TECHNICAL MEMORANDUM

Merced River Watershed: Climate Change Impact Report

PREPARED FOR:

MERCED IRRIGATION DISTRICT
WATER & POWER

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EXECUTIVE SUMMARY

To assess how the Merced Irrigation District (MID) could be impacted by changes in future climate, Dewberry performed a two-part analysis using both historical data and future projections. In the first part of the analysis, a stationarity analysis using change point and trend tests was conducted on long-record gages measuring *historical* temperature, snow water equivalent, precipitation and streamflow. For the second part of the analysis, a precipitation-runoff model from the Merced Irrigation District Hydrologic and Hydraulic Optimization (MIDH2O) model was run for three future scenarios based on projections from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) for short term impacts (Year 2035), as summarized by findings in the California Department of Water Resources "California Climate Science and Data for Water Resources Management report", June 2015. The scenarios were: Low (T+3° F), Intermediate (T+5° F) and High (T+10° F) warming. All future simulations were compared to the historical "baseline" simulation, which was derived from the climatologically average 1998-1999 Water Year. The main objective was to quantify changes in the timing and magnitude of the snowpack and ensuing runoff.

Major findings of Part 1 (Stationarity Analysis) include:

- There has been a very strong decrease in the number of days that with a minimum temperature below 32°F, both at lower and higher elevations. The decrease in nights with freezing temperatures was widespread across the watershed. Specifically, 15 out of the 23 stations (65%) showed a decrease in days below freezing.
- There was a weak increase in very hot summer days where high temperatures exceed 90° F.
- The Julian day of maximum SWE showed a weak negative trend implying the peak snowpack is occurring earlier in the year.
- There was a weak negative trend was peak flow. Spatially, the decreases in peak flow were homogenous across the region. There are more sites showing a decrease in peak flow than showing an increase, which could be associated with changes in the hydrological conditions during the springtime peak flow season.

To explore the implications of how streamflow could change in a projected warmer future climate, a precipitation-runoff model using HEC-HMS version 4.2 was developed for the Merced River watershed. The WY1999 was selected as the reference "baseline" year, given that this year produced precipitation near climatological averages across the Merced River Watershed. The model was forced with precipitation and temperature data derived from the available meteorological stations in the watershed.

For precipitation data, 12-hour period average values, in a Standard Hydrologic Grid (SHG) format, were used. For temperature, hourly gridded data was developed using a second-order polynomial approximation to observed hourly data. For future scenarios, temperature grids were modified by adding a constant temperature change of up to 10° F across the entire watershed, as a function of season. These were used as input into the HEC-HMS model projections of New Exchequer Dam inflow under warmer conditions. The precipitation input was not changed, although the HEC-HMS model in the snowmelt computation routine adjusted the snow level internally to higher elevation based on the temperature grids.

Major findings of Part 2 (Future Projections) include:

- There were large differences in the timing of the peak flow. For example, even with a relatively low warming of 2-3°F ("T+3" scenario), maximum discharge occurs at least 1 month earlier than the base case.
- There were large differences in the peak flow during precipitation events. With increased temperature more precipitation falls as rain than snow. Since, the watershed responds much quickly to rainfall than snow, higher immediate runoff generated increases chances of winter and early-spring flooding.
- Conversely, the peak runoff during the melt season (April to July) is reduced as the snowpack becomes smaller, and the snowmelt starts earlier in the season. The April – July runoff volume decreased by 11%, 14%, and 34% in the three scenarios compared to the base condition.
- As more of the precipitation occurred as rainfall, there was a significant reduction in the snow water equivalent and the snow-covered areas in the watershed.
- With increased temperatures, the snow-covered areas recede to higher elevation.

An important disclaimer is that this study did not analyze the likelihood of any of the scenarios and thus makes no judgment regarding the chances of any scenario as being the most likely.

1.0 INTRODUCTION

To assess how the Merced Irrigation District (MID) could be impacted by changes in future climate, Dewberry performed a two-part analysis using both historical data and future projections. In the first part of the analysis, a stationarity analysis using change point and trend tests was conducted on long-record gages measuring *historical* temperature, snow water equivalent, precipitation and streamflow. For the second part of the analysis, a precipitation-runoff model from the Merced Irrigation District Hydrologic and Hydraulic Optimization (MIDH2O) model was run for three different modeling scenarios to reflect the results of Phase 5 of the Coupled Model Intercomparison Project (CMIP5) for short term impacts (Year 2035) (guided by findings in the California Department of Water Resources "California Climate Science and Data for Water Resources Management report", June 2015; hereafter referred to as CA-DWR Report).

2.0 STATIONARITY ANALYSIS

Trend analyses on the Annual Maximum Series (AMS) of several meteorological variables were completed for the Merced River Watershed to investigate whether non-stationarity exists. The hydrology-related variables tested were peak daily discharge, 24, 48, 72 and 96-hour accumulated precipitation, peak snow water equivalent (SWE) and the date of the peak SWE. In addition, the temperature-related variables tested were the annual days when maximum temperatures were greater than 90°F and annual days when minimum temperatures were less than 32°F. Table 1 shows a summary of all variables.

Table 1: Variables used in stationarity analysis

Temperature
Days > 90°F
Days < 32°F
Precipitation
24-hour total
48-hour total
72-hour total
96-hour total
Snow Water Equivalent (SWE)
Max SWE
Date of Max SWE
Streamflow
Peak Daily Discharge

Quality controlled daily station data was collected from several networks in and around the Merced River Watershed. Figure 1 shows all gages from which data were collected, which were further filtered with a quality control check before use in the trend analyses. The primary data sources were:

- National Centers for Environmental Information (NCEI) - https://www.ncei.noaa.gov
- United States Geological Survey (USGS) - https://waterdata.usgs.gov/ga/nwis/rt
- Flood Emergency Response Information Exchange (FERIX) - http://ferix.water.ca.gov/webapp/home.jsp
- National Resources Conservation Service (NRCS) - https://www.wcc.nrcs.usda.gov

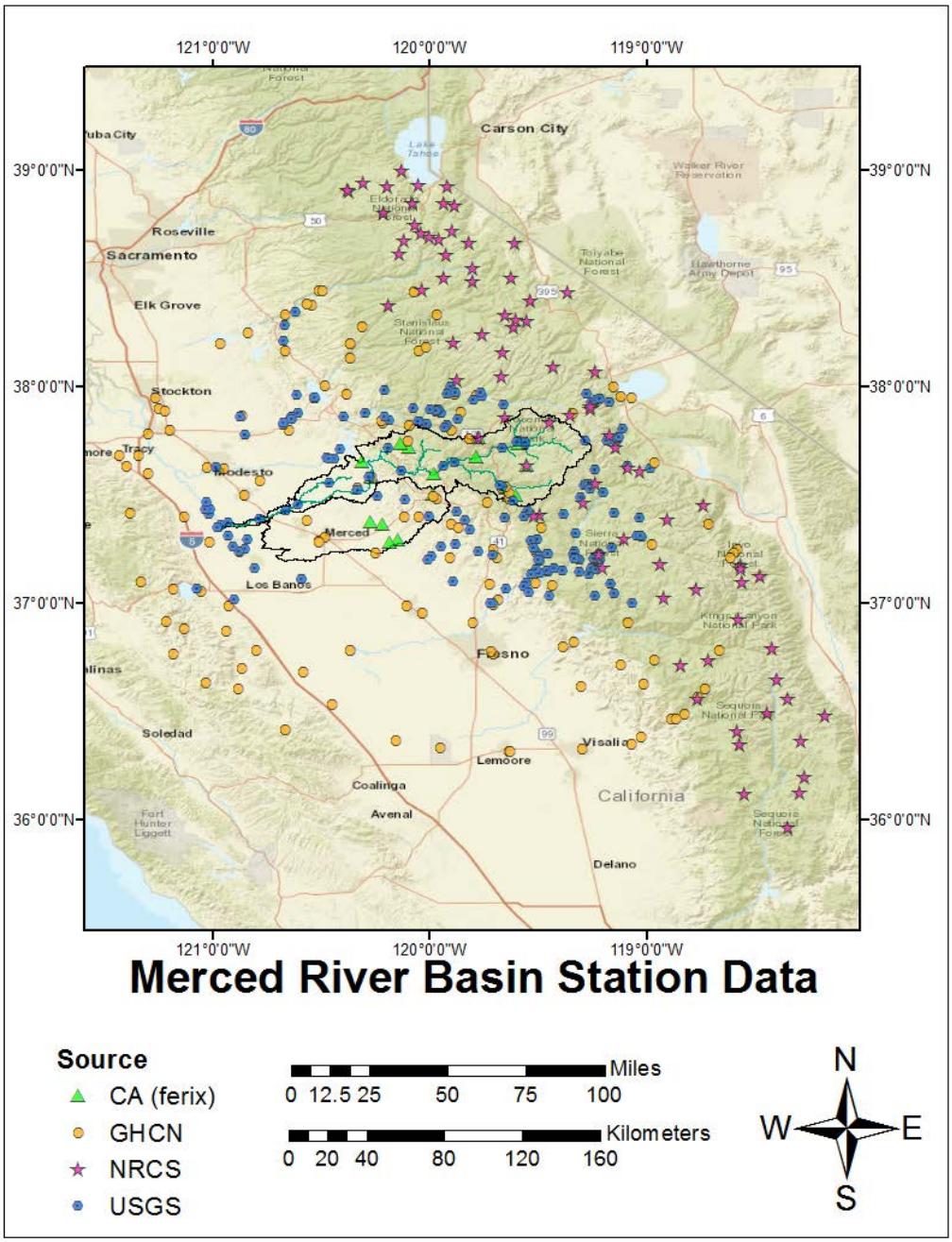


Figure 1: Location of meteorological station

The following three qualifications were used to ensure necessary data coverage for inclusion in the trend analyses:

- Years with more than 10 missing days were excluded,
- Only stations with a qualifying year after 2000 were included,
- The minimum number of qualifying years was 40 (though note that these did not have to be consecutive years) for all variables except 30 for SWE.

For the SWE-related trend analyses, only one station was eligible after the applications of the qualifications listed in the previous page. In order to qualify more stations for use in these trend analyses, the minimum record length was reduced to 30 years, which resulted in 11 qualifying stations. The final list of stations used for the trend analyses is listed in Table 2.

