Title

Percent bias assessment of water supply outlooks in the Colorado River basin

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PERCENT BIAS ASSESSMENT OF WATER-SUPPLY OUTLOOKS IN THE COLORADO RIVER BASIN

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ABSTRACT

Water-supply forecasts on various watersheds are intended to predict the April through July (snowmelt) runoff and assist in estimating the total water-year runoff, and are thus are very important to users of water from those watersheds. Water-supply outlooks, a type of forecast, are made on major contributing watersheds of the Colorado River. This study reviewed the characteristics of twenty-eight watersheds on the Colorado River. During that review, a strong linear relationship was found between watershed elevation and yield. As elevation increased, the runoff yield increased in a linear fashion. When studying the relationship between runoff and area, it was found that there was a non-linear relationship between increasing area and increasing runoff. The skill level of April to July forecasts was examined using percent bias as a representative summary measure of forecast skill. Review of percent bias of forecasts during dry, near normal and wet years indicates that in dry years the forecasts have a positive bias while those in wet years have a negative bias. Forecasts for near normal runoff years show limited or no bias toward over or under prediction. Seventy percent of the values for the absolute value of percent bias for individual forecasts were 40 percent or less. (KEYWORDS: bias, forecast, runoff, forecast skill, Colorado River)

INTRODUCTION

The Colorado River basin in the western United States encompasses one-fifth the area of the continental United States over seven states, with an area of 242,000 square miles. Snowmelt runoff from the seasonally snow-covered mountains that comprise the headwaters of watersheds within the Colorado River basin provide water to a significant area of the southwestern United States. Water managers use seasonal water-supply outlooks, which are prepared monthly during the snow accumulation and ablation periods to effectively plan and schedule water deliveries, releases and transfers within the basin. The forecasts are prepared jointly by the Natural Resources Conservation Service (NRCS) and the National Weather Service (NWS) (Pagano et al., 2004). The basis for the forecasts is mainly the relations between snow conditions, precipitation and discharge, primarily naturalized flow in past years. These predictions use primarily information on snowpack, and precipitation and hydrologic conditions to make statistical forecasts of runoff volume past the forecast point for a specified period of time. These water-supply outlooks have been prepared on some Colorado River watersheds since the 1950's. In much of the basin, the outlooks are issued from January to May and are intended to forecast runoff in the April through July period (CBRFC, 2013). The investigation of the skill of water-supply forecasts in the Colorado River basin reported here assesses patterns across the basin and identifies characteristics of forecast points with different skill levels.

Evaluations of Forecast Skill

In addition to the water-supply outlooks for the Colorado River Basin, water-supply forecasts are also made on other watersheds in the western United States, including locations in California. Evaluations of the skill of these various forecasts were made in the late 1950's on various subsets of these forecasts. Additional work to evaluate forecast skill was done again in the mid 1980's. Starting in 2002, the latest work was initiated to evaluate the skill of water-supply forecasts in the western United States.

In 2004, Pagano evaluated forecasts using Nash-Sutcliffe scores and other measures on 29 unregulated rivers in the western United States (Pagano et al., 2004). The report also presented a historical review of skill assessment reports for water-supply forecasts. Pagano found high skill for forecasts issued on 1 April. Forecasts made earlier in the season contained more uncertainty but were shown to still be skillful. Pagano also found that areas with wet winters and dry springs presented higher forecast improvement over the forecast season than areas with dry winters and wet springs. Pagano also found mixed changes in skill over time when comparing different areas of the study. In 2006, Hartmann and others performed an assessment of water-supply outlooks in the Colorado

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River Basin which established a baseline for identifying improvements in hydrologic forecasts (Hartmann et al., 2006). The work by Morrill and others was an assessment of the strengths and weaknesses of seasonal water-supply outlooks at fifty-four sites in the Colorado River basin using an assortment of skill measures (Morrill et al., 2007). Morrill found that the water-supply outlooks were an improvement over climatology during the historical record for most sites. They also found that most of the forecasts were conservative, with above-average flows under predicted and below-average flows over predicted. The reports of Pagano, Hartmann and Morrill provide an excellent starting point for the skill evaluation of seasonal water-supply outlooks for the Colorado River basin.

