Trends in both the magnitude and timing of streamflow are of principal interest to water resource managers (Lins and Slack, 1999; McCabe and Wolock, 2002).Similarly, the first day after April 1 when a reported SWE measurement of 0.0 millimeters is observed signals the "melt day," or the end of the snow season during the course of a water year. Additionally, for each water year, the peak SWE and days since the beginning of the water year (October 1) to reach peak SWE are investigated for linear trends. Table 1 summarizes the results of this analysis. Most stations tend to show declining peak SWE observations and occur at an earlier date in the water year. Table 1 also summarizes the amount of stations that exhibit earlier or later initial starts to the snow season and those stations that exhibit earlier or later melt days. The length of the snow season at a particular SNOTEL gage is defined as the duration of time, in days, since the first observation of SWE after the beginning of the water year to the first observation of 0.0 millimeters of SWE after April 1 (i.e., the melt day). Of the SNOTEL gages included in this study, approximately 60% (238 stations) of the gages exhibited a decreasing linear trend in the length of the snow season (Figure 7). Of those gages located within the Colorado River Basin, 66% (52 stations) exhibited a decreasing linear trend in the length of the snow season. The Cascade station in Colorado lost approximately 1.4 days of its snow season over the course of its gage record; conversely, the Hams Fork station in southern Wyoming gained approximately 1.3 days to its snow season over the course of its gage record. The median loss to the length of the snow season over each gage in the Colorado River Basin is approximately 0.2 days. Details are in the caption following the image Figure 7 Open in figure viewer PowerPoint Changes to the Length of the Snow Season Over the Course of the Station Record at Each SNOTEL Station. Dark circles indicate a decrease in the length of the snow season over the period of record for the station. White circles indicate longer snow seasons over the period of record for the station. Table 1 summarizes the potential shift in timing of the snow season throughout the Western U.S. and Colorado River Basin. Those stations showing earlier starts to the snow season and a later melt day also tend to trend toward higher peak annual SWE; conversely, those showing later starts to the snow season and an earlier melt day also tend to trend toward lower peak annual SWE. Most SNOTEL stations in the Western U.S. (235 or 60%) and including those in the Colorado River Basin (49 or 62%) reporting an earlier melt day also show a trend toward earlier peak annual SWE as well. Half of the 238 stations reporting an earlier melt day also report a later start to the snowpack season. Trends in Snowfall and Rainfall Frequency Most SNOTEL stations record SWE and total precipitation daily, regardless of whether that precipitation occurs as snow or rain. The assumption was made that the recording of a precipitation event coupled with an increase to or stationary SWE observation would indicate a snow event, whereas a recording of precipitation coupled with a decrease to the station's SWE observation indicate a rain or rain-on-snow event. Miller and Piechota (2008) hypothesized that rain events over the Colorado River Basin region has increased due to increasing temperature trends in the basin; in turn, a corresponding decrease in snowfall frequency would also be apparent. However, the results of this study do not confirm that hypothesis with any statistical significance using SNOTEL stations and this methodology. A relatively sparse meteorological monitoring network such as the SNOTEL network may not be dense enough to capture potentially spatially localized rainfall events, particularly over the Colorado River Basin. Statistically significant seasonal trends in the frequency of rainfall and snowfall events were not apparent. Despite the lack of statistical significance, it may be worth noting that at the annual time scale, moderate increases in rainfall frequency were observed, as approximately 74% of SNOTEL stations showed an increasing trend (67% of SNOTEL stations located in the Colorado River Basin). The average increase in rainfall frequency was approximately 0.1 days per water year. No consistent trends in snowfall frequency were observed throughout the dataset, although decreasing trends were detected in eastern Utah just inside the Lower Green Headwater Basin on the Wasatch Front Range. The Daniels-Strawberry station at the mouth of the Strawberry River showed a decrease of approximately 1.6 days per water year and contributes to flow in the Green River, a major tributary to the Colorado River. While the results of the current study do not confirm the hypothesis proposed by Miller and Piechota (2008), the results do support those proposed by Huntington et al. (2004) and others regarding hydrologic intensification. The results of the current study do support that the volume of inflow as precipitation over the Western U.S. and Colorado River Basin has decreased over approximately the last 25 years. Trends