Table 2: Summary of qualifying gages

ID	Name	Source	Lat	Lon	Elevation (ft)	Variable Tested
ALP	ALPHA	NRCS	38.81	-120.22	7600	SWE
USC00040343	ASH MOUNTAIN CA US	GHCN	36.49	-118.83	1708	P, T
USC00040379	AUBERRY 2 NW CA US	GHCN	37.09	-119.51	2090	P, T
USC00040449	BALCH POWER HOUSE CA US	GHCN	36.91	-119.09	1735	P
11284400	BIG C AB WHITES GULCH NR GROVELAND CA	USGS	37.84	-120.18	2587	SF
11237000	BIG C BL HUNTINGTON LK CA	USGS	37.22	-119.21	6630	SF
USC00040755	BIG CREEK PH 1 CA US	GHCN	37.21	-119.24	4878	P, T
356	BLUE LAKES	NRCS	38.61	-119.92	8067	SWE
USC00041277	CALAVERAS BIG TREES CA US	GHCN	38.28	-120.31	4695	P, T
USC00041428	CAMP PARDEE CA US	GHCN	38.25	-120.84	658	P, T
11278400	CHERRY C BL DION R HOLM PH NR MATHER CA	USGS	37.89	-119.97	2204	SF
11277300	CHERRY C BL VALLEY DAM NR HETCH HETCHY CA	USGS	37.97	-119.92	4404	SF
11278300	CHERRY C NR EARLY INTAKE CA	USGS	37.89	-119.96	2272	SF
USC00041697	CHERRY VALLEY DAM CA US	GHCN	37.97	-119.92	4765	P
462	EBBETTS PASS	NRCS	38.55	-119.80	8661	SWE
463	ECHO PEAK	NRCS	38.85	-120.08	7653	SWE
11278000	ELEANOR C NR HETCH HETCHY CA	USGS	37.97	-119.88	4500	SF
USC00042756	ELLERY LAKE CA US	GHCN	37.94	-119.23	9645	P
1	EXCHEQUER	NRCS	37.59	-120.27	805	P, SWE, T
473	FALLEN LEAF	NRCS	38.93	-120.05	6242	SWE
USW00093193	FRESNO YOSEMITE INTERNATIONAL CA US	GHCN	36.78	-119.72	333	P, T
USC00043261	FRIANT GOVERNMENT CAMP CA US	GHCN	37.00	-119.71	410	P, T
USC00043551	GRANT GROVE CA US	GHCN	36.74	-118.96	6600	P, T
508	HAGANS MEADOW	NRCS	38.85	-119.94	7742	SWE
USC00043747	HANFORD 1 S CA US	GHCN	36.32	-119.64	237	P, T
518	HEAVENLY VALLEY	NRCS	38.92	-119.92	8534	SWE
USC00043939	HETCH HETCHY CA US	GHCN	37.96	-119.78	3870	P, T
USC00044176	HUNTINGTON LAKE CA US	GHCN	37.23	-119.22	7020	P, T
USC00044705	LAKE SABRINA CA US	GHCN	37.21	-118.61	9065	P

P = Precipitation, SF = Streamflow, T = Temperature, SWE = Snow Water Equivalent

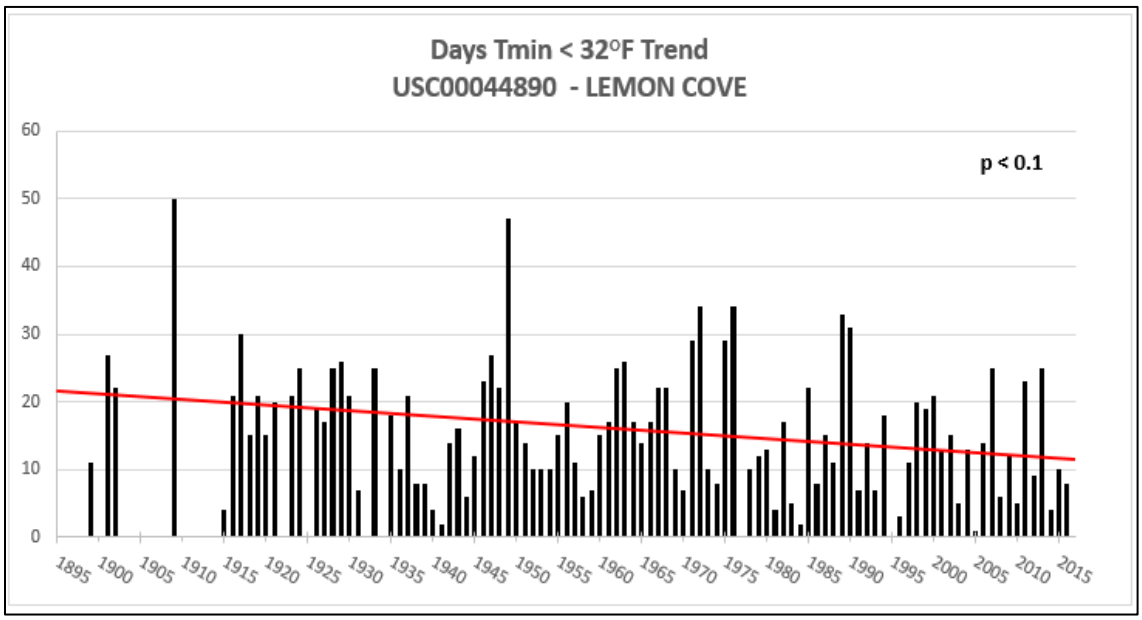
Table 2 (continued)

ID	Name	Source	Lat	Lon	Elevation (ft)	Variable Tested
575	LEAVEITT MEADOWS	NRCS	38.30	-119.55	7198	SWE
USC00044890	LEMON COVE CA US	GHCN	36.38	-119.03	513	P, T
USW00023110	LEMOORE REEVES NAS CA US	GHCN	36.33	-119.95	232	P
USC00045119	LOS BANOS ARBURUA RANCH CA US	GHCN	36.87	-120.94	843	P
11282000	M TUOLUMNE R A OAKLAND RECREATION CAMP CA	USGS	37.83	-120.01	2800	SF
USC00045233	MADERA CA US	GHCN	36.95	-120.04	270	P, T
11249500	MADERA CN A FRIANT CA	USGS	37.00	-119.71	554	SF
USC00045532	MERCED CA US	GHCN	37.29	-120.52	154	P, T
11264500	MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA	USGS	37.73	-119.56	4030	SF
11266500	MERCED R A POHONO BRIDGE NR YOSEMITE CA	USGS	37.72	-119.67	3862	SF
11270900	MERCED R BL MERCED FALLS DAM NR SNELL CA	USGS	37.52	-120.33	326	SF
11272500	MERCED R NR STEVINSON CA	USGS	37.37	-120.93	71	SF
USW00023258	MODESTO CITY CO AIRPORT CA US	GHCN	37.62	-120.95	73	P, T
11289000	MODESTO CN NR LA GRANGE CA	USGS	37.67	-120.47	287	SF
USC00046168	NEWMAN CA US	GHCN	37.28	-121.02	90	P, T
11244000	NF WILLOW C NR BASS LAKE CA	USGS	37.29	-119.53	3200	SF
11242400	NF WILLOW C NR SUGAR PINE CA	USGS	37.40	-119.57	5230	SF
USC00046252	NORTH FORK RANGER STATION CA US	GHCN	37.23	-119.51	2645	P
11301000	OAKDALE CN NR KNIGHTS FERRY CA	USGS	37.86	-120.63	348	SF
USC00046675	PANOCHE 2 W CA US	GHCN	36.61	-120.88	1400	P
11243500	PGE NO 3 CONDUIT NR BASS LAKE CA	USGS	37.29	-119.53	3178	SF
USC00046896	PINE FLAT DAM CA US	GHCN	36.82	-119.34	615	P
11237500	PITMAN C BL TAMARACK C CA	USGS	37.20	-119.21	7020	SF
697	POISON FLAT	NRCS	38.51	-119.63	7736	SWE
11235500	PORTAL POWERPLANT AT HUNTINGTON LAKE CA	USGS	37.26	-119.16	7000	SF
724	RUBICON 2	NRCS	39.00	-120.13	7619	SWE
11300500	S SAN JOAQUIN CN NR KNIGHTS FERRY CA	USGS	37.85	-120.64	363	SF
11261500	SAN JOAQUIN R A FREMONT FORD BRIDGE CA	USGS	37.31	-120.93	66	SF
11242000	SAN JOAQUIN R AB WILLOW C NR AUBERRY CA	USGS	37.14	-119.45	1175	SF
11274000	SAN JOAQUIN R NR NEWMAN CA	USGS	37.35	-120.98	69	SF
USC00047846	SAN LUIS DAM CA US	GHCN	37.05	-121.06	277	P, T
11281000	SF TUOLUMNE R NR OAKLAND RECREATION CAMP (	USGS	37.82	-120.01	2800	SF
USC00048380	SO ENTRANCE YOSEMITE N.P. CA US	GHCN	37.51	-119.63	5047	P, T
USC00048353	SONORA CA US	GHCN	37.97	-120.39	1675	P, T
USC00048406	SOUTH LAKE CA US	GHCN	37.17	-118.57	9580	P
778	SPRATT CREEK	NRCS	38.67	-119.82	6063	SWE
USW00023237	STOCKTON METROPOLITAN AIRPORT CA US	GHCN	37.89	-121.23	26	P, T
11290000	TUOLUMNE R A MODESTO CA	USGS	37.63	-120.98	58	SF
11276600	TUOLUMNE R AB EARLY INTAKE NR MATHER CA	USGS	37.88	-119.95	2441	SF
11276900	TUOLUMNE R BL EARLY INTAKE NR MATHER CA	USGS	37.88	-119.97	2286	SF
11276500	TUOLUMNE R NR HETCH HETCHY CA	USGS	37.94	-119.80	3430	SF
11289500	TURLOCK CN NR LA GRANGE CA	USGS	37.67	-120.44	268	SF
USC00049073	TURLOCK NUMBER 2 CA US	GHCN	37.50	-120.86	115	P
USC00049367	VISALIA CA US	GHCN	36.33	-119.30	303	P, T
USC00049582	WEST POINT CA US	GHCN	38.38	-120.55	2775	P
11246500	WILLOW C A MOUTH NR AUBERRY CA	USGS	37.15	-119.46	1175	SF
USC00049855	YOSEMITE PARK HEADQUARTERS CA US	GHCN	37.75	-119.59	4018	P, T

P = Precipitation, SF = Streamflow, T = Temperature, SWE = Snow Water Equivalent

Trends in AMS values were calculated using (i) Pearson and (ii) Spearman correlations. The latter is non-parametric and thus is less sensitive to outliers. All results are presented for the Spearman correlation method, though the Pearson correlation showed very similar results. For all variables except temperature, the Water Year was used to find the AMS. Figure 2 shows examples of a significant and non-significant trend test result.

The assumed Null Hypothesis was that there is no trend in any of these data sets. The probability that the Null Hypothesis is true is **ρ** and the probability the Null Hypothesis is false is 1 - **ρ**. Therefore, if **ρ** = 0.1, then there is a 90% chance that the Null Hypothesis is false and a trend exist. In the figures below **ρ** < 0.1 and **ρ** = 0.22, therefore there is more than 90% chance, and 78% chance that there is a trend. A commonly accepted statistical criteria is to accept that a trend exist if **ρ** < 0.1 thus rejecting the Null Hypothesis. For data sets with **ρ** > 0.1 we accept the Null Hypothesis and assume that the statistics do not show enough evidence to assume the trend is significant.