In order to evaluate the skill of the forecasts, a method of quantitatively evaluating the forecasts versus the observed flows was needed. Pagano noted that one challenge in forecast evaluation was to normalize forecast errors to allow a fair comparison between small streams and larger rivers. Pagano maintained that it is desirable that the evaluation measures be chosen carefully so they are understandable and relevant to forecast users. A set of Matlab scripts developed to calculate various forecast skill measures which were used during the Morrill investigation were reviewed. Based on these criteria, the Percent Bias was chosen for this introductory review of forecast skill.

$$Percent\ bias\ = \left(\frac{forecast - observation}{observation}\right) x\ 100 \qquad (1)$$

As shown in Equation 1, percent bias (pbias) is the error in the forecast (forecast – observation) normalized by the observation. The best percent bias is zero, with positive scores indicating over forecast (forecasts exceeding the observation) and negative scores indicating under forecast (forecasts less than the observation).

ANALYTIC PROCEDURE

Source of Data

Forecast and observation data for twenty-eight locations that currently forecast April to July runoff were obtained from the Colorado Basin River Forecast Center (CBRFC) (CBRFC, 2013). The April through July forecast period was chosen to enable comparison between similar forecast periods at the various locations in the western United States, including California. Hydrologic information such as gage elevation, watershed area and map coordinates for each forecast point was obtained from the USGS NWIS system (USGS, National Water Information System). All the forecasts were made after 1950, and the record usually extended to 2012 but with considerable variation in time period covered. The forecasts examined in this study were made monthly from January to May. The forecasts were an estimate of the water volume in thousands of acre-feet (taf) passing the forecast point during the forecast period. The actual forecast period at the various forecast locations showed considerable variation over the historical record. Many of the early forecasts were based on a forecast period from April through September. In the 1960's, forecasts were made with the beginning of the forecast period corresponding with the month of forecast. In other words, a March forecast would be March through September, and an April forecast would be April through September. Since the 1980's, most forecasts use an April through July forecast period, which corresponds with the April through July forecast period in the western Sierra Nevada of California. Data used in this study included the forecast period (for example April through July), month of forecast (January, February, March, April or May for this study), forecast flow in thousand acre feet (taf), observed flow (taf), "reasonable" maximum and minimum flow percent of average for forecast period, and mean flow for the forecast period.

The twenty–eight forecast locations are shown in Figure 1 along with state boundaries, a graphic representation of watershed hydrology showing HUC designations, and a graphic representation of topography. Details of the forecast points are shown in Table 1. The table shows the site number, the descriptive location of the gage, the NWS designation, the USGS designation, the measurement characteristic of the location (observed or naturalized flow), the elevation of the gage, the start year and end year of the data at that location, and the decimal latitude and longitude of the location. Observed flows are flows that can be directly observed and are generally found in headwater basins with very few diversions and no large reservoirs that impact the natural flow (personal communication, CBRFC, 2013). Naturalized flows are calculated to estimate the unregulated flow at the measurement point, with allowance for diversions and/or reservoirs in the contributing watershed.

RESULTS AND DISCUSSION

Basin Characteristics

The forecast points covered a wide range of elevation and areas across the upper and lower Colorado River basin and the basin characteristics add context to the percent-bias analysis. The highest forecast point was #10 - Blue River inflow to Dillon Reservoir, CO. at 8760 feet. The lowest forecast point was #1 – Virgin River at Virgin UT at 3500 ft. The largest watershed which also had the highest flow was #19 – Lake Powell at Glen Canyon Dam with an area of 111,700 square miles, and average forecast flow of 7155 (taf). The smallest watershed, which also had the smallest flow, was #15 – Ashley Creek near Vernal, UT with an area of 101 sq. miles, and an average flow of 50 taf.

The mean volume of flow for the latest forecast period was obtained from the forecast and observation data set, and area of the drainage area in square miles was obtained from the USGS records for the twenty-eight sites, as shown in Table 1. These data enabled calculation of the watershed yield in feet for the locations. The April through July yields range from a low of 0.07 feet on the relatively low elevation #16-San Juan River to a maximum of 1.11 feet on the relatively high #2-Lake Granby inflow.

