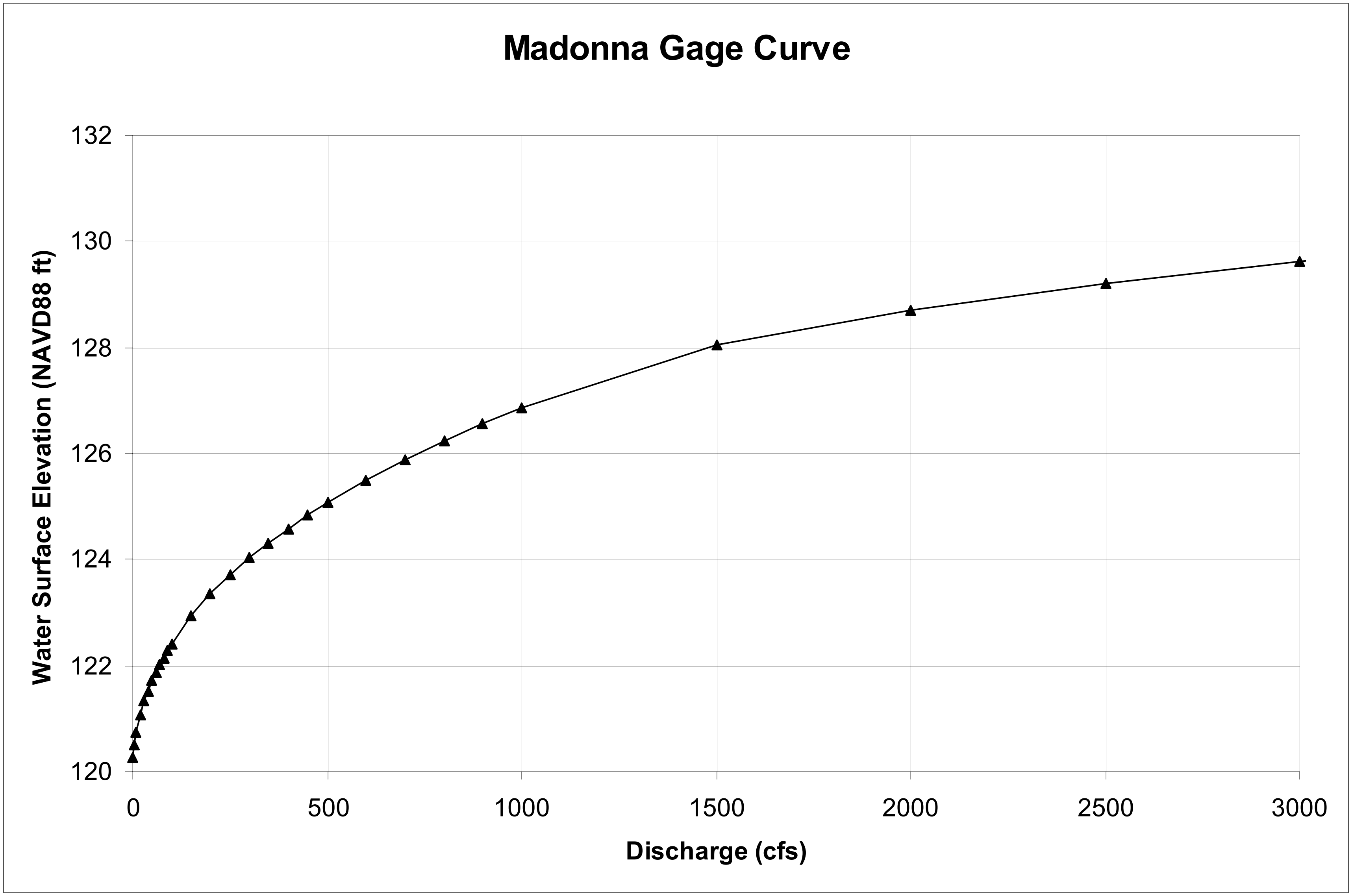


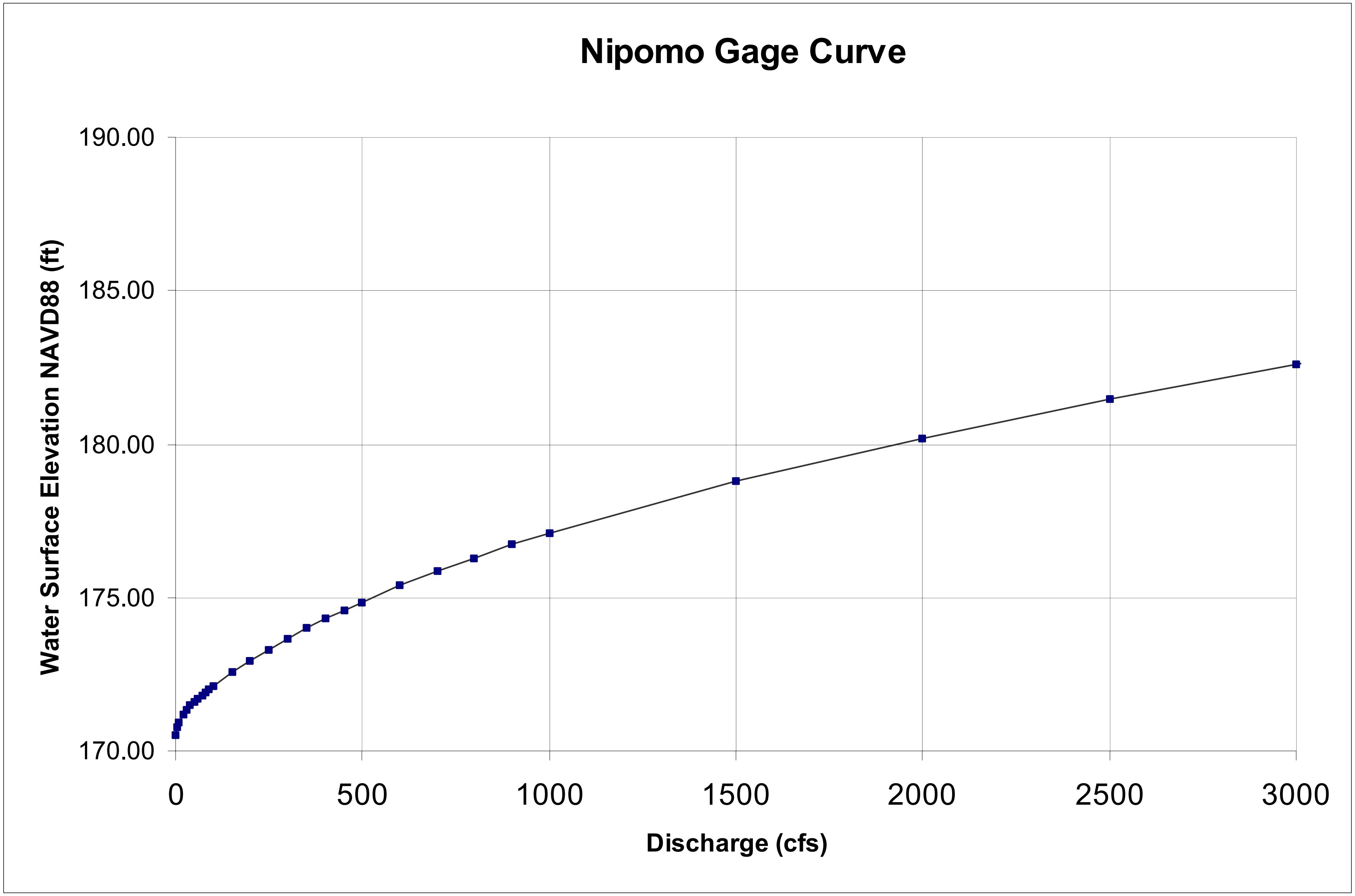
Elks Lane Gage Curve
147
145
143
141
139
137
135
133
131
Water Surface Elevation (NAVD88 ft)
0
500
1000
1500
2000
2500
3000
Discharge (cfs)



Andrews Gage Curve
Water Surface Elevation (NAVD88 ft)
273
272
271
270
269
268
267
266
265
0
500
1000
1500
2000
2500
3000
Discharge (cfs)


Jesperson Curve
Water Surface Elevation (NAVD88 ft)
111
109
107
105
103
101
99
0
500
1000
1500
2000
2500
3000
Discharge (cfs)


Madonna Gage Curve
132
130
128
126
124
122
120
0
500
1000
1500
2000
2500
3000
Water Surface Elevation (NAVD88 ft)
Discharge (cfs)


Nipomo Gage Curve
190.00
185.00
180.00
175.00
170.00
Water Surface Elevation NAVD88 (ft)
0
500
1000
1500
2000
2500
3000
Discharge (cfs)