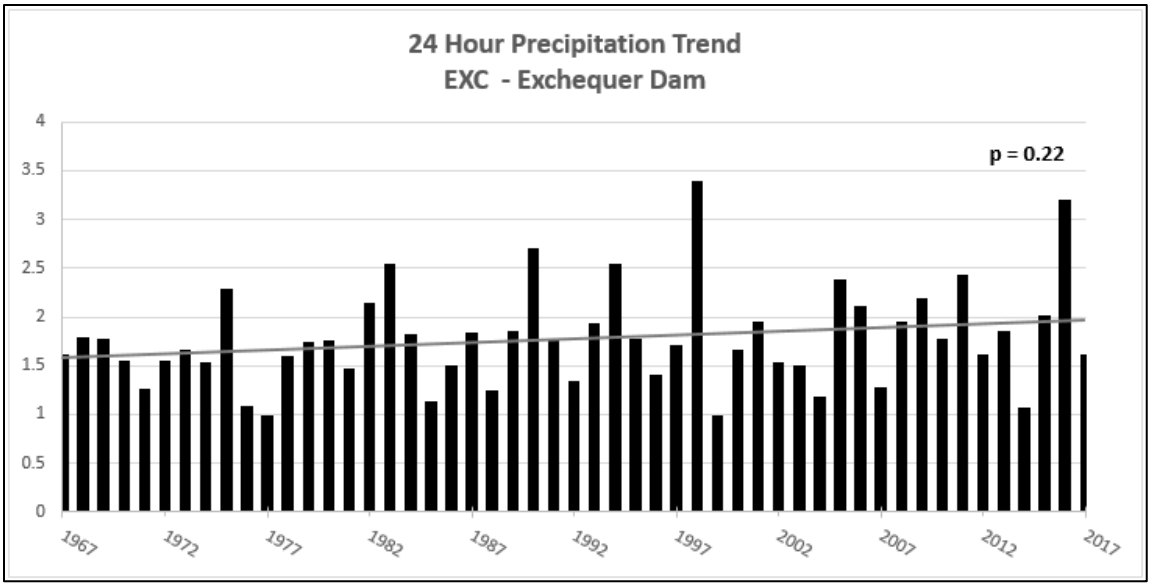


Figure 2: Example of trend test results showing (top) significant and (bottom) insignificant trend

The results of the trend analyses were examined from a quantitative and spatial perspective. Table 3 shows the summary of the trend test results. Spatial maps of trend test results are located in Appendix A.

Table 3: Results of the trend analyses based on meteorological variables

Precipitation Trends				
Total Stations: 35	24 hour	48 hour	72 hour	96 hour
Positive	1	1	0	0
Negative	2	2	1	1
None	32	32	34	34

Temperature Trends		
Total Stations: 23	Days > 90°F	Days < 32°F
Positive	8	1
Negative	9	15
None	6	7

Snow Water Equivalent		
Total Stations: 11	SWE	Julian Date of Max SWE
Positive	0	0
Negative	0	2
None	11	9

Peak Flow	
Total Stations: 34	SF
Positive	3
Negative	7
None	21

The most notable finding showing non-stationarity across Merced River Watershed was a very strong decrease in the number of days that are below 32°F, both at lower and higher elevations. Specifically, 15 out of the 23 stations (65%) showed a decrease in days below freezing. Interestingly, for days above 90°F, there are only marginal increases. However, spatially, there are significant positive trends at the lower elevation stations. The negative trends in days below 32°F are more evenly split between the lower and upper elevations (Appendix A, panel a).

There were two other variables that showed trends. The first is the Julian day of maximum SWE (Appendix A, panel h), which showed a weak negative trend implying the peak snowpack is occurring earlier in the year. As stated previously, the POR was reduced from 40 years to 30 years for this trend analysis in order to qualify more stations. Thus, the shorter record introduces more uncertainty, and caution is advised with the SWE results.

The other variable that showed a weak negative trend was peak flow. Spatially, the decreases in peak flow were homogenous across the region (Appendix A, panel i). There are more sites showing a decrease in peak flow than showing an increase, which could be associated with changes in the hydrological conditions during the springtime peak flow season.

3.0 PROJECTION OF FUTURE FLOWS IN A WARMER CLIMATE

To explore the implications of how streamflow could change in a potential warmer future climate, a precipitation-runoff model was developed for the Merced River watershed. Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) program version 4.2 was used. The WY1999 was selected as the reference "baseline" year, given that this year produced precipitation near climatological averages across the Merced River Watershed. The HMS model required two meteorological inputs: precipitation and temperature. For precipitation, 12-hour period average values were input into the model, derived from 9 hourly, and 12 daily precipitation gages in and near the watershed (David Ford Consultants, 2016).

For temperature, hourly grids were developed using the CA-DWR stations shown in Table 4. Appendix B outlines manual quality control procedures that were undertaken before developing temperature grids. Overall, data completeness was considered very adequate, with at least 3 stations available 100% of the time, at least 5 stations 86% of the time and at least 7 stations 80% of the time. A three-hour running average was applied to each site's temperature time series to smooth out potentially localized temporal and spatial spikes that may not have been indicative of the broader area.

Table 4: Hourly temperature gages used to develop terrain dependent hourly temperature grids across the MID watershed

Station Name	Station ID	Elevation (feet)	% Data Completeness
Crane Flat Lookout	CFL	5,957	65%
Dudley Ranch (Coulterville)	DUC	3,654	83%
Exchequer Dam	EXC	651	99%
Gin Flat	GIN	7,050	6%
Mariposa Grove	MPG	6,400	76%
Mariposa Ranger Station	MRP	2,250	95%
Merced River near Briceburg	MBB	1,150	32%
Ostrander Lake	STR	8,200	91%
Snow Flat	SNF	8,700	4%
Tenaya Lake	TNY	8,150	92%
Yosemite at Yosemite Valley	YYV	4,200	80%
SF Merced River near Wawona	YOW	4,957	80%

Due to the large elevation span across the area and sensitivity of temperature to elevation, developing a realistic estimate of temperature variation was critical, especially to model snow

melt. However, this was problematic given that the highest elevation in the Merced River watershed is over 12,000 feet, while the highest temperature gage is below 9,000 feet. Although past studies have suggested using a single lapse rate, given the good gage coverage below 9,000 feet, a more realistic method was employed. A second order polynomial was fit gage temperatures (T_i) determine the lapse rate for every hour:

$$Lapse\ Rate(t) = a_0 + a_1 T_i(t) + a_2 T_i^2(t)$$

The inclusion of a non-linear dependence allowed for an improved estimate of lapse rate during moderate to strongly stratified (i.e. inversion) conditions. Overall, the 2nd order polynomial resulted in a satisfactory fit as measured by a relatively low mean absolute error over the WY1999 of 2.9° F (for reference, the temperature span across the watershed due to sunny, weakly stratified conditions can exceed 50° F). Figure 3a and 3b shows an example of how the fit performed during low and high lapse rate conditions. After manually inspecting a large number of fits, it was determined that a non-physical fit occurred during situations where there was a temperature inversion, such as shown in Figure 3a. For such cases, the lapse rate for elevations above 8,500 feet was set to a constant 3.8° F per 1,000 feet.

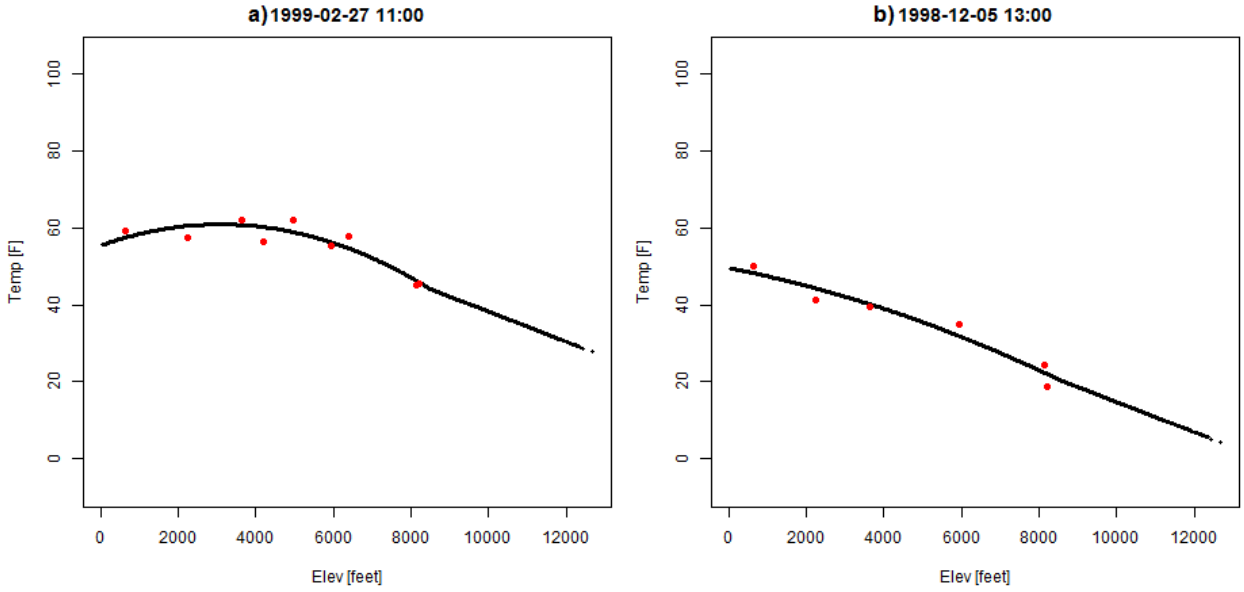


Figure 3: Example of temperature scatter and polynomial fit during (a) low lapse rate, including a temperature inversion in the lower 2,500 feet, and (b) high lapse rate conditions

After ensuring that inflows during WY1999 had reasonable consistency with temperature and precipitation forcing grids, three scenarios of a warming climate were developed as shown in Table 5. The scenarios were guided by the CA-DWR report, which showed stronger warming during the summertime compared to the wintertime.

Table 5: Temperature increases associated with three climate change scenarios

Scenario	ID	Daily Temperature Increase April 1 to October 31	Daily Temperature Increase November 1 to March 31
Current Condition	Base	None	None
"3 degree"	T + 3	3° F	2° F
"5 degree"	T + 5	5° F	3° F
"10 degree"	T + 10	10° F	6° F

Temperature grids were modified by adding a constant temperature change to everywhere within the watershed, as a function of season (as shown in Table 5). These were used as input into HMS projections of New Exchequer Dam inflow under warmer conditions. The precipitation input was not changed, although the HMS model adjusted the snow level internally to higher elevation based on the temperature grids.