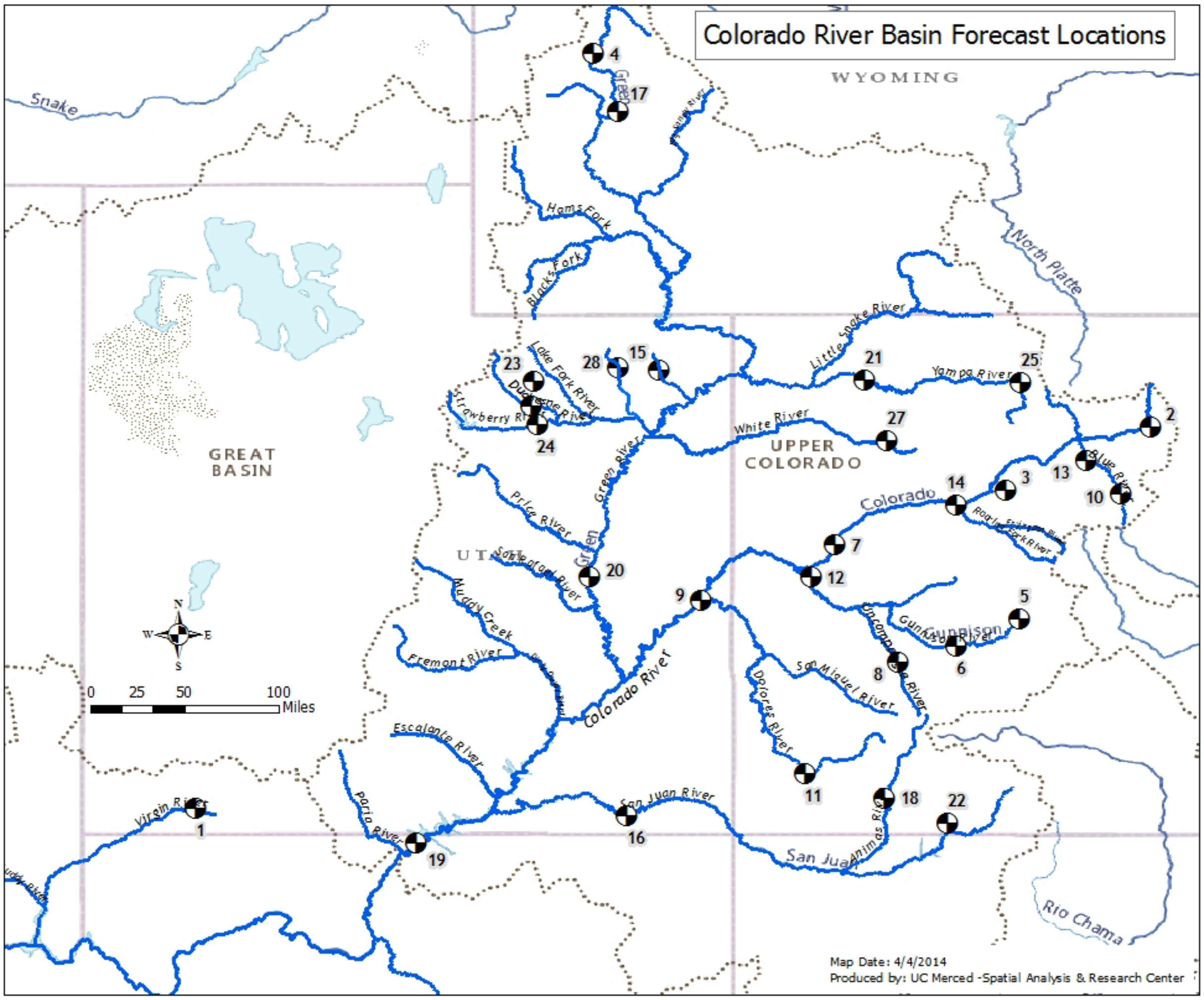

Figure 1. Map of Forecast Points – See Table 1 for names and characteristics

Table 1. Location summary and yield calculation

Site No.	Location	NWS	USGS	Type	Elevation Ft.	Start Year	End Year	Lat.	Long.	April July Mean TAF	Area Sq Miles	Calc Yield Ap-Jul Ft.
1	VIRGIN RIVER AT VIRGIN, UT	VIRU1	9406000	Observed	3,500	1958	2012	37.204	-113.180	58	956	0.09
2	COLORADO RIVER BELOW LAKE GRANBY, CO.	GBYC2	9019000	Naturalized	8,050	1954	2013	40.140	-105.835	221	312	1.11
3	EAGLE RIVER BELOW GYPSUM, CO	GPSC2	9070000	Naturalized	6,275	1975	2012	39.649	-106.953	336	944	0.56
4	GREEN RIVER AT WARREN BRIDGE, NEAR DANIEL, WY	WBRW4	9188500	Observed	7,469	1958	2011	43.019	-110.119	243	468	0.81
5	EAST RIVER AT ALMONT, CO	ALEC2	9112500	Naturalized	8,006	1957	2012	38.664	-106.848	182	289	0.99
6	GUNNISON RIVER INFLOW TO BLUE MESA RESERVOIR	BMDC2	9124800	Naturalized	7,519	1972	2012	38.451	-107.332	676	3,510	0.30
7	COLORADO RIVER NEAR CAMEO, CO	CAMC2	9095500	Naturalized	4,814	1957	2012	39.239	-108.266	2,357	8,050	0.46
8	UNCOMPAHGRE RIVER AT COLONA, CO	CLOC2	9147500	Naturalized	6,319	1954	2012	38.331	-107.779	137	448	0.48
9	COLORADO RIVER NEAR CISCO, UT	CLRU1	9180500	Naturalized	4,090	1957	2012	38.811	-109.293	4,440	24,100	0.29
10	BLUE RIVER INFLOW TO DILLON RESERVOIR,CO	DIRC2	9050700	Naturalized	8,760	1972	2012	39.626	-106.066	163	335	0.76
11	DOLORES RIVER AT DOLORES, CO	DOLC2	9166500	Observed	6,940	1954	2012	37.473	-108.497	247	504	0.76
12	GUNNISON RIVER NEAR GRAND JUNCTION, CO	GINC2	9152500	Naturalized	4,628	1954	2012	38.983	-108.450	1,478	7,928	0.29
