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William Paul Miller

University of Nevada, Las Vegas

Thomas C. Piechota

University of Nevada, Las Vegas, thomas.piechota@unlv.edu

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Regional Analysis of Trend and Step Changes Observed in Hydroclimatic Variables around the Colorado River Basin

W. PAUL MILLER

Boulder Canyon Operations Office, Bureau of Reclamation, Boulder City, and Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, Nevada

THOMAS C. PIECHOTA

Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, Nevada

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ABSTRACT

Recent research has suggested that changes in temperature and precipitation events due to climate change have had a significant impact on the availability and timing of streamflow. In this study, monthly temperature and precipitation data collected over 29 climate divisions covering the entire Colorado River basin and monthly natural flow data from 29 U.S. Geological Survey (USGS) gauge locations along the Colorado River are investigated for trend or step changes using parametric and nonparametric statistical tests. Temperature increases are persistent (at least 10 climate divisions over 6 months in trend analysis) throughout the year over the Colorado River basin, whereas precipitation only notably increased over 17 climate divisions (during trend analysis) during February and remained relatively unchanged otherwise. These results correspond with changes in naturalized streamflow throughout the year. Streamflow increases are recorded between November and February but exhibit a decreasing trend over the traditional peak runoff season (April through July). Under trend analysis, 18 flow stations exhibited increasing trends in January and 19 flow stations exhibited decreasing trends in June. It is likely that increasing temperature trends have affected the character of precipitation in the Colorado River basin, causing a change in the timing of runoff events.

1. Introduction

The upper Colorado River basin (see Fig. 1) serves Wyoming, Colorado, Utah, and New Mexico and exists within a supply-driven environment; that is, water resources and supplies are primarily governed by seasonal snowpack and streamflow events. California, Arizona, and Nevada rely on water resources delivered from the lower Colorado River basin within a demand-driven framework. The inflow to the system is nearly constant and governed by water released from the upper Colorado River basin; releases within the lower Colorado River basin are dictated by consumptive use within the lower Colorado River basin and regulated by

the Colorado River Compact (Sax et al. 2000). Although it is primarily a source of water for consumptive use, the Colorado River is also required in hydropower generation, flood control, recreation, and environmental health. However, a recent extreme drought has begun to strain water resources within the Colorado River basin, and it has emphasized the need to understand the impacts and effects of climate change and climate variability within the basin.

The release of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Alley et al. 2007) has brought the issue of climate change and climate trends to the forefront of scientific and political communities. Trends in climate variability, particularly those associated with precipitation, temperature, and streamflow, have become particularly important in the western United States, specifically in the Colorado River basin, which is currently experiencing the longest drought on the observed historical record (e.g., Piechota et al. 2004; Pagano and Garen 2005;

Corresponding author address: Dr. Thomas C. Piechota, Department of Civil and Environmental Engineering, University of Nevada, 4505 Maryland Pkwy., Box 454015, Las Vegas, NV 89154-4015.

E-mail: thomas.piechota@unlv.edu

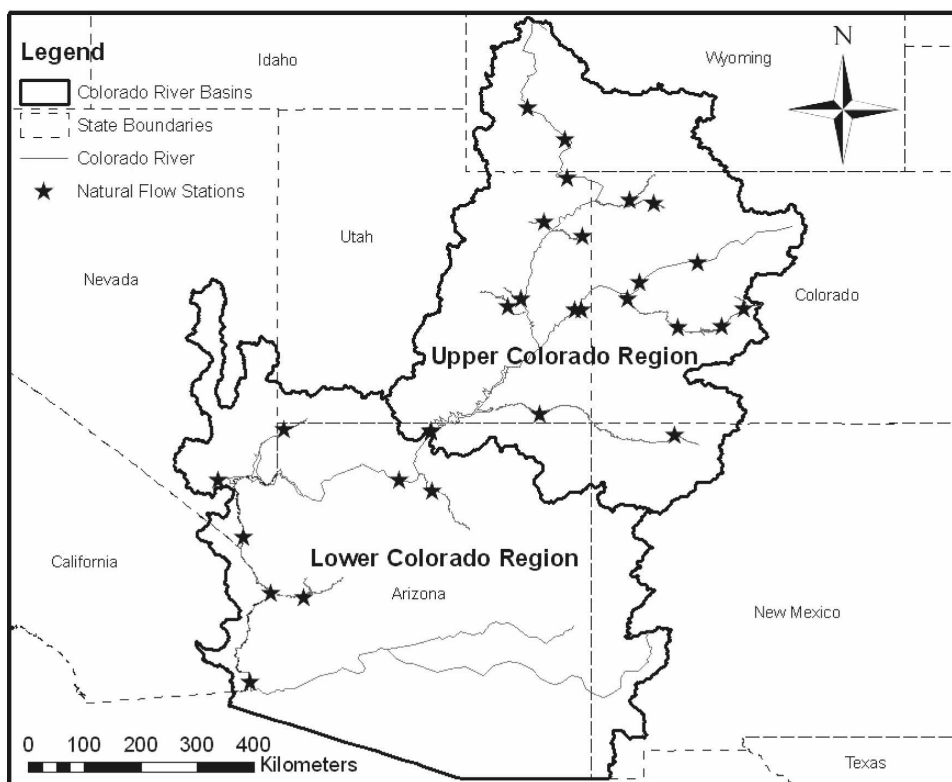


FIG. 1. Colorado River basin divided into upper and lower regions within United States. Colorado River, major tributaries, and associated locations of natural flow stations used in this study. Denver, CO, located at approximately 39.75°N, 104.87°W.

Timilsena et al. 2007). As the importance of resource management becomes apparent to a broad range of communities, water managers strive to understand the impact of climate variability on water use and delivery. Recent studies have indicated that climate change may lead to an intensification of hydrologic processes (e.g., Huntington 2006), which may affect the nature of precipitation events and timing and magnitude of streamflow (e.g., Regonda et al. 2005). In response to the changing needs of water resource managers, models and data analysis have become prevalent in the hydrologic sciences. Results of model runs and analysis of historical data have focused on changes in both magnitude and timing of hydrological and climatic parameters.

Christensen and Lettenmaier (2007) recently investigated the potential effects of climate change on the water resources within the Colorado River basin using the Colorado River Reservoir Model (CRRM) forced with results from the Variable Infiltration Capacity (VIC) macroscale hydrology model. The VIC model incorporated downscaled results from 11 general circulation models (GCMs), which were run to simulate future climate conditions given unconstrained emissions

growth or the elimination of emissions growth by the year 2100 as defined by scenarios A2 and B1, respectively, in the IPCC Fourth Assessment Report (Alley et al. 2007). Under the A2 scenario, Christensen and Lettenmaier (2007) observed an average increase in temperature between 1.2° and 4.4°C, a decrease in precipitation between 1% and 2%, and a decrease in mean runoff up to 11%. Under the B1 scenario, an average increase in temperature between 1.3° and 2.7°C, a change in precipitation between -1% and 1%, and a decrease in mean runoff up to 8% was forecasted. Of particular interest to this study, changes in runoff are noted as the result of changes in precipitation, temperature, and seasonality. Decreases in streamflow or changes to timing of seasonal streamflow rates can have a detrimental effect on the Colorado River system, affecting the ability to effectively meet water delivery requirements, generate hydroelectricity, and sustain environmental efforts.