Simulations used the 1998-1999 water year as a reference point, as this year was a climatologically average year. First, a "base" simulation of inflows into MID's New Exchequer Dam was developed, which was able to reproduce the observed yearly inflow within 11%. It should be noted that the simulation had a slight delay in flow timing, showing peak yearly snowmelt runoff occurring during mid-June instead of late May. Next, three perturbed simulations were conducted using the warmer temperatures as shown in Table 1. Table 6 and Figure 4 show monthly inflow for the base case and each perturbed scenario.

There were large differences in the timing of the peak flow. For example, even with a relatively low warming of 2-3°F ("T+3" scenario), maximum discharge occurs at least 1 month earlier than the base case. As can be expected, as the temperature is increased further, even more drastic changes are noted. In the most severe "T+10" scenario, the peak flow occurs during February versus June.

Table 6: Monthly Inflow to New Exchequer Dam under base and three climate change scenarios

	Monthly Inflow To New Exchequer (a.f.)			
	BASE T	T+3	T+5	T+10
OCT	9,775	10,281	10,587	11,177
NOV	3,723	3,843	4,000	6,357
DEC	10,433	17,140	22,210	56,671
JAN	57,097	67,506	73,261	110,209
FEB	124,705	141,227	148,447	179,049
MAR	92,347	102,129	108,556	116,614
APR	122,131	142,663	157,631	158,904
MAY	144,216	149,709	151,362	98,675
JUN	168,635	102,286	76,511	39,543
JUL	36,703	23,562	19,166	12,042
AUG	11,040	8,063	6,395	4,443
SEP	4,404	3,584	3,208	3,039
APRIL-JULY	471,685	418,220	404,670	309,164
TOTAL	785,209	771,993	781,334	796,722

There were large differences in the peak flow during precipitation events. With increased temperature more precipitation falls as rain than snow. The precipitation that falls as snow does not contribute to the immediate runoff but is 'stored' in the snowpack. **At higher air temperature, more precipitation falls as rainfall, and the higher immediate runoff generated increases chances of flooding.** Figure 5 shows the daily inflow hydrograph at New Exchequer Dam at the base condition and the three climate change scenarios. The daily average flows at higher temperature scenarios during precipitation events in December to February period were much higher compared to the base condition. Conversely, the peak runoff during the melt season (April to July) is reduced as the snowpack becomes smaller, and the snowmelt starts earlier in the season. The April – July runoff volume decreased by 11%, 14%, and 34% in the three scenarios compared to the base condition.

As more of the precipitation occurred as rainfall, **there was a significant reduction in the snow water equivalent and the snow-covered areas in the watershed**. Figure 6 shows the watershed-wide snow water equivalent in the watershed under the different climate change scenario. The peak snow water equivalent in the watershed changed from 565,914 acre-feet in the base condition to 457,766 acre-feet, 402,395 acre-feet and 228,839 acre-feet under the T + 3, T + 5 and T + 10 scenarios respectively. There is also significant change in the extent of the snow-covered areas. Figure 7 shows the extent of the snow-covered areas on April 1. **With increased temperatures, the snow-covered areas recede to higher elevation**.

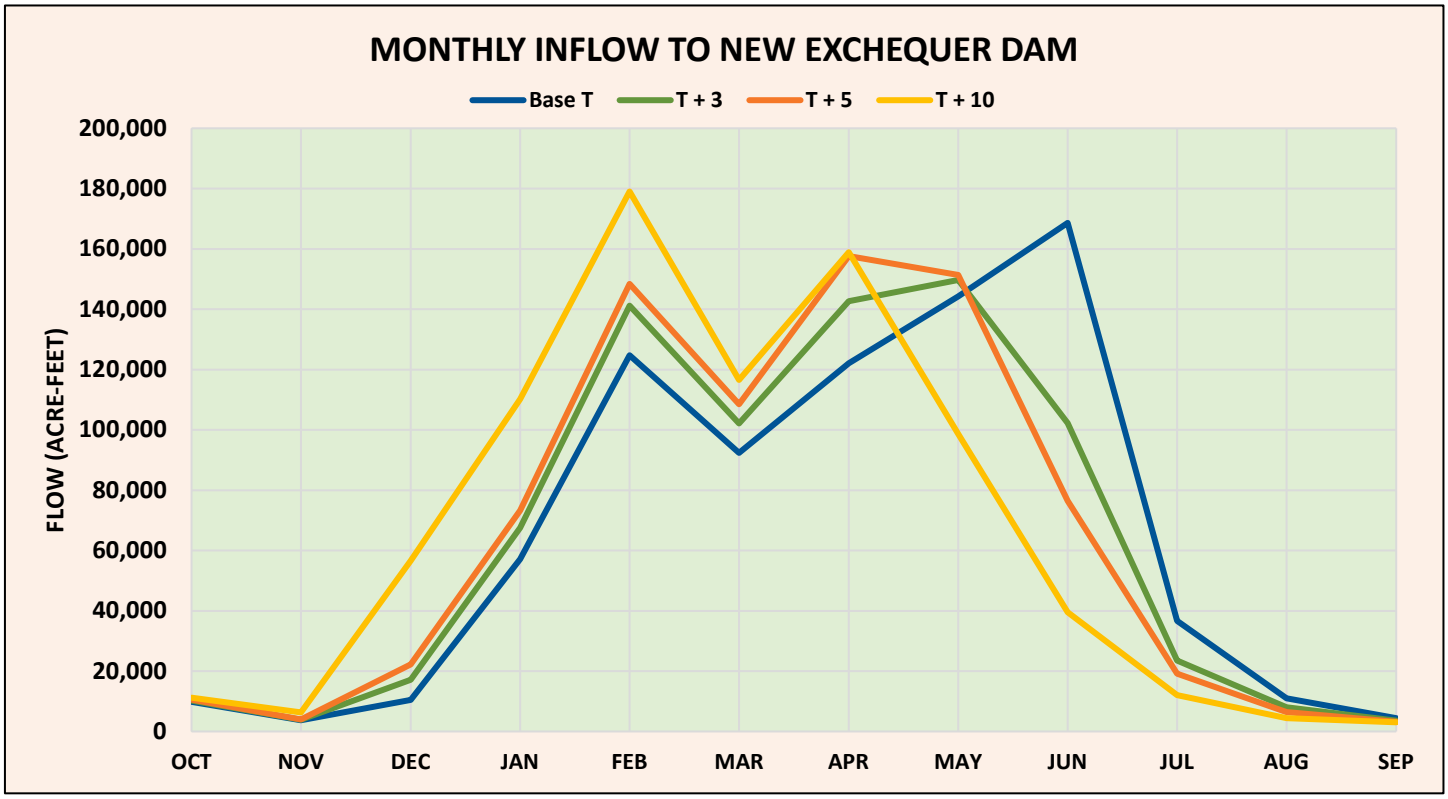


Figure 4: Monthly Inflow to New Exchequer Dam under base and three climate change scenarios

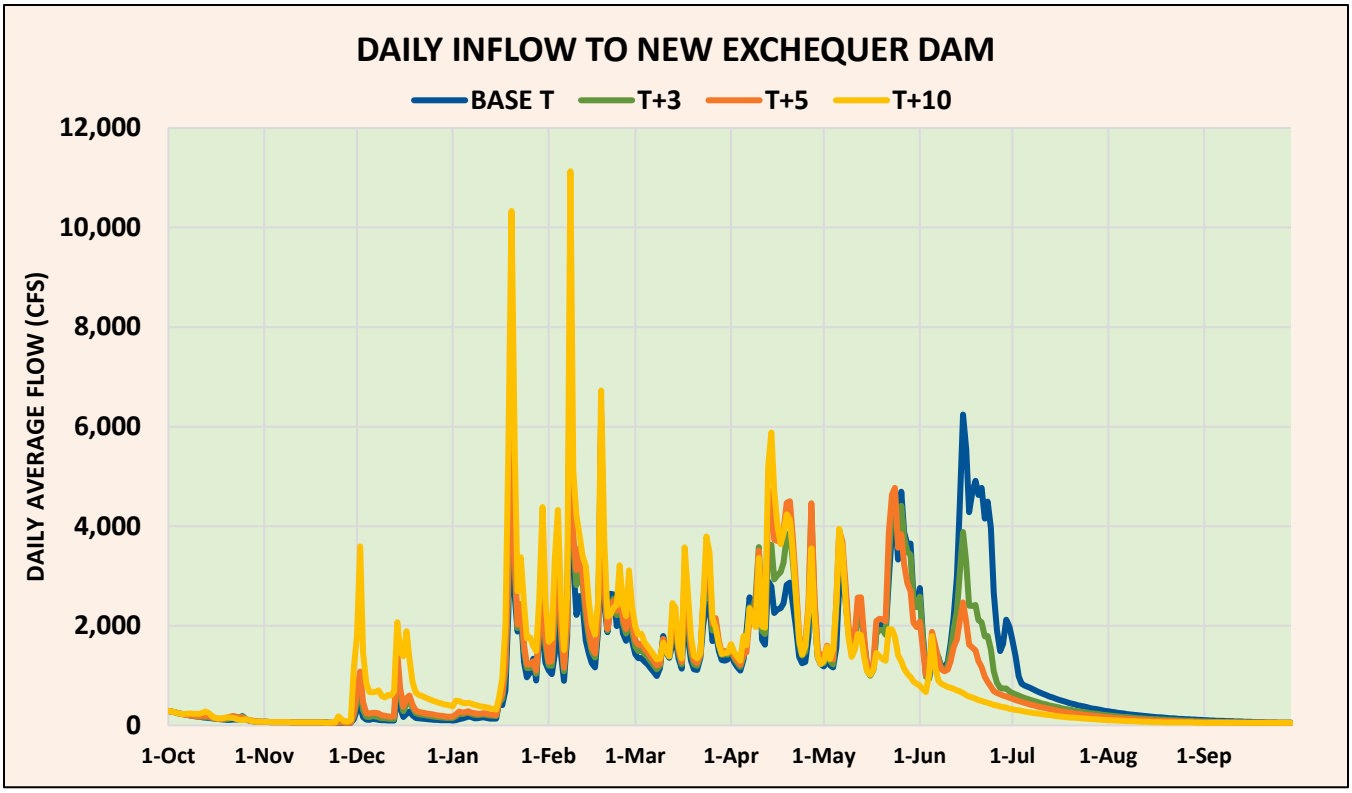


Figure 5: Daily Inflow to New Exchequer Dam under base and three climate change scenarios