13	BLUE RIVER INFLOW TO GREEN MOUNTAIN RESERVOIR, CO	GMRC2	9057500	Naturalized	7,683	1954	2012	39.880	-106.333	275	599	0.72
14	ROARING FORK AT GLENWOOD SPRINGS, CO	GWSC2	9085000	Naturalized	5,721	1954	2012	39.544	-107.329	692	1,453	0.74
15	ASHLEY CREEK NEAR VERNAL, UT	ASHU1	9266500	Observed	6,231	1954	2012	40.578	-109.621	50	101	0.77
16	SAN JUAN RIVER NEAR BLUFF, UT	BFFU1	9379500	Naturalized	4,048	1957	2012	37.147	-109.864	1,095	23,000	0.07
17	NEW FORK RIVER NEAR BIG PINEY, WY	BPNW4	9205000	Observed	6,800	1975	2012	42.567	-109.929	355	1,230	0.45
18	ANIMAS RIVER AT DURANGO, CO	DRGC2	9361500	Observed	6,502	1954	2012	37.279	-107.880	417	692	0.94
19	LAKE POWELL AT GLEN CANYON DAM, AZ	GLDA3	9379900	Naturalized	3,715	1964	2012	36.937	-111.483	7,155	111,700	0.10
20	GREEN RIVER AT GREEN RIVER, UT	GRVU1	9315000	Naturalized	4,040	1957	2012	38.986	-110.151	2,960	44,850	0.10
21	YAMPA RIVER NR MAYBELL, CO	MBLC2	9251000	Naturalized	5,900	1957	2012	40.503	-108.033	936	3,410	0.43
22	PIEDRA RIVER NEAR ARBOLES, CO	PIDC2	9349800	Observed	6,148	1972	2012	37.088	-107.397	209	629	0.52
23	ROCK CREEK NEAR MTN HOME, UT	ROKU1	9279000	Naturalized	7,250	1965	2012	40.493	-110.578	88	147	0.94
24	STRAWBERRY RIVER NEAR DUCHESNE, UT	STAU1	9288180	Naturalized	5,722	1954	2012	40.155	-110.554	125	917	0.21
25	YAMPA RIVER AT STEAMBOAT SPRINGS, CO	STMC2	9239500	Naturalized	6,695	1954	2012	40.484	-106.832	258	568	0.71
26	DUCHESNE RIVER NEAR TABIONA, UT	TADU1	9277500	Naturalized	6,190	1954	2012	40.300	-110.602	108	353	0.48
27	WHITE RIVER NEAR MEEKER, CO	WRMC2	9304500	Observed	6,300	1954	2012	40.034	-107.862	278	755	0.58
28	WHITEROCKS RIVER NEAR WHITEROCKS, UT	WTRU1	9299500	Observed	7,200	1954	2012	40.594	-109.932	54	109	0.77