GCMs are used for the assessment of climate change and climatic variability over the Colorado River basin. The IPCC recently reported mean global air temperature raising an average of 0.2°C decade⁻¹; historically, increasing trends in mean global air temperature are

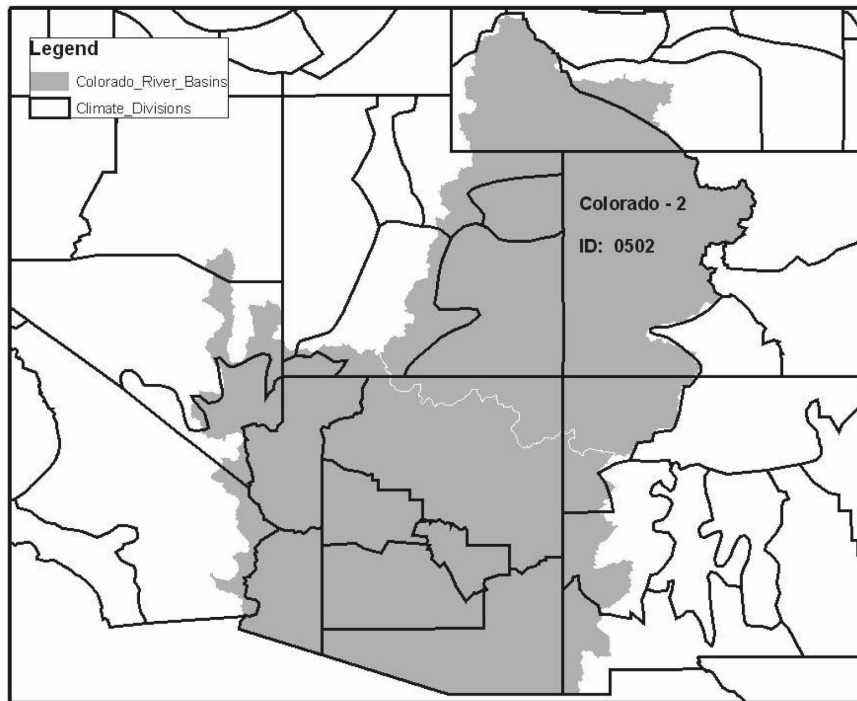


FIG. 2. Colorado River basin (shaded) intersected by 29 climate divisions. Climate divisions (bold lines) indicate geography and politics. State boundaries/climate divisions refer to sequential numerical value assigned to states in alphabetical order (e.g., Alabama = 01), and identifying value (e.g., Colorado-2 is 0502).

associated with decreasing trends in mean annual snowpack in the Northern Hemisphere (Alley et al. 2007). Although not addressed explicitly in this study, snowpack is considered to be the dominant hydrologic determinant within the Colorado River basin, making up 63% of the annual precipitation in the upper Colorado River basin and 39% of the annual precipitation in the lower Colorado River basin (Serreze et al. 1999). The distinction between precipitation as rainfall and snowfall events is important, as the frequency of these events relative to each other often corresponds to changes seen in temperature and streamflow trends.

The impact of snowpack on streamflow has been previously studied (e.g., Groisman et al. 2001; Fassnacht 2006), and researchers have used GCMs and the VIC model to quantify trends related to snowpack and dependent streamflow in the Colorado River basin (e.g., Hamlet et al. 2005). Trends in precipitation as snowfall and rainfall, temperature, and streamflow studied at the basin scale are useful for water managers and those studying inflow forecasts; however, trends at more local and regional scales are desired to better manage and allocate water resources, particularly in the Colorado River basin.

In this study, statistical analysis over the 29 climate

divisions covering the entire Colorado River basin is performed in an effort to quantify the likelihood of trends in precipitation, temperature, and streamflow. An effort to distinguish between linear and step trends in monthly data is also made using a variety of parametric and nonparametric statistics. The main contribution of this research is the identification of spatial and temporal nature of trends observed over each climatic parameter and a comprehensive analysis that looks at interdependency between each variable.

2. Data

Data in this study were obtained from several different government agencies and included monthly data spanning from 1951 through 2005. Climate divisions incorporated in this study are defined by the National Climatic Data Center (NCDC) based on geographical and political boundaries (Fig. 2). For the purposes of this study, climate divisions use a four-digit identification number, in which the first two numbers are associated with a particular state and the second two numbers identify a particular climate division within the state. For instance, the climate division identification number 0502 corresponds to the state of Colorado (05) and the second climate division (02).

Monthly average precipitation data used in this study were obtained from the NCDC and represent all reporting stations within a climate division recording temperature and precipitation data (NCDC 1994). When NCDC developed the climate division data, equal weights were given to each recording station and reported in inches. Similarly, monthly average temperature data over each climate division were collected from the NCDC. Temperature data were bias corrected by the NCDC for differences in spatial and temporal characteristics between each gauge using a method described by Karl et al. (1986). The NCDC reports that temperature bias errors at each station were small and less than 0.3°F (NCDC 1994).

Climate division data have been available over the 48 contiguous states since 1895, though the divisional boundaries and data derivation have been subjected to change and revision since inception. The latest significant changes occurred in the late 1960s. The average precipitation and temperature data over each division is derived by taking an average of reporting from the National Weather Service (NWS) Cooperative Observer Program (COOP) stations within the division. The number and distribution of COOP stations has changed over time and may not be representative of topographical impacts to climate within a division. Although this may be considered a limitation in the dataset, the data correspond well to large-scale historical climate anomalies such as droughts, both spatially and temporally (Guttman and Quayle 1996).

Streamflow data used in this study consist of natural flow data calculated and distributed by the Bureau of Reclamation using information from U.S. Geological Survey (USGS) stream gauging locations, reservoir operations, and depletion histories of Colorado River water users (Prairie and Callejo 2005). The Colorado River from the Green River below the Fontenelle Reservoir in Wyoming to Imperial Dam at the southern international boundary between Arizona and Mexico is divided into distinct reaches bounded by USGS stream gauge locations. Natural flow in the upper and lower Colorado River basins has been derived using historical data; natural flow is defined as the sum of historical flow observed at a particular USGS gauge station included in this study and total flow depletion over the reach above the gauging station. This flow is then adjusted to subtract or add additional flow subjected to reservoir regulation. As detailed by Prairie and Callejo (2005), natural flow is defined as

$$\text{Natural Flow} = \text{Historic Flow} + \text{Total Depletion} \pm \text{Reservoir Regulation.} \quad (1)$$

The period of natural flow record provided by the Bureau of Reclamation is water years 1906–2005, and it was recently used in the development of shortage criteria governing reservoir operations in the lower Colorado River basin during times of low storage (Bureau of Reclamation 2007).

Prior to 1971, consistent and complete records for many of the 29 USGS flow stations used in this study did not exist. In summary, the historical monthly record was extended by first using robust statistical methods (e.g., *k*-nearest neighbors bootstrapping) to derive cumulative annual streamflow values in the Colorado River basin. Through multiple linear regression and statistical analysis of the error term, these annual flows were temporally disaggregated to the monthly time scale. The extended streamflow and historical records have similar statistical properties (T. Lee and J. Salas 2006, unpublished manuscript; Salas et al. 2005).