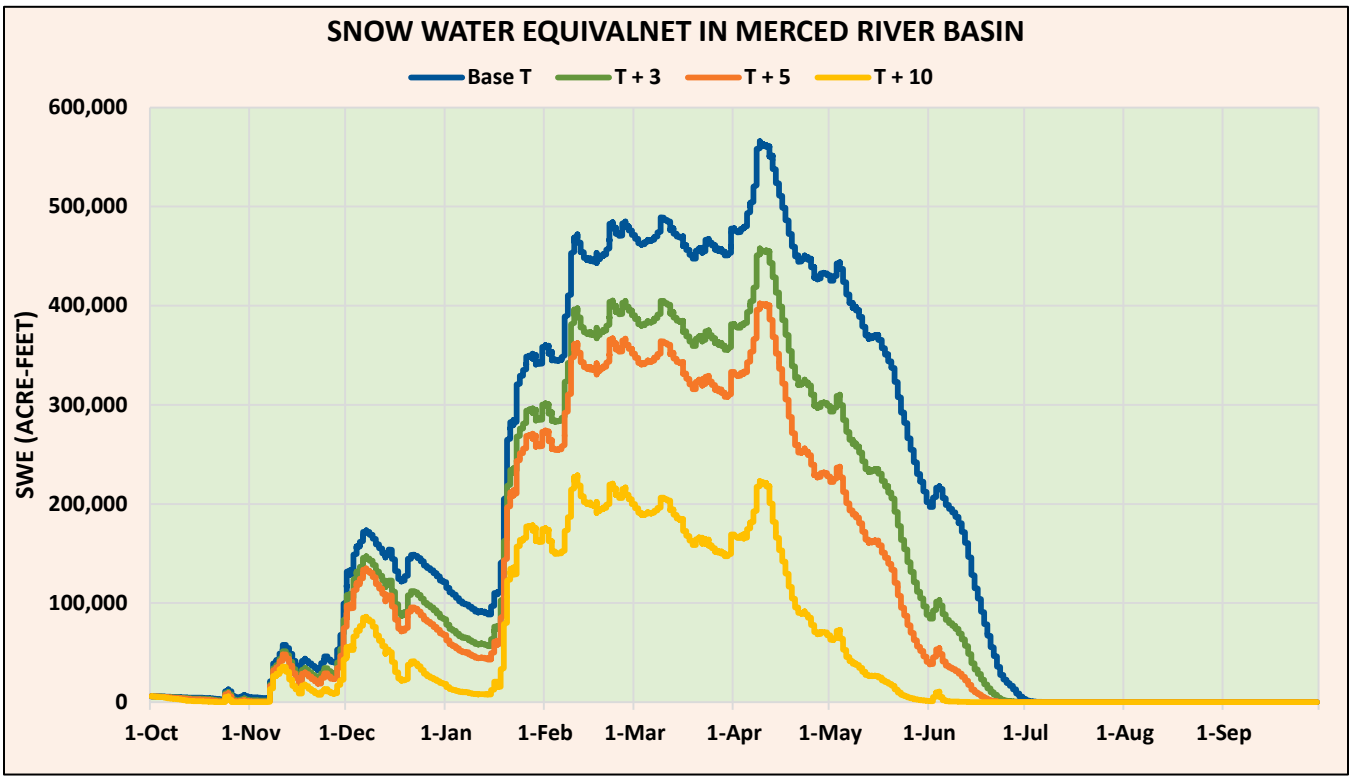


Figure 6: SWE in Merced River Watershed under base and three climate change scenarios

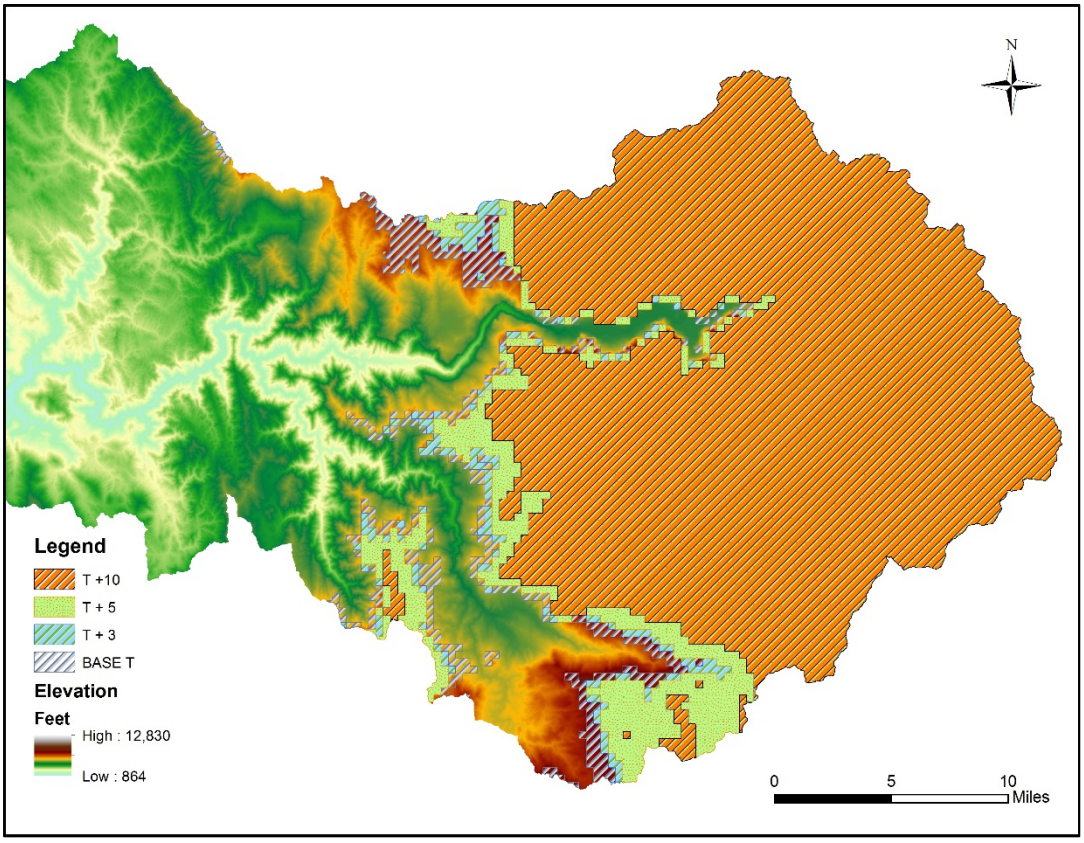


Figure 7: HMS simulated SWE coverage under base and three climate change scenarios

4.0 CONCLUSION

Using temperature gages with at least 60 qualifying years of data, increases in mean temperature were found across the Merced River Watershed. However, the increases were not equally distributed across seasons. There was a weak increase in very hot summer days where high temperatures exceed 90° F. On the contrary, very strong decreases in freezing nights (daily low temperatures below 32° F) were noted. The decrease in nights with freezing temperatures was widespread across the watershed. Despite the strong signal showing warmer nights, there was no statistically significant decrease in maximum yearly snow water equivalent, or the date of the maximum snow water equivalent. Also, there was no statistically significant changes in heavy precipitation. There was a weak downward trend in annual maximum streamflow.

When the increase in future temperature projection scenarios as suggested in the CA-DWR report was used in a precipitation-runoff model, the changes in the peak streamflow, timing of runoff volume in the New Exchequer Reservoir, and the SWE in the Merced Watershed were significant. With increase in temperature, more precipitation falls as rain thus increasing the chances of flooding. More of the runoff occurs in February to April as compared to May to July. And, amount of snowpack in the watershed decreases and the snow coverage recedes to higher elevations.

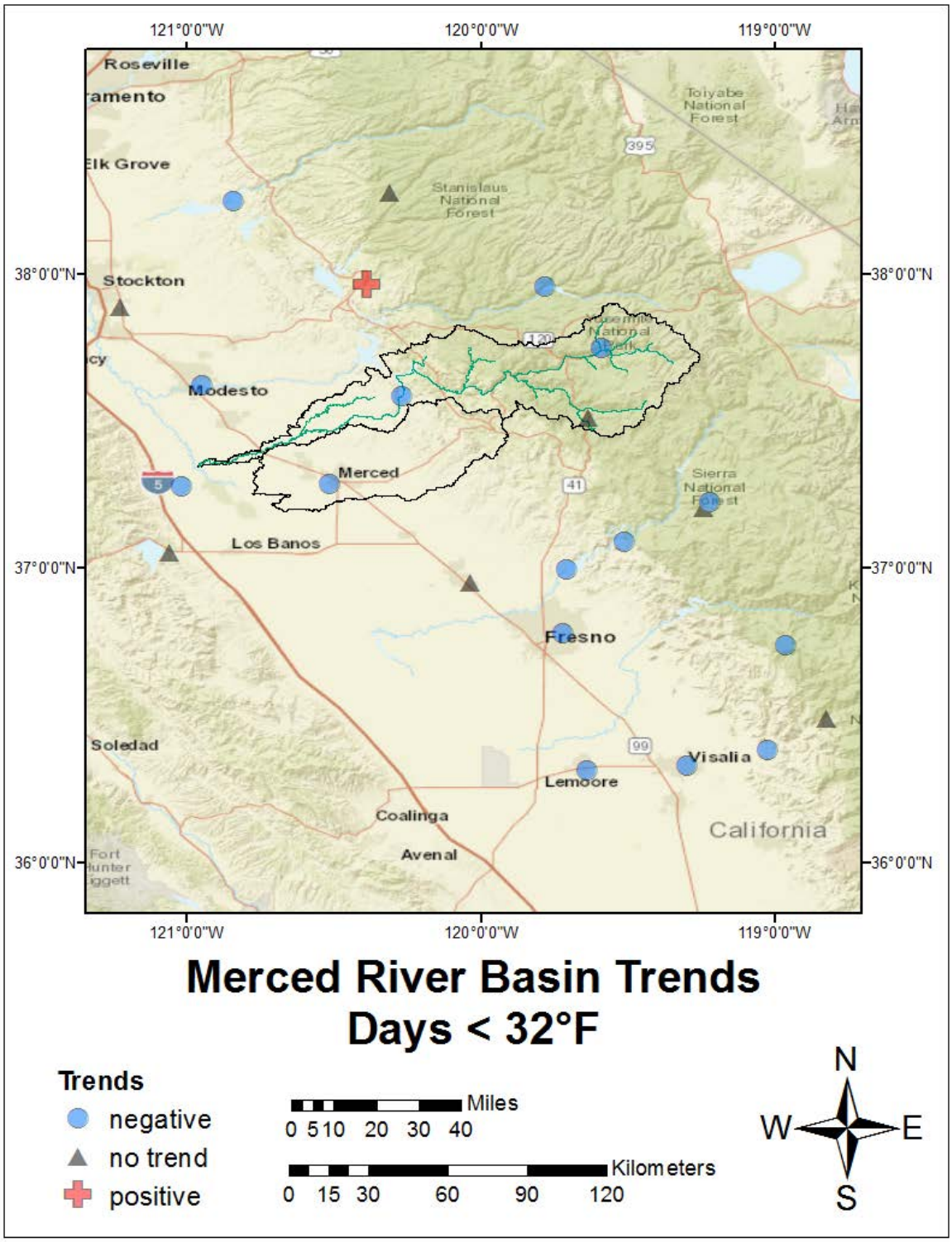
5.0 REFERENCE

California Department of Water Resources, 2015: California Climate Science and Data for Water Resources Management. Accessed August 25, 2017.