in Colorado River Basin Streamflow USGS HCDN Streamflow Observations The USGS currently operates 43 stations within the Colorado River Basin that are within the HCDN as described by Slack et al. (1993). It is important to note that while Slack et al. (1993) identified periods of the streamflow record as minimally affected by anthropogenic factors, this study uses the entire period of record at each of these stations. Applying the Kendall's ? statistical test to daily USGS HCDN time-series data revealed interesting trends throughout the Upper Colorado River Basin (Figure 8). Gages in the northern area of the basin located within the Upper Green, Lower Green, and Yampa subbasins yielded frequent decreasing trends at the 99% confidence interval. However, a small cluster of gages in the Gunnison and northern portion of the San Juan subbasins yielded frequent increasing trends at the 99% confidence interval. Details are in the caption following the image Figure 8 Open in figure viewer PowerPoint Trend Results and Confidence Intervals From Kendall's ? Statistical Test Applied Over the Period of Record of Daily Streamflow at Each USGS HCDN Gage. Daily Streamflow Trends Daily time series are investigated over the operational record of the gage for linear trends in annual water year flow volume. Of the 43 stations investigated, 29 (67%) exhibit a decreasing trend in water year flow volume. While the magnitude of decreasing volume range between approximately 4,900 cubic meters (4 acre-feet) and 25.040 million cubic meters (20,300 acre-feet), the average decrease in flow relative to each station is approximately 0.3% per year. Over the Colorado River Basin, 34 stations (79%) exhibited decreasing linear trends in April through July runoff. Again, the average decrease in April through July runoff relative to each station is relatively small and is approximately 0.5% per year. Table 3 shows that most stations (67%) in the Colorado River Basin exhibit both decreasing April through July runoff in conjunction with decreasing water year runoff. Of the 14 stations with increasing trends in water year runoff volume, 9 stations also exhibit increasing April through July runoff; over the Colorado River Basin, the majority of annual runoff has traditionally been observed during these months. There are no stations within the Colorado River Basin that exhibit increasing April through July runoff and decreasing water year runoff. Table 3. Results of Linear Trend Analysis Applied Over Each USGS Station Considered. Streamflow Station Characteristics USGS HCDN 43 Stations Decreasing water year volume 29 (67) Increasing water year volume 14 (33) Decreasing

April-July volume 34 (79) Increasing April-July volume 9 (21) Increasing water year/increasing April-July volume 9 (21) Increasing water year/decreasing April-July volume 0 (0) Decreasing water year/increasing April-July volume 5 (12) Decreasing water year/decreasing April-July volume 29 (67) Earlier peak flow/earlier date to 50% annual flow 32 (74) Earlier peak flow/later date to 50% annual flow 1 (2) Later peak flow/earlier date to 50% annual flow 3 (7) Later peak flow/later date to 50% annual flow 7 (16) Note: Values in parentheses are percentages. Trends in the Timing of Daily Runoff The timing of inflow in the Colorado River Basin is not only important to water resource managers but also to those who benefit from timely inflows impacting hydroelectric and environmental endeavors. For the purposes of this study, the maximum daily flow observed over the course of a water year is referred to as the "peak flow."Investigation into the frequency of precipitation events with a more robust gaging network (e.g., COOP stations) in conjunction with temperature observations may provide improved insight as to the changing character of precipitation in the basin.Whereas Mote (2003) observed less change in SWE at higher elevations (greater than approximately 5,900 feet) in the Pacific Northwest, the results of this study indicate no less potential impacts to SWE at high elevations over the Western U.S. The magnitude of decreasing trends throughout the SNOTEL record is relatively small; however, it is important to interpret these observations as point measurements that are representative of broad spatial areas where a small change in a point SWE observation may represent a large change in the aggregated volume of snowpack over a large area.Reclamation operates the Aspinall Unit (i.e., the system of three dams, Blue Mesa, Crystal, and Morrow Point and their associated reservoirs) within this subbasin to protect endangered fish species within the Gunnison River while also providing water for municipal and agricultural use in accordance with the Aspinall Unit Operations Draft Environmental Impact Statement (U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, 2009).Research has indicated that climate change may significantly impact snowpack and streamflow in snowmelt dominated basins (e.g., Cooley, 1990; Salathe, 2005; Parry and Intergovernmental Panel on Climate Change, Working Group II, 2007) and are indicative of drought and arid conditions in the American Southwest (Seager et al., 2007; Timilsena and Piechota, 