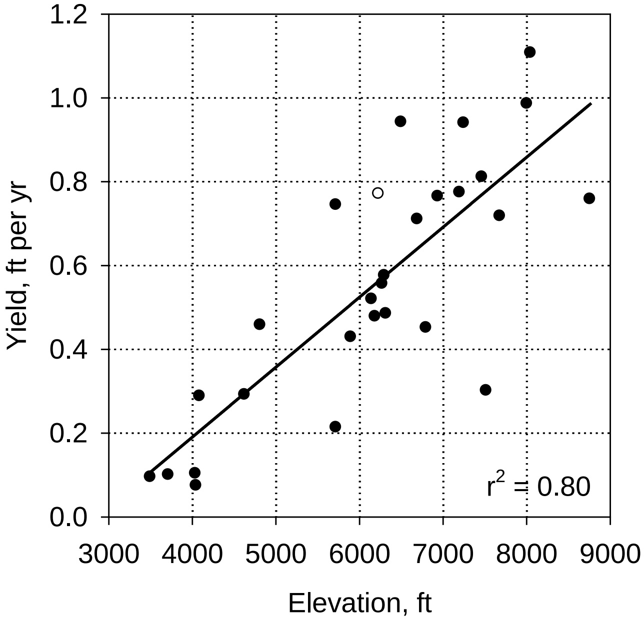

Figure 2 shows that yield increases with increasing elevation at the 28 gage locations, with the least-squares line illustrating this relationship, with an r^2 of 0.80. This relationship may be due to increased orographic precipitation at higher elevation, increased impervious substrate at higher elevation, fewer trees or vegetation at higher elevation, or a combination of the above factors. There are random components of each calculated yield as shown by the moderate amount of scatter in the graph. These random components may be due to watershed vegetation cover, rock cover, aspect (direction the watershed faces), plus possibly the influence of neighboring topography on the usual storm direction.

Figure 2. Watershed yield and elevation – data from Table 1

Figure 3 presents a relationship between increasing watershed area and increasing watershed runoff during the April through July period. Both the runoff and area are represented on a linear scale in the left panel of the graph. In the right panel, the area is represented by a logarithmic scale. The relationship between area and runoff is strong with an r^2 of 0.93. The non-linearity in the relationship observed in the left panel and also shown in the right panel may arise from the information that as the area of the watershed increases, increasing areas of low elevation or desert areas are included in the watershed, thus the reduction in increased runoff as the size increases. There is an increase in variability of runoff in the mid to higher discharges, which may attenuate at the highest discharges. This may be explained by noting that the mid-sized watersheds may contain a more heterogeneous mix of characteristics than the smaller watersheds. The largest watersheds would have a more expected or “average” mix of characteristics.