David Ford Consultants, 2016: Hypothetical storm development for McClure Lake, Merced River and Merced Stream Group sub-basins. Submitted to Merced Irrigation District on November 4, 2016.

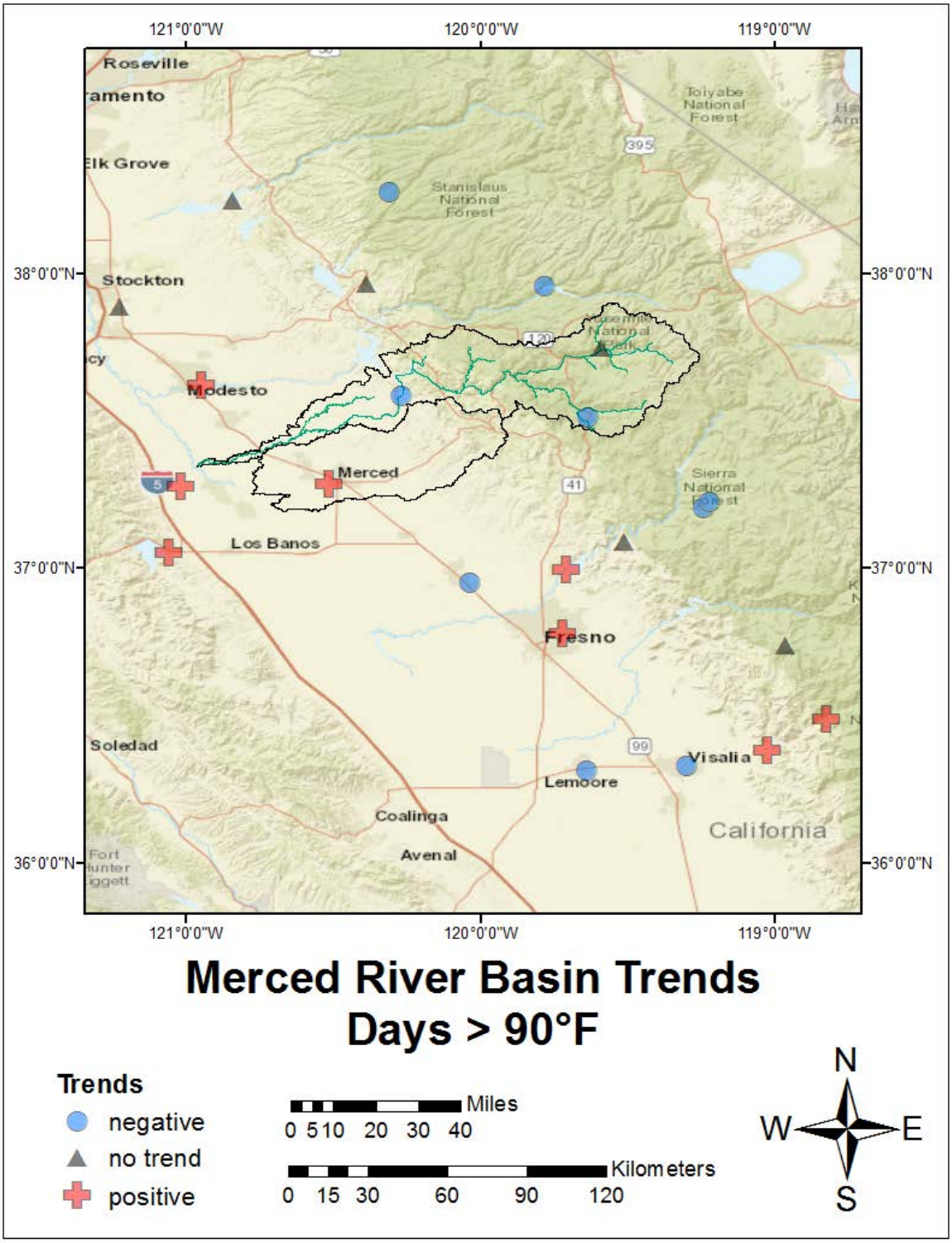
APPENDIX A

Spatial representation of trend test results



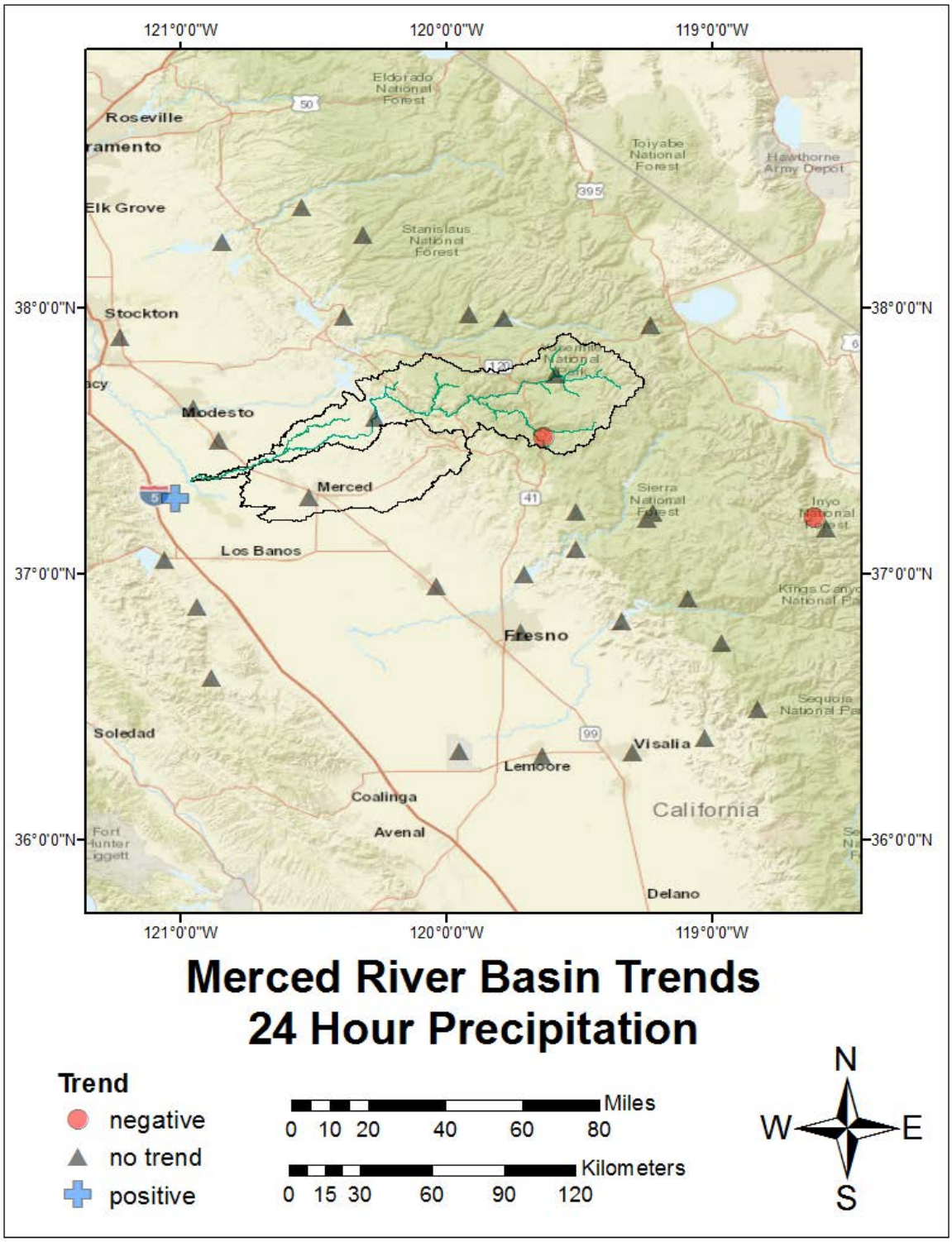
(a)

Number of days minimum temperatures were less than 32°F



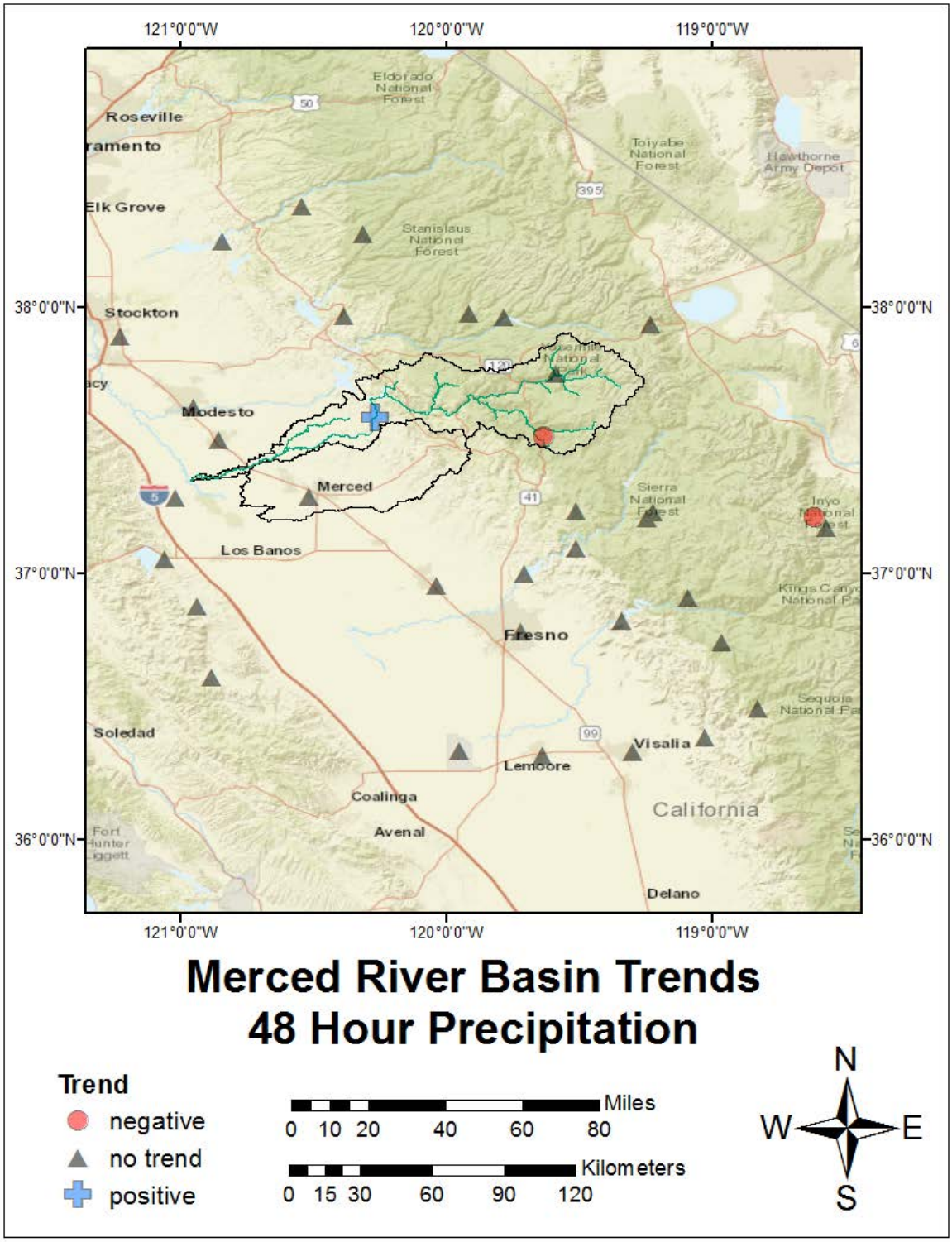
(b)