A Microsoft Excel application customized using Visual Basic based on a trend analysis software (TREND) that was originally developed by Chiew and Siriwardena (2005) was used in the analysis.

3. Methodology

Monthly time series for each dataset over each climate division were subjected to statistical analysis using a variety of methods in an effort to detect trends in temperature and precipitation between 1951 and 2005 and trends in streamflow between 1906 and 2005. Each climate division was evaluated independently for trends in temperature and precipitation data. Trends in streamflow data were based on locations along the Colorado River. Kalra et al. (2008) used three statistical tests to evaluate linear trends and two statistical tests to evaluate step changes at USGS streamflow gauge stations over the conterminous United States and snowpack telemetry (SNOTEL) stations in the western United States. In this study, those same statistical tests were used to evaluate linear trends and step changes in monthly time series observed over climate divisions and gauge locations in the Colorado River basin. These tests are thoroughly explained in Chiew and Siriwardena (2005).

The Mann–Kendall test is a nonparametric test in which the rank of data values within a time series are compared. A test statistic, *S*, is derived through

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^n \text{sgn}(R_j - R_i) \right], \quad (2)$$

where *R* is the rank of value *x* within a time series *X*, *n* is the number of values within the time series, and $\text{sgn}(x) = 1$ for $x > 0$, $\text{sgn}(x) = 0$ for $x = 0$, and

$\text{sgn}(x) = -1$ for $x < 0$. The z -statistic z , from which significance levels can be derived from a normal probability table, is

$$z = |S|/\sigma^{0.5}, \quad \text{where} \quad (3)$$

$$\sigma = n(n-1)(2n+5)/18. \quad (4)$$

Spearman's ρ test is similar to the Mann–Kendall test in that it is a nonparametric rank-based test for trends within a time series. However, unlike the Mann–Kendall test, the Spearman's ρ test describes the correlation of the data with time, as opposed to other values within the time series. The z -statistic ρ_s is described by

$$\rho_s = S_{xy}/(S_x S_y)^{0.5}, \quad \text{where} \quad (5)$$

$$S_x = \sum_{i=1}^n (x_i - \bar{X})^2, \quad (6)$$

$$S_y = \sum_{i=1}^n (y_i - \bar{Y})^2, \quad \text{and} \quad (7)$$

$$S_{xy} = \sum_{i=1}^n (x_i - \bar{X})(y_i - \bar{Y}). \quad (8)$$

Like the Mann–Kendall test, ρ_s can be compared to a normal probability table to derive levels of significance.

A parametric, linear regression statistical test is also used in this study. A test statistic, S , is derived through

$$S = b/\sigma, \quad (9)$$

where b is defined as

$$b = \frac{\sum_{i=1}^n (x_i - \bar{X})(y_i - \bar{Y})}{\sum_{i=1}^n (x_i - \bar{X})^2} \quad (10)$$

and σ is defined as

$$\sigma = \sqrt{\frac{12 \sum_{i=1}^n (y_i - a - bx_i)^2}{n(n-2)(n^2-1)}}, \quad (11)$$

where a is estimated to be

$$a = \bar{Y} - b\bar{X}. \quad (12)$$

The S statistic can then be compared to critical table of t values, using $n-2$ degrees of freedom, to derive significance levels for each dataset.

Two statistical tests were used to assess step changes within the time series data at each climate division. In step change analysis, a time series is often split and one section of data values is compared to another. In this

study, 55 yr of data were considered for temperature and precipitation data and 100 yr of data were considered for naturalized streamflow data. Regonda et al. (2005) present evidence that streamflow changes are influenced by stronger trends in observational data recorded after 1974. Other studies support a step change in streamflow and snowpack observations reported after 1970 (McCabe and Wolock 2002; Mote 2006; Mote et al. 2005). Thus, for the purpose of step change analysis, time series data were divided into the first 24 yr of data (1951–74) and the latter 31 yr of data (1975–2005) for temperature and precipitation datasets. Similarly, streamflow time series were divided into the first 69 yr of data (1906–74) and the latter 31 yr of data (1975–2005). Although this distinction is important for step change statistical analysis, it is not used in trend analysis.

The rank-sum test is a nonparametric test comparing the medians in two different datasets; in this study, comparing the median of the earlier dataset to the median of the later dataset. Values over the entire time series are converted to ranks relative to the entire time series; S is the sum of the ranks in the smaller dataset. In this case, S is the first 24 yr of observations for the temperature and precipitation datasets. A theoretical mean, μ , and standard deviation, σ , are defined as

$$\mu = n(N+1)/2 \quad \text{and} \quad (13)$$

$$\sigma = [nm(N+1)/12]^{0.5}, \quad (14)$$

where n is the number of values in the small dataset, m is the number of values in the large dataset, and N is the total number of values in the time series. The z statistic Z_{rs} is computed as

$$Z_{rs} = (S - 0.5 - \mu) \quad \text{if} \quad S > \mu, \quad (15)$$

$$Z_{rs} = 0 \quad \text{if} \quad S = \mu \quad \text{and} \quad (16)$$

$$Z_{rs} = (S + 0.5 - \mu) \quad \text{if} \quad S < \mu. \quad (17)$$

Then Z_{rs} can be compared to a normal probability table to derive a level of significance.

The Student's t test is a parametric statistical test comparing the means of two datasets. A test statistic, t , is defined as

$$t = \frac{(\bar{X} - \bar{Y})}{S \sqrt{\frac{1}{n} + \frac{1}{m}}}, \quad (18)$$

where \bar{x} is the mean of the first dataset, and \bar{y} is the mean of the second dataset. Here, n and m are the number of observations in the first and second dataset,

respectively. Here, S is the standard deviation of all the collected observations.

In this study, trends and step changes in time series were investigated at the 90%, 95%, and 99% confidence levels. Specifically, test statistics derived from the previously described statistical methods were compared to critical values expressed on standard probability tables. In an effort to prevent bias introduced by any single statistical test, a time series must show an increasing or decreasing trend at least at the 90% confidence level for all three linear trend tests to be recognized as exhibiting a linear change. Analogously, a time series must indicate an increasing or decreasing step change at least at the 90% confidence level for both step change analytical tests to be recognized as displaying a step change.

It is important to note that the overall confidence level reported in this study is based on all of the tests. The confidence levels between tests do not have to agree; rather, the lowest confidence level value is reported for each month over each climate division. For instance, in trend analysis, statistical analysis using the Mann–Kendall and linear regression statistical tests may indicate an increasing trend with a 95% confidence level. However, analysis performed using the Spearman's ρ statistical test may indicate an increasing trend with only a 90% confidence level for the same month over the same climate division or gauge location. In this case, the parameter in question would be reported as exhibiting an increasing trend with a 90% confidence level over a particular climate division.