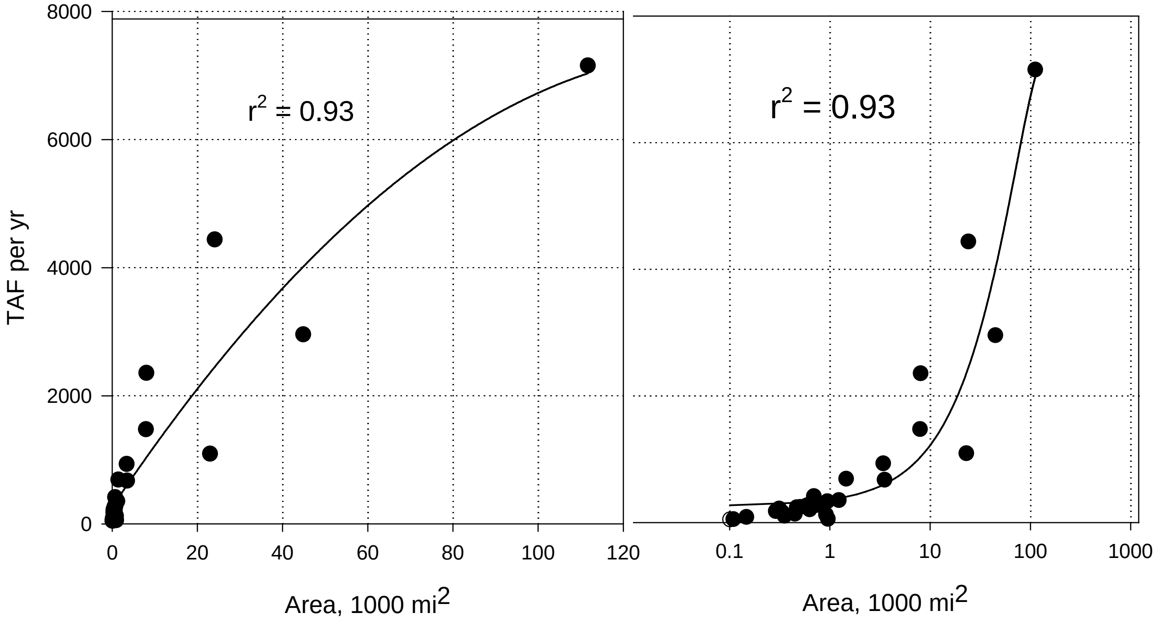

Figure 3. Runoff as function of watershed area – Data from Table 1

Forecast Skill

Figure 4 consists of two panels of information on site #4, the Green River. The bottom panel shows the anomaly of the April through July runoff separated into three flow magnitudes. The first set is the years with a fraction of less than or equal to 0.30 which are the "low" flows. The "mid" flows have a fraction of greater than 0.30 and less than or equal to 0.70. The "high" flows have a fraction of greater than 0.70. The interannual variability of runoff is shown clearly in the bottom panel along with multi-year flow regimes. There is a tendency for a dry year to follow a dry year for up to two years and wet years to follow wet years for up to four years. The top panel shows the time series of percent bias categorized by these three types of runoff years. Using the year 1970 as an example, the bottom panel indicates that the observed runoff was slightly drier than normal, yet still classified as a mid-flow year. The top panel shows that there was no bias in the forecast; the forecast was equal to the observation. Another observation is that there are really a limited number of years with very small (less than +/-5%) percent bias.

A summary of the percent-bias analysis from the top panel is contained in Table 2. It indicates that the low flows have a mixed tendency to over forecast (7 occurrences) or under forecast (5 occurrences). There are more over forecasts for mid flow than under forecasts. The high flows are definitely under forecast with 12 under forecasts and only 2 over forecasts.