Numer of days maximum temperatures were greater than 90°F



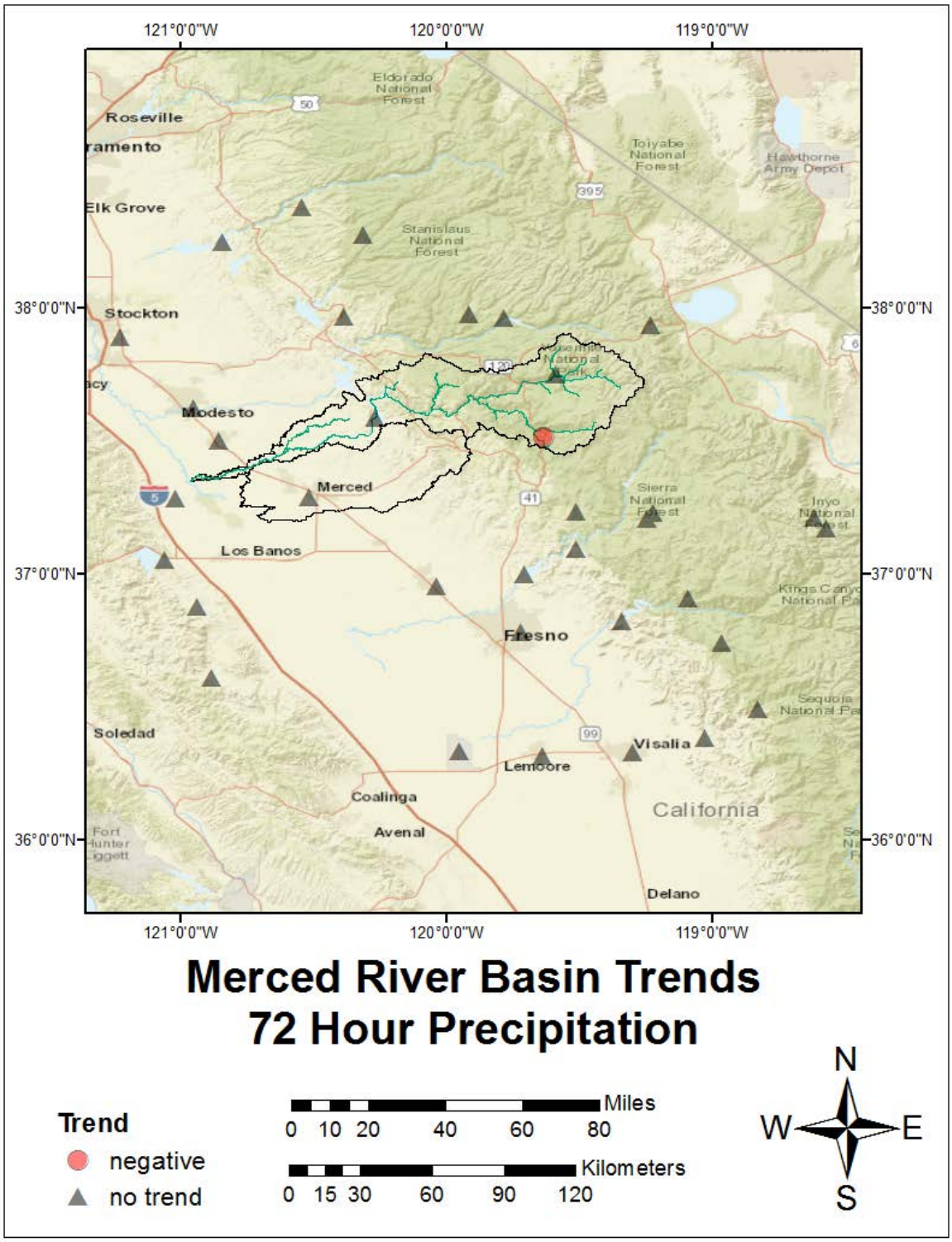
(c)

24-hour rainfall events



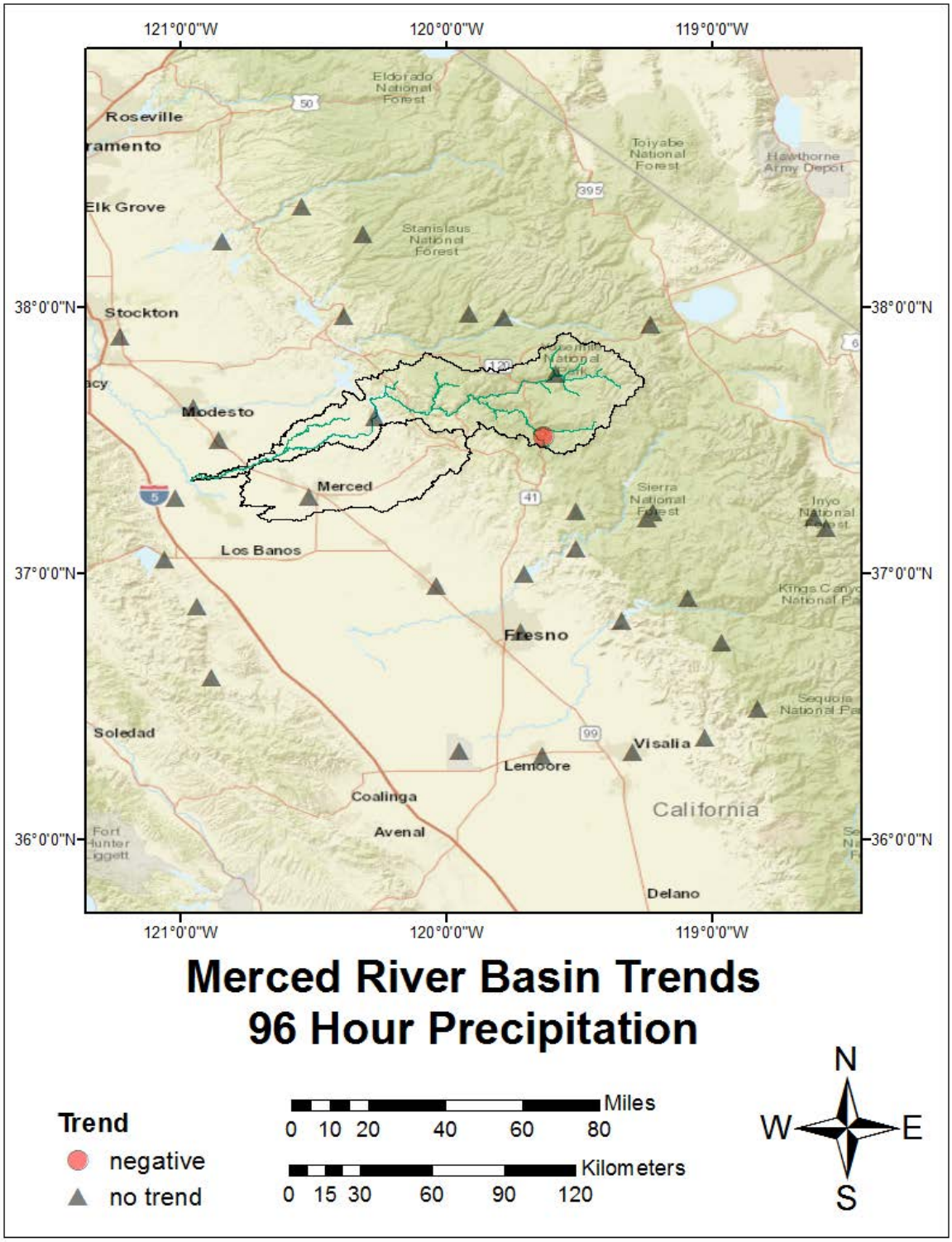
(d)

48-hour rainfall events



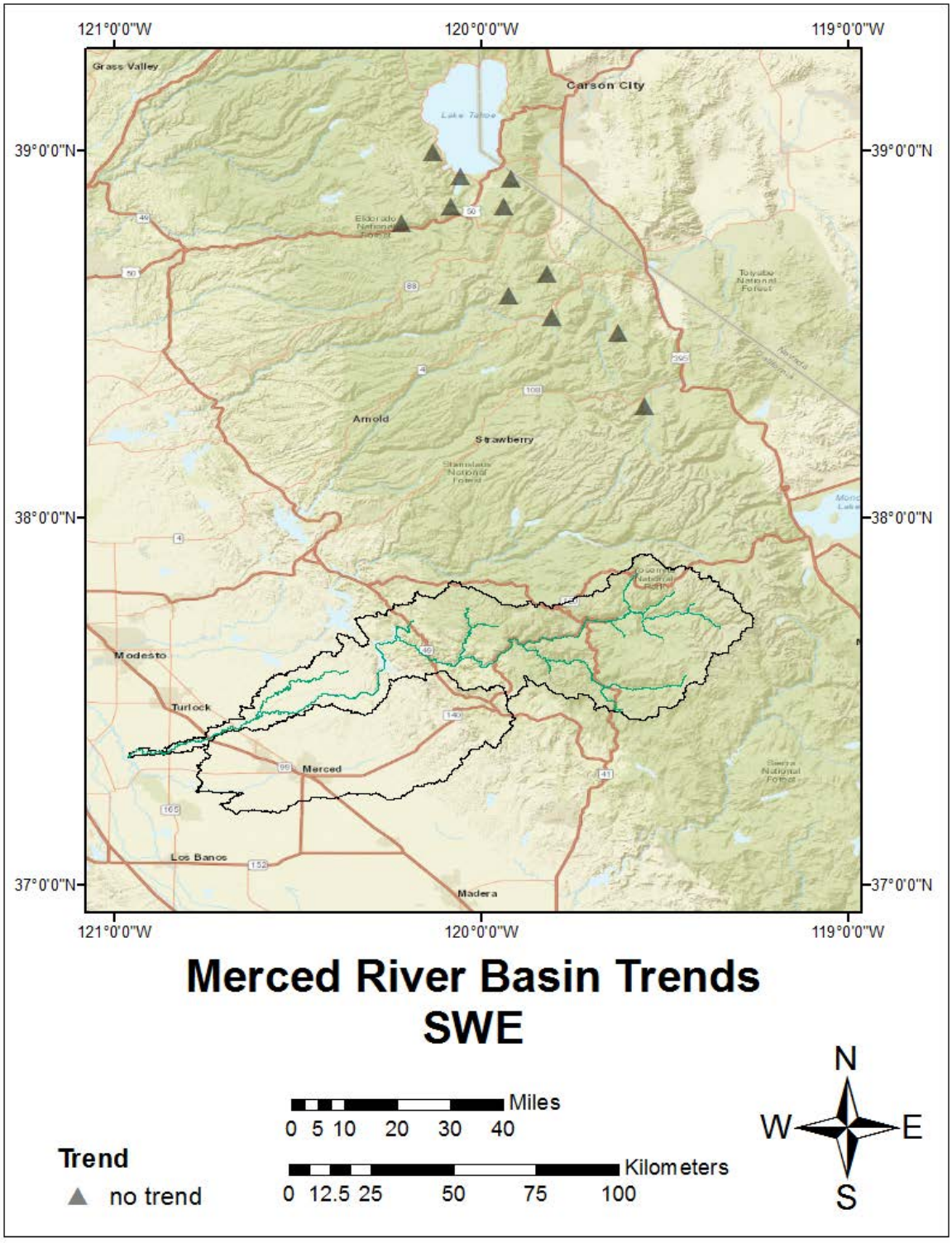
(e)