4. Results and discussion

Trend or step change results are assessed based on the confidence level calculated through use of the previously described statistical tests. Although the magnitude of the change observed in the historical record is not explicitly calculated in this study, the confidence level is a quantitative measure of the confidence that there is really a trend in a particular variable. The test statistic typically increases, along with the confidence level, with greater changes in magnitude seen in trend or step change analysis.

a. Temperature

Increasing temperature observations have been consistently increasing worldwide, and forecasts indicate this trend will continue (e.g., Christensen et al. 2004; Hamlet et al. 2005; Alley et al. 2007). Figure 3 illustrates monthly trends observed in climate divisions encompassing the Colorado River basin. Increasing temperature trends were observed consistently throughout the year, often times at greater than a 95% confidence

level. Notably, increasing temperature trends were observed throughout the year below the Hoover Dam and in southern Arizona and California, areas that depend on Colorado River water to meet irrigation demands (e.g., Wang and Cai 2007; Bureau of Reclamation 2007; Sax et al. 2000).

The Colorado River system is highly dependent on streamflow that is a result of snowmelt in the upper Colorado region, especially in the months of April through July (e.g., Fassnacht 2006; Hamlet et al. 2005). Temperature trends in the upper Colorado basin consistently increased over the April through July time frame; however, it is notable that temperature trends in the months prior, January through March, were also increasing. Increasing temperatures may affect the timing of snowmelt in the region and, in turn, affect the timing of streamflow in the region (Regonda et al. 2005).

Step changes in temperature over the same region generally agreed with profiles observed with linear trend analysis (Fig. 4). However, more instances of decreasing change in temperature characteristics were seen in the step change profiles, particularly in May, July, and October. All instances were at the 90% confidence level, and with the exception of July, tended to occur on the outer boundaries of the Colorado River basin. Increasing temperature trends in March and April may correspond to earlier peak streamflow rates observed in Regonda et al. (2005).

b. Precipitation

Precipitation, and the state in which it occurs, is important in the Colorado River basin. Precipitation in the form of snow is a benefit, particularly in the upper Colorado River basin, because snowfall replenishes mountain storage and is the source of snowmelt in the critical spring runoff season. Winter rainfall events in the Colorado River basin cause concern because they do not replenish mountain snowpack storage and can come at the expense of snowfall events (Groisman et al. 2001). Increased rainfall events naturally increase streamflow through surface runoff; when rainfall events begin to occur in place of historically observed snowfall events, streamflow rates increase and tend to peak earlier in the year. Huntington (2006) cites this global phenomenon as evidence of water cycle intensification, which impedes the ability of water managers to assess water resource availability.

Figures 5 and 6 depict the spatial profile of trend and step changes in precipitation in the Colorado River basin, respectively. There were some increases in precipitation in the late fall and winter months or the beginning of the water year. Interestingly, December indi-

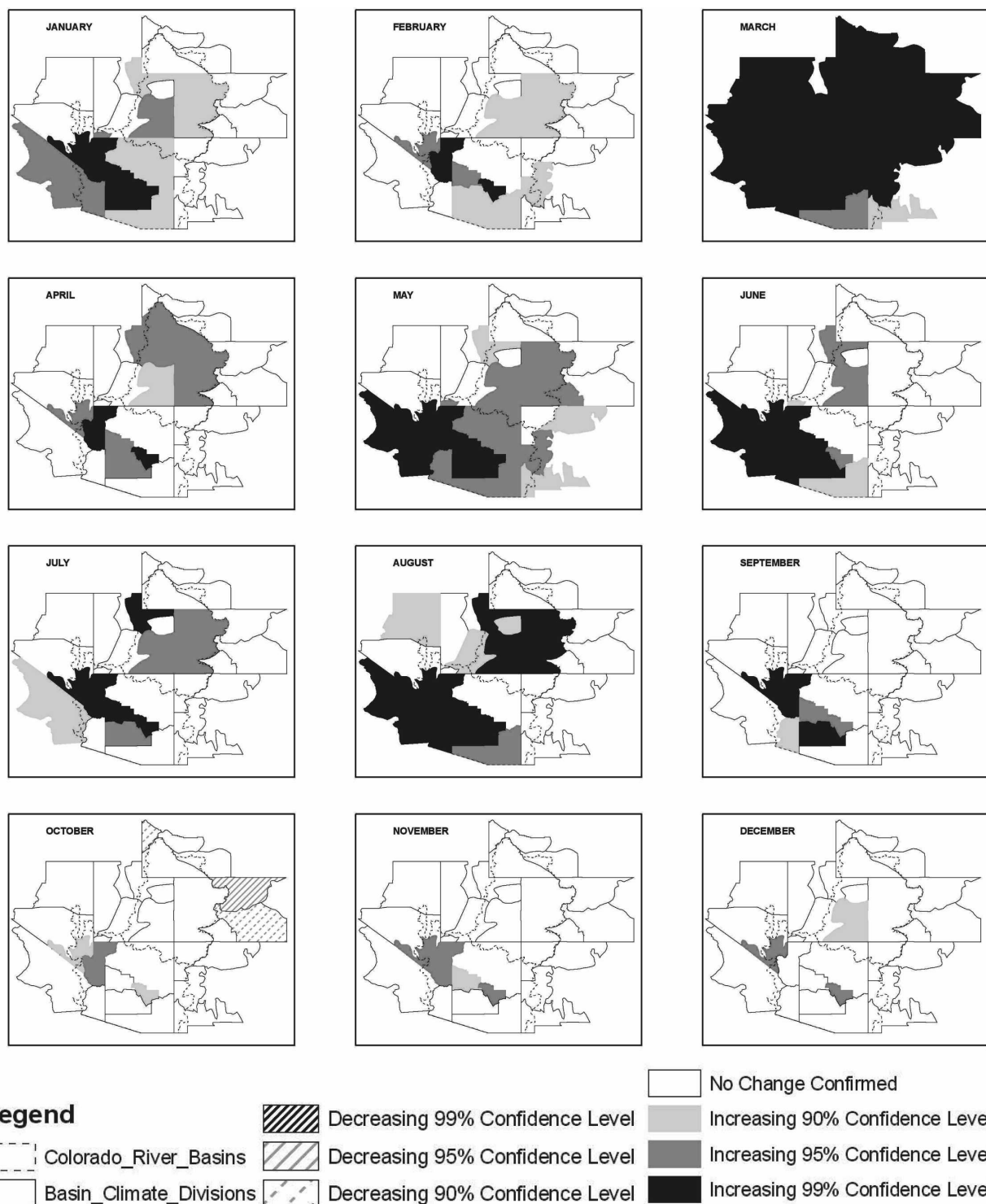


FIG. 3. Trends in temperature data over each climate division intersecting Colorado River basin.

cates decreasing trends in the northwest, mountainous portion of the upper Colorado River basin. Precipitation generally remained relatively unchanged during the peak runoff season (April–July).

c. Streamflow

Resource managers depend on accurate inflow forecasts to plan delivery schedules, hydropower genera-