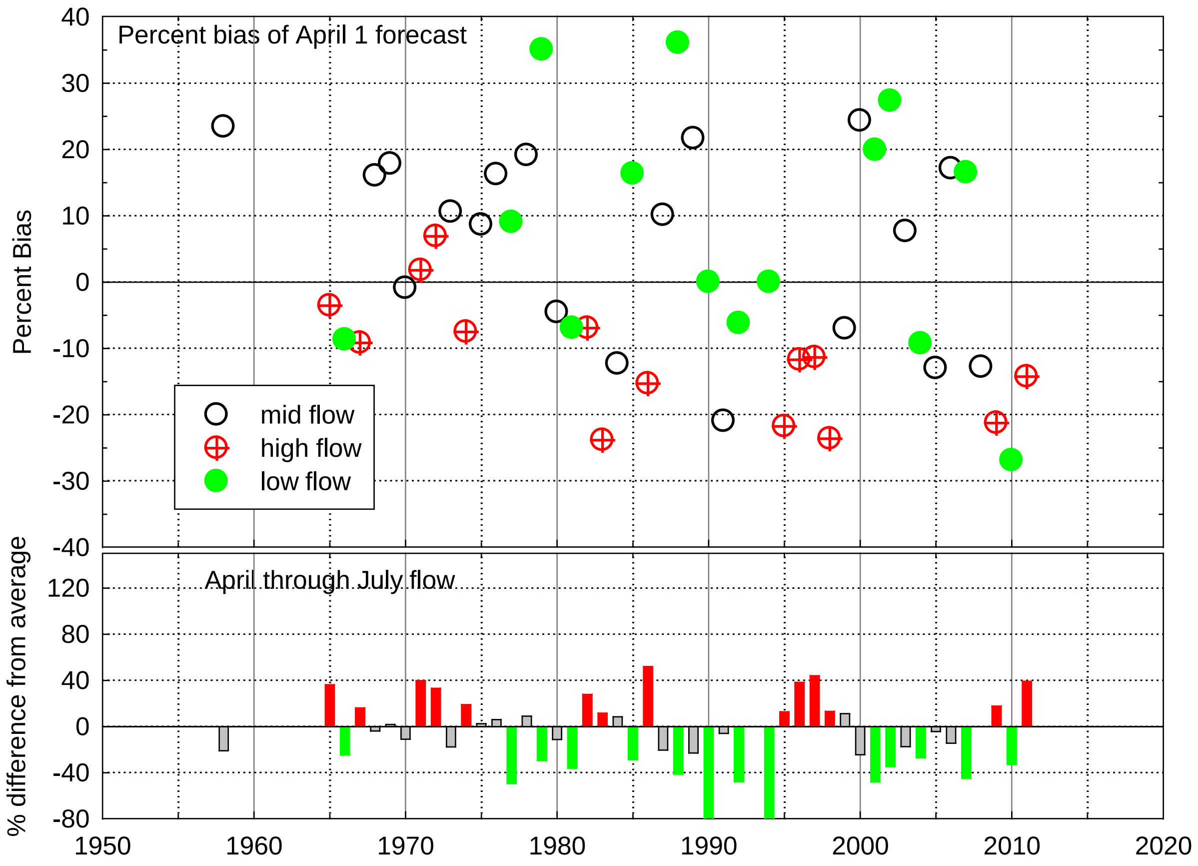

Figure 4. Percent Bias time series for #4 - Green River

Table 2. Summary of percent bias for #4 – Green River

	Low	**Mid**	**High**
Over forecast (+)	7	12	2
Under forecast(-)	5	6	12

Figure 5 is similar to the previous figure but is for the East River. At this location, there is a tendency for dry years to follow dry year for up to four years and wet years to follow wet years for up to four years. The summary contained in Table 3 indicates that the low flows are over forecast (13 to 0). According to the top panel in Figure 5, forecasts for years with mid flows appear equally located around zero bias with a tighter distribution than seen on the Green River. The information for mid flows in Table 3 does not indicate a tendency toward over or under forecasting. There is a definite tendency to under forecast the high flows (3 over forecast to 13 under forecast). Review of the percent bias graphs for the remaining 26 forecast points indicates that the remaining point have similar distributions as Figure 5 and the information from Figure 5 and Table 3 is representative of other locations.