72-hour rainfall events



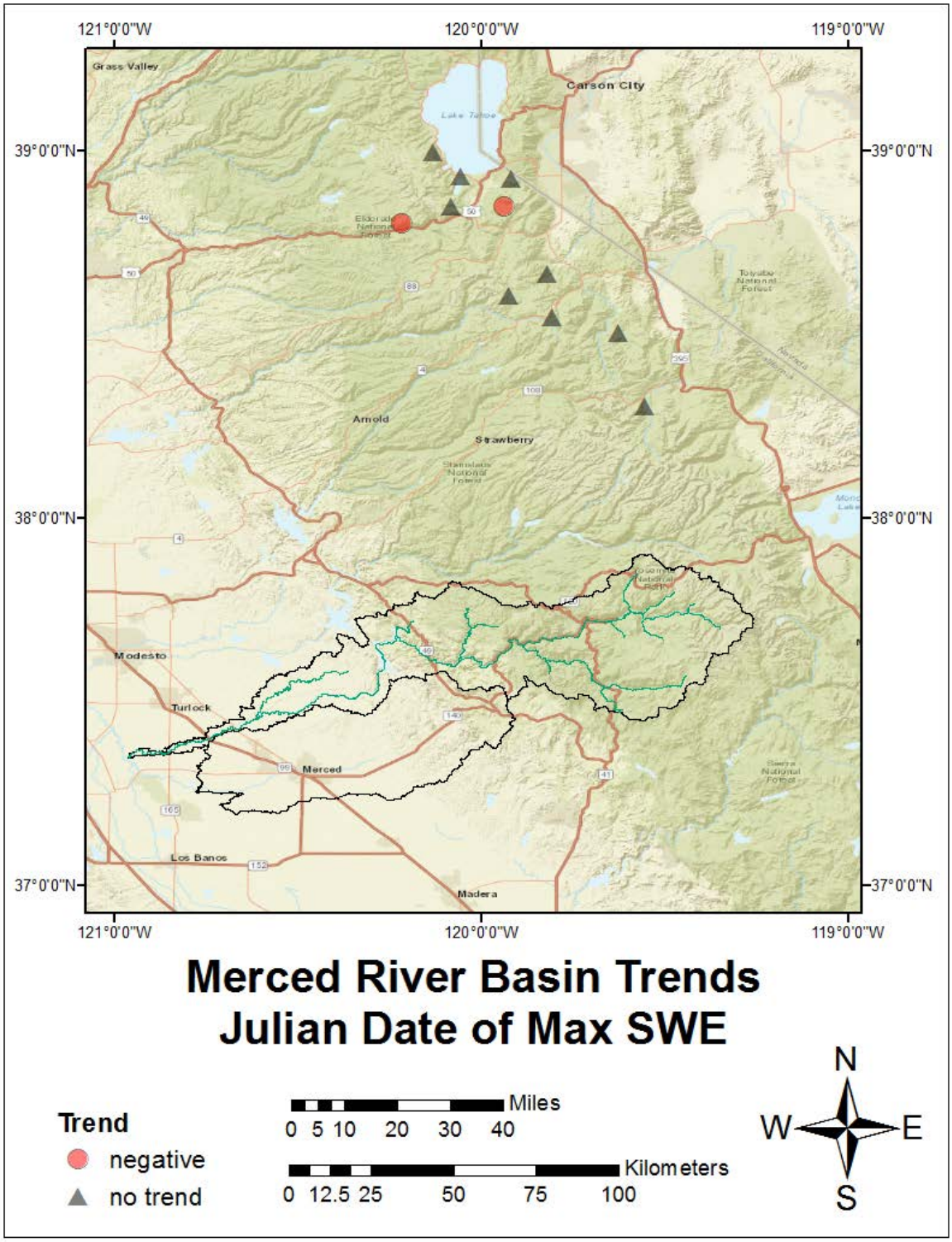
(f)

96-hour rainfall events


121°0'0"W
120°0'0"W
119°0'0"W
39°0'0"N
38°0'0"N
37°0'0"N
Grass Valley
Carson City
Lake Tahoe
Arnold
Strawberry
Modesto
Turlock
Merced
Los Banos
Madera
Merced River Basin Trends
SWE
Miles
0 5 10 20 30 40
Kilometers
0 12.5 25 50 75 100
Trend
no trend
N
W
E
S

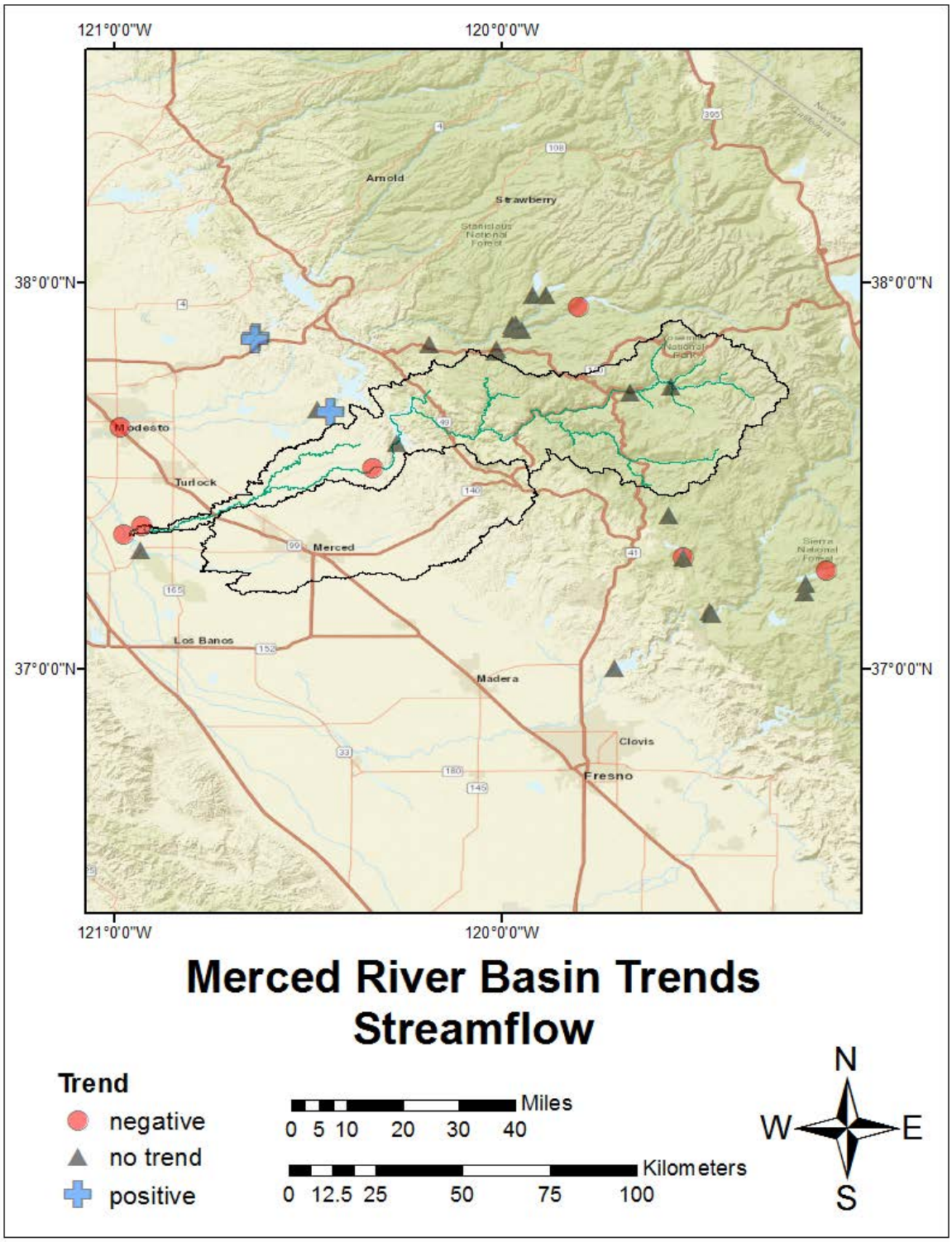
(g)

SWE



(h)

Julian day of maximum SWE


121°0'0"W
120°0'0"W
38°0'0"N
37°0'0"N
Arnold
Strawberry
Stanislaus National Forest
Modesto
Turlock
Merced
Los Banos
Madera
Clovis
Fresno
Sierra National Forest
Merced River Basin Trends
Streamflow
Trend
negative
no trend
positive
Miles
0 5 10 20 30 40
Kilometers
0 12.5 25 50 75 100
N
W
E
S

(i)

Peak flow

APPENDIX B

Summary of manual quality control changes that were completed before the development of watershed-wide temperature grids

10/23/1998 at 6AM local: only 2 stations. Solution: interpolate between 5 and 7 AM at the MRP site.

10/24-25, 1998: Only 2 stations. Solution: Crane Flat Lookout was linearly interpolated. No major issues expected because it was nighttime with little temperature change.

12/23-24, 1998: No active stations at 1AM and 2AM. Missing data was linearly interpolated. No major issues expected because it was nighttime with little temperature change.

2/22/1999: At least 8 hours of missing data across all stations starting late afternoon local time. High pressure overhead so solution was to linearly interpolate during missing data.

3/20/1999: At least 6 hours of missing data across all stations during late evening/overnight. Weak disturbance passed through but little if any frontal zones. Interpolated during missing data.

8/2/1999: Removed a few outlier values at South Fork Merced River (at Wawona) gage.

9/23/1999: Removed about 24 hours' worth of outlier values at Dudley and both Yosemite River gages.

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