2008).Knowles et al. (2006) noted a reduction in the ratio between the winter SWE and total winter precipitation between water year 1949 and 2004 that correlated with changing temperature trends over the Western U.S. Knowles et al. (2006) further found the largest changes to winter precipitation typically occurred in March, supporting other studies indicating a shift in changing character of precipitation (e.g., Serreze et al., 1999; Mote, 2003, 2006; Mote et al., 2005).The majority of stations (74%) yield earlier peak flows and reach 50% of the annual flow earlier, which supports various other studies which have noted a trend toward earlier runoff in the Colorado River Basin (e.g., McCabe and Clark, 2005; Regonda et al., 2005; Stewart et al., 2005; Miller and Piechota, 2008).SNOTEL Station Characteristics Western U.S. Colorado River Basin 398 Stations 79 Stations Decreasing water year precipitation 342 (86) 69 (87) Increasing water year precipitation 56 (14) 10 (13) Decreasing peak SWE/earlier peak 227 (57) 46 (58) Decreasing peak SWE/later peak 69 (17) 18 (23) Increasing peak SWE/earlier peak 57 (14) 10 (13) Increasing peak SWE/later peak 45 (11) 4 (5) Earlier snow/earlier melt 179 (45) 41 (52) Later snow/earlier melt 119 (30) 30 (38) Earlier snow/later melt 68 (17) 5 (6) Later snow/later melt 32 (8) 3 (4) Notes: The number of stations exhibiting a particular behavior is presented with the percentage with respect to the total number of gages presented in parenthesis.Flaming Gorge Dam is operated in accordance with the EIS published by Reclamation (U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, 2005) in order to protect critical habitat for endangered fish species in the region while maintaining water use development goals under the Colorado River Storage Project.With continued drought and decreased spring runoff, water resource managers and water supply forecasters must continue to investigate methods to improve projections of water supply as the climate changes in addition to continuing effective water management policies and conservation practices.Due to increasing temperatures, research has shown a trend toward earlier spring runoff in both observed data (e.g., Cayan et al., 2001; Mauget, 2003; Regonda et al., 2005; Stewart et al., 2005; Kalra et al., 2008; Miller and Piechota, 2008) and modeled data (e.g., Hamlet et al., 2005, 2007; Maurer and Duffy, 2005).The Navajo Reservoir is operated under accordance with Environmental Impact Statement published by Reclamation (2006) and in conjunction with the Fish and Wildlife Service's (FWS) San Juan River Basin Recovery Implementation Program (U.S. Fish and Wildlife Service, 2006) in an effort to protect critical habitat to endangered fish species in the basin.Methodology Trends in hydroclimatic observations from SNOTEL and USGS stations are investigated using Kendall's tau (?) nonparametric test for monotonic trend with a correction for ties.Details are in the caption following the image Figure 2 Open in figure viewer PowerPoint The Spatial Distribution of (a) SNOTEL Gages Over the Western U.S. and (b) USGS HCDN and Reclamation Natural Flow Stations Over the Colorado River Basin Included in This Study.It is acknowledged that the length of this record is relatively limited compared to snow records used in other studies (e.g., Knowles et al., 2006), and that it is often desirable to have longer periods of record to evaluate statistically significant trends.Due to the short length of the SNOTEL record, the presence of persistent drought over the majority of most stations' records, and temporal variability over the gage records, there is a lack of statistical significance in the daily records of cumulative water year precipitation.Figure 6 shows the results of Kendall's ?-test over daily observational SWE time series derived from each of the SNOTEL stations included in this study over the continental U.S. Of the 398 stations for which the Kendall's ?-test are applied, approximately 72% (287 stations) indicate a decreasing trend at the 90% confidence interval; 69% (275 stations) indicate a decreasing trend at the 99% confidence interval.Trends in the Timing Characteristics of Snow Season For the analysis here, it is assumed that a reported SWE measurement >0.0 millimeters indicates the presence of snowpack at a particular station; as such, the first indication of snowpack during the water year is interpreted from reported SNOTEL measurements.The subbasin contributes approximately 13.2% of the annual water year runoff to the Colorado River and is primarily regulated by Reclamation through the Fontenelle and Flaming Gorge Dams.Based on daily SNOTEL observations, the length of snowpack season has shortened during this period of drought, and corresponds to below average aggregate April through July runoff in Colorado headwater river basins.Essentially, Kendall's ?-108?22?-107?3?-108?3?-106?44?-107?17?-107?46?-107?37?-107?30?-107?15?-106?48?-107?21?-106?36?-107?9?-107?3?-107?30?-106?57?-106?46?-106?36?-106?40?-105?50?-107?42?-105?38?-105?32?-106?3?-105?7?-105?11?-106?40?-105?45?-107?48?-106?10?-106?58?-107?43?-107

??52?-106?20?-106?50?-106?22?-106?6?-105?46?-105?46?-105?53?-105?35