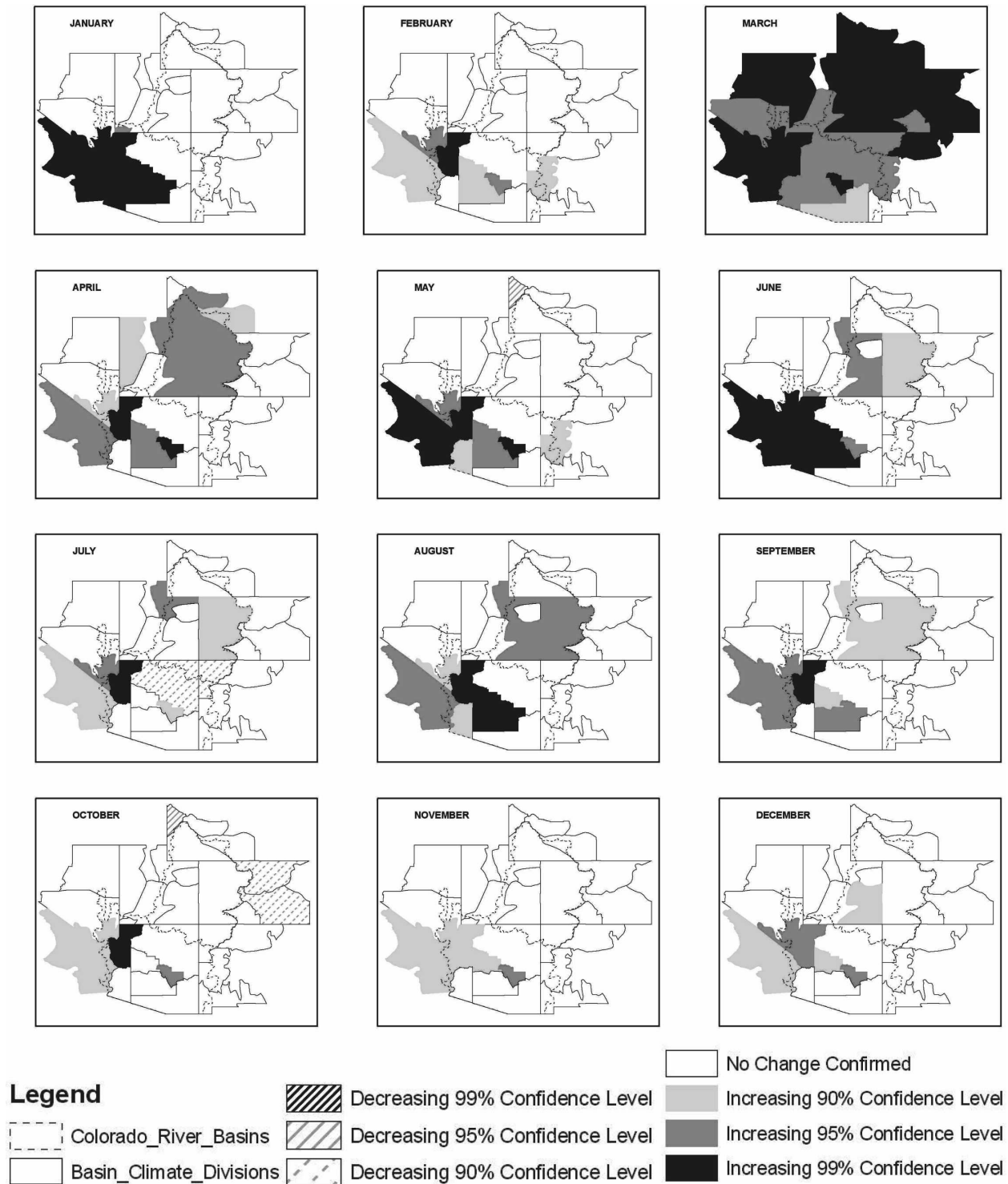


FIG. 4. Step changes in temperature data over each climate division intersecting Colorado River basin.

tion, agricultural requirements, and the continued sustainability of environmental projects and programs. Lins and Slack (1999) note that streamflow has increased across the majority of the United States, which

correlates to increasing trends in precipitation and temperature observations noted by Huntington (2006) and Groisman et al. (2001).

Figures 7 and 8 illustrate trend and step changes in

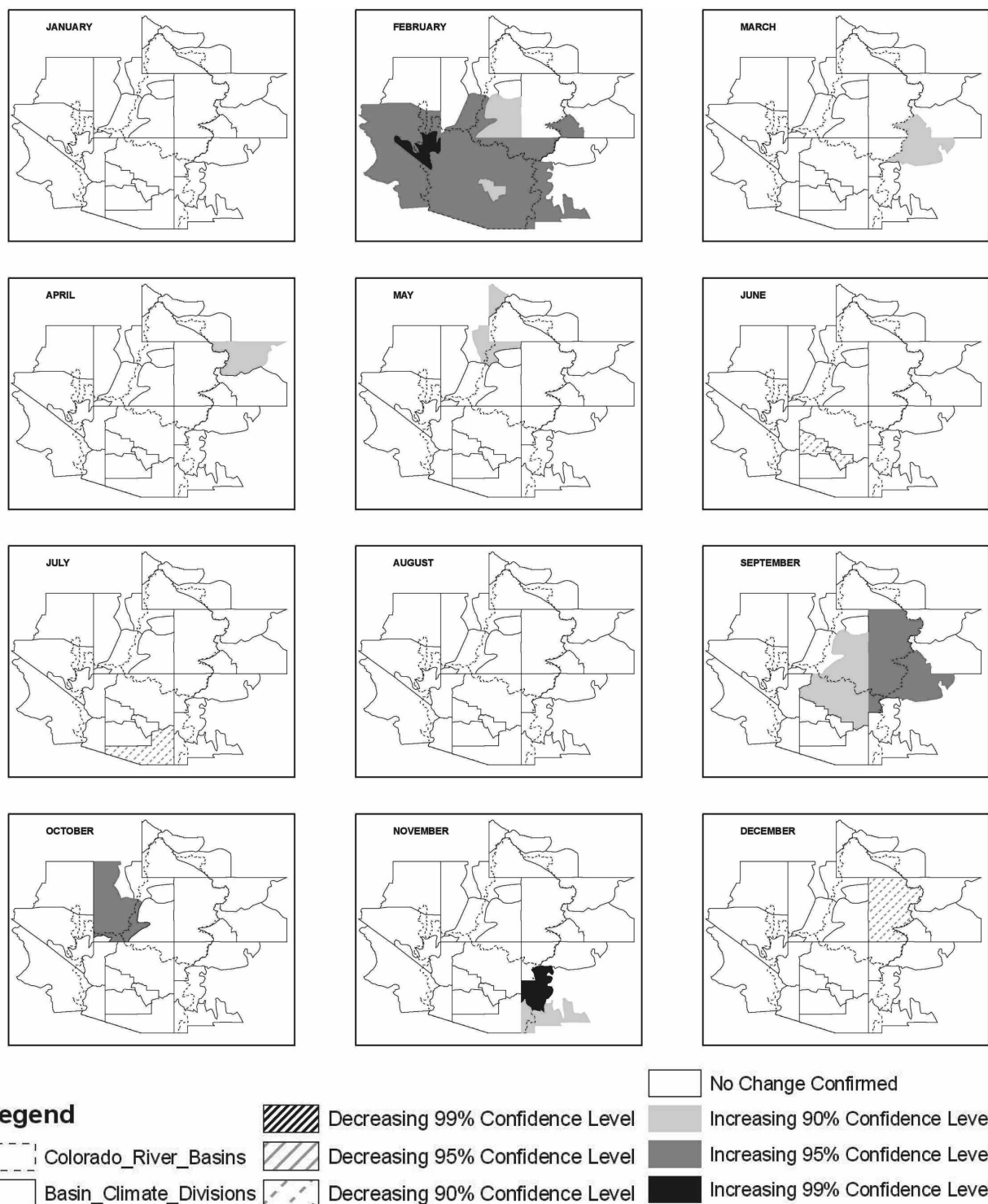


FIG. 5. Same as Fig. 3 but for precipitation.

streamflow observed at USGS gauges with naturalized flow data. Increasing trends and step changes were consistently observed in the upper Colorado River basin in the early part of the year, particularly in January

through March. This corresponds well with trends and step changes observed in precipitation and temperature data observed in the same region over the same time frame. These results agree with previous studies pub-

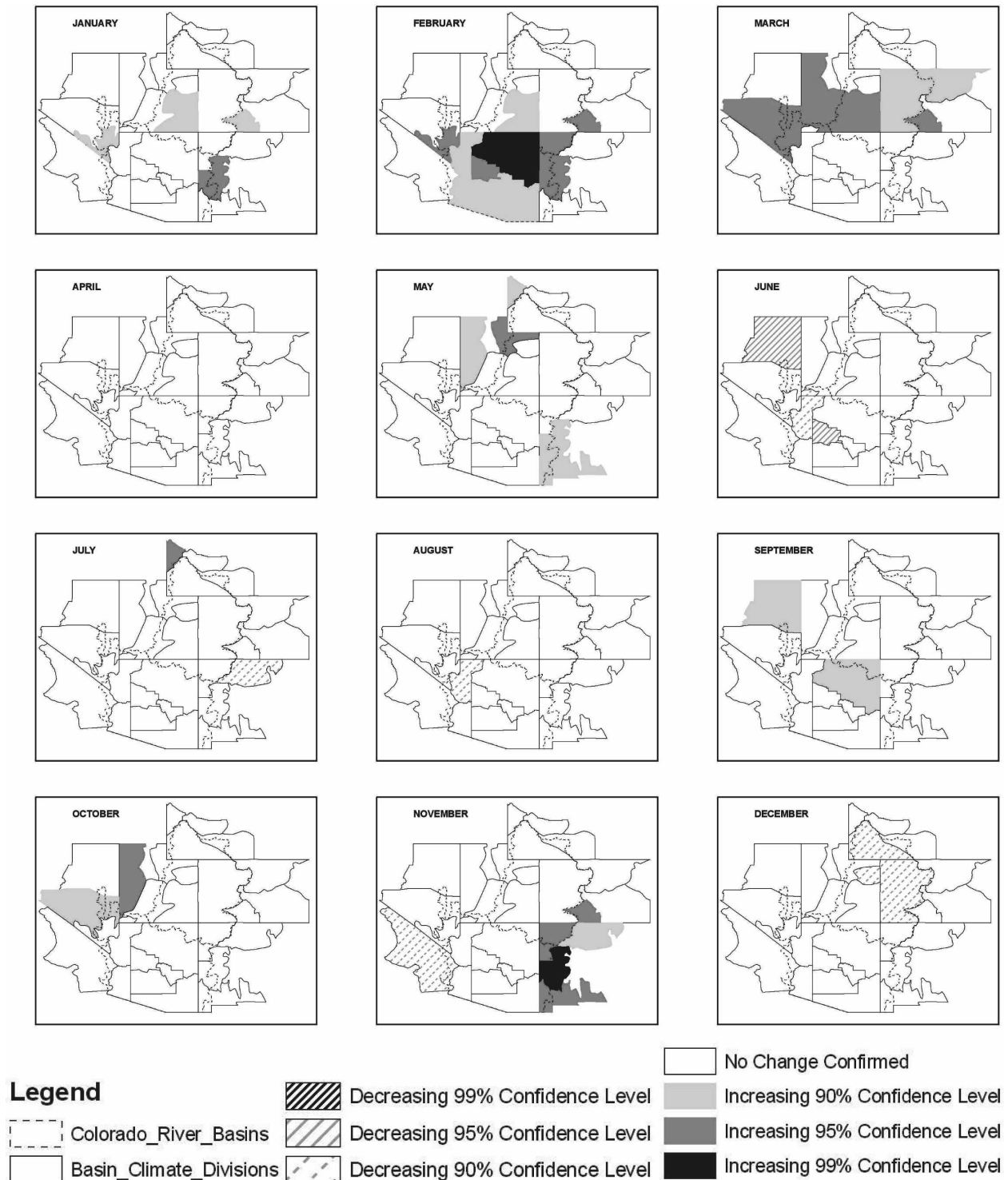


FIG. 6. Same as Fig. 4 but for precipitation.

lished by Lins and Slack (1999), McCabe and Wolock (2002), and Regonda et al. (2005). Interestingly, a corresponding decreasing trend in streamflow in later months is not prevalent in this study. However, this

may be because of a high degree of streamflow variability in the Colorado River basin, particularly during the peak runoff season (e.g., Pagano and Garen 2005). Increased variability of streamflow in the spring and

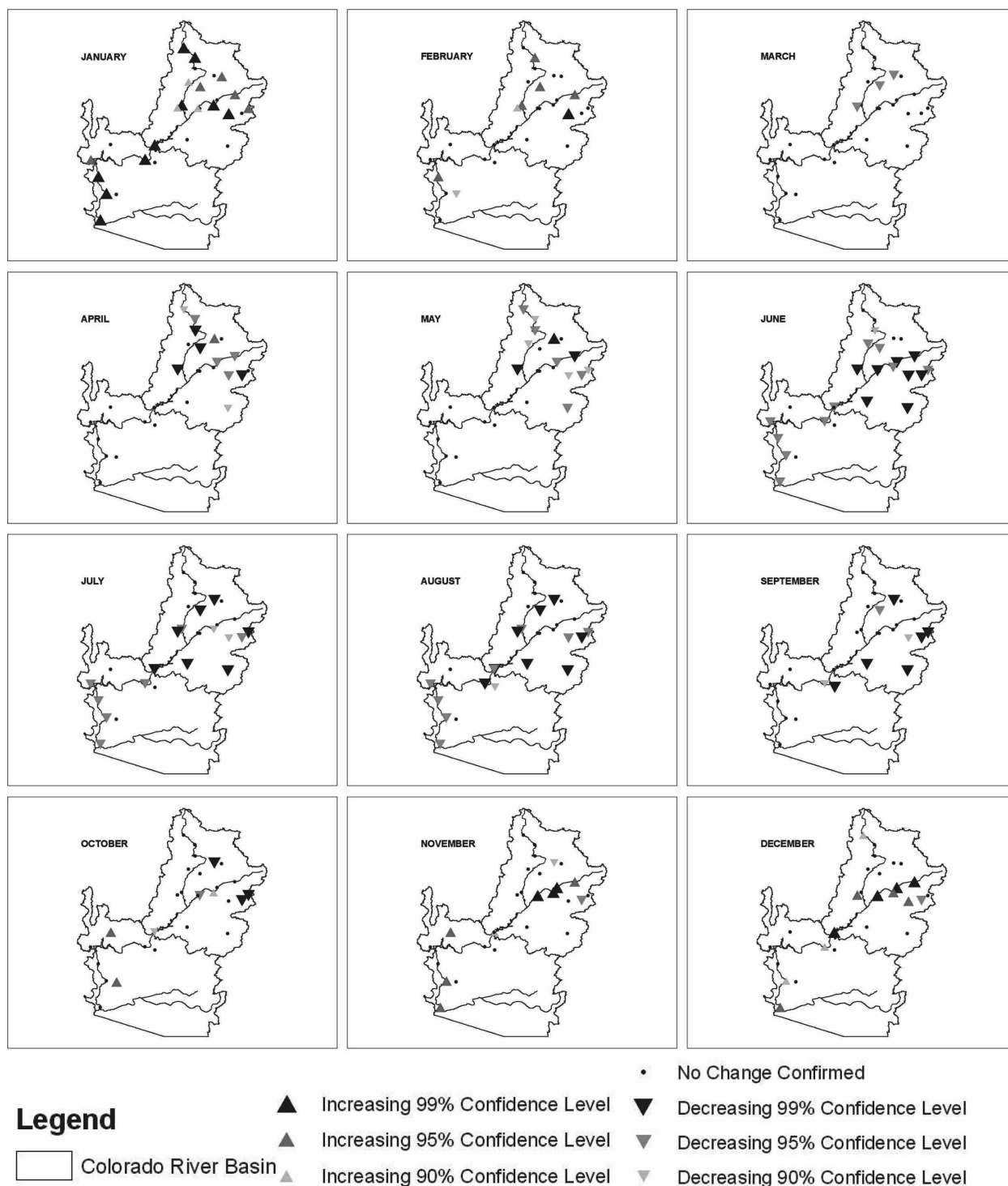


FIG. 7. Trends in natural streamflow data at USGS gauges where natural flow data have been calculated.

summer months may impede the detection of trends or step changes within data by relatively simple statistical tests. Streamflow in fall and winter months is much less variable; thus, changes in observational data can be detected easier.

d. Interdependency of variables

The hydrologic cycle is known to be an interconnected and dependent system, whose complexity is only bounded by the scale in which the system is studied. In

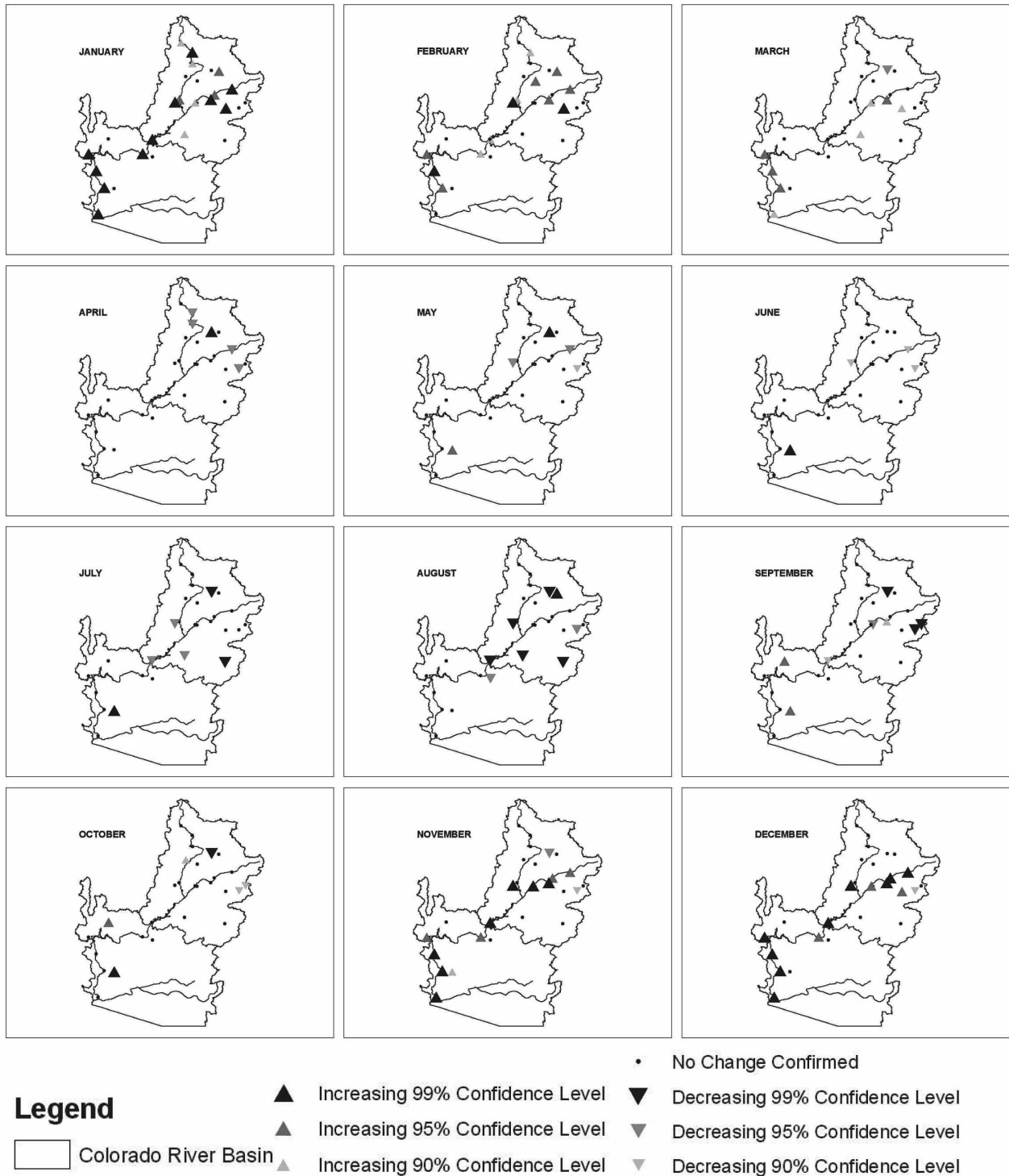


FIG. 8. Same as Fig. 7 but for step changes.

this study, three variables were studied within a complex river basin that is subject to varying and changing hydroclimatic conditions. It is acknowledged that this study does not address variables such as snowpack,

groundwater, or evapotranspiration. However, the interdependency between temperature, precipitation, and streamflow appears to be particularly strong. Figure 9 summarizes the frequency of increasing and de-

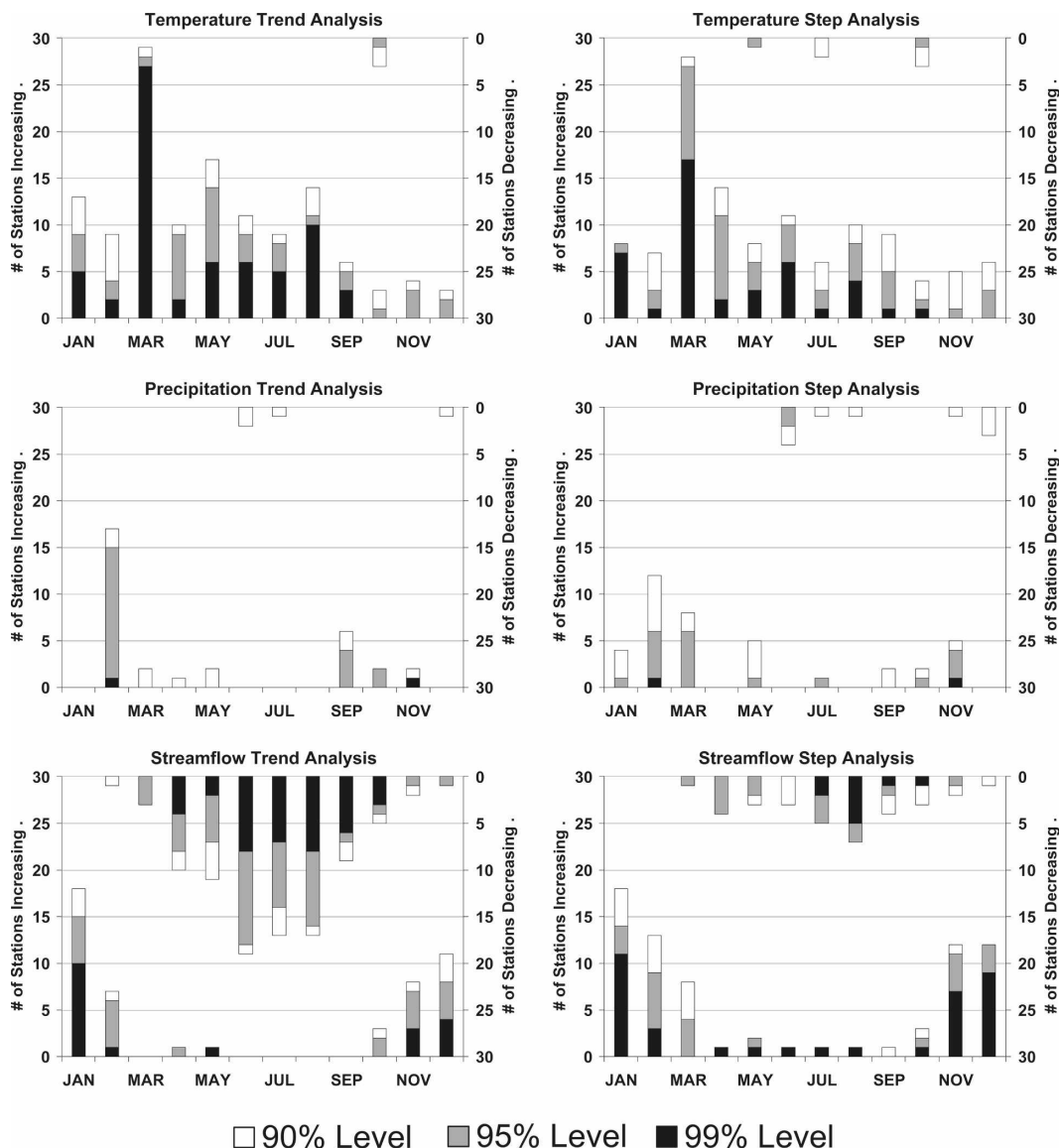


FIG. 9. Plots showing number of stations (29 climate divisions or 29 naturalized flow gauge locations) having increasing or decreasing trends or step changes in Colorado River basin. (left) Observations from trend analysis and (right) observations from step change analysis. In plots, bars along lower horizontal axis correspond to number of stations with increasing trend measured on left vertical axis. Bars along upper horizontal axis correspond to number of stations with decreasing trend measured on right vertical axis.

creasing trends for each variable over the course of the year. Increasing trends in streamflow correspond to increasing trends in temperature and precipitation, particularly during the end and beginning of the water year (October through January). The results indicate that increasing trends in temperature in the Colorado River basin coincided with increases in precipitation, particularly during the early part of the year. In addition, an increase in precipitation coincides with increased streamflow.

The prospect of prolonged and extreme drought and

potential adverse impacts due to climate change are of primary importance to water resource managers in the Southwest and the Bureau of Reclamation (e.g., Bureau of Reclamation 2007) who depend on resources provided by the Colorado River and associated reservoirs. Increasing temperature trends, such as those shown in this study, have been associated with increasing trends in drought duration and drought severity in the Southwest and parts of the interior west (Andreadis and Lettenmaier 2006). Easterling et al. (2007) suggest that increased precipitation since 1980 in the contigu-

ous United States has “masked” drought events predominantly driven by increasing temperature trends. Whereas increasing temperature trends are apparent in this study, precipitation trends are not. Consequently, droughts have not been “masked” in the Colorado River basin; the basin is currently enduring the aforementioned longest drought on the observed record (e.g. Timilsena et al. 2007).

Recent research, such as Huntington (2006), proposes that climate change will lead to an “intensification” of hydrologic processes, such as higher peak streamflow rates, in response to more frequent and intense rainfall events. Although streamflow trends in this study support Huntington (2006), precipitation trends do not. Because precipitation trends are not readily apparent in this study, it is possible that the state (i.e., rain or snow) and interaction of precipitation (e.g., evaporation and seepage losses) are changing. Thus, more attention and research must be focused on the character of precipitation events (e.g., Trenberth et al. 2003).

Although snowpack is not considered in this study, it is possible that decreasing trends in streamflow that are prevalent during the traditional peak runoff season (April through July) are because of a lack of snowmelt contributing to spring runoff. Because there are increasing trends in precipitation during the winter months, it is possible that increasing temperature trends have contributed to an environment that is not conducive to maintaining snowpack reserves.

5. Conclusions

The nature of trends and changes in key hydrologic parameters is critical for long-term water management in the Colorado River basin. In this study, temperature, precipitation, and streamflow data were investigated in an effort to identify trends and step changes apparent between 1951 and 2005. Each parameter was studied over climate divisions or USGS gauge locations encompassing the entire Colorado River basin.

Increasing temperature trends were evident across much of the Colorado River basin. Whereas increasing temperature trends are evident over the entire year, temperature trends were most significant in the first quarter of the year, January through March. Increasing temperature trends correspond well spatially with trends observed in the precipitation record, as increasing precipitation trends were most prevalent in January through March. These findings agree with previous studies, which indicate a correlation between increasing temperatures and precipitation consistent with global warming and climate change research (e.g. Huntington 2006; Hamlet et al. 2005; Alley et al. 2007).

Increasing streamflow trends in January through March and decreasing streamflow trends during peak runoff months (April through July) were seen in this study. This correlates well with findings in Regonda et al. (2005), which indicate peak streamflow rates occurring earlier in the year. Streamflow trends, when taken within the context of these results and previous study, agree with precipitation and temperature trends observed in this study. These results are reasonable when considering the dynamic relationship between the parameters and the possible changing character of precipitation in the Colorado River basin. It is interesting to note that decreasing streamflow trends are apparent at the 99% confidence interval throughout the Colorado River basin during the traditional peak flow months, despite the high variability of streamflow rates that have historically occurred in the Colorado River basin (e.g., Pagano and Garen 2005; Woodhouse and Lukas 2006). Should the current severe drought continue, perhaps streamflow trends will become more prevalent in the winter months, when streamflow rates have been traditionally less variable. Further research needs to be done regarding the changing character and state of precipitation to better assess the impact to streamflow in the Colorado River basin.

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