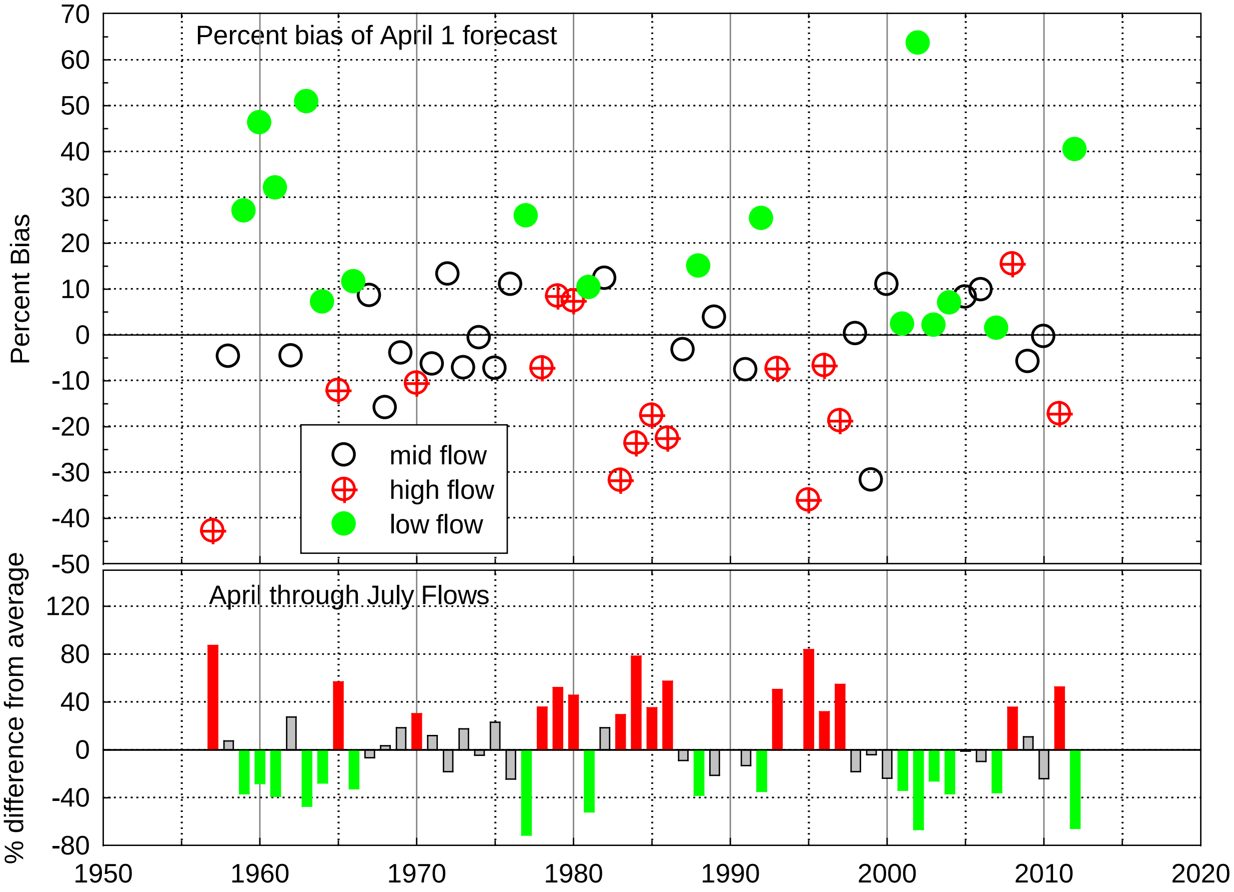

Figure 5. Percent Bias time series for #5 - East River

Table 3. Summary of percent bias for #5 – East River

	Low	**Mid**	**High**
Over forecast (+)	13	8	3
Under forecast(-)	0	11	13

It has been seen that the percent-bias values are distributed around zero. It is therefore helpful to calculate the absolute value of the percent bias as a measure of the magnitude of forecast bias. Figure 6 shows the mean and dispersion of the absolute value of the pbias scores for each of the watersheds in the study. The box graphs are interpreted as follows. The highlighted bar extends from the 25th percentile to the 75th percentile, with the median shown as a vertical line. The vertical tics are the 10th percentile and the 90th percentile. The table entries are ranked top to bottom by increasing April through July flows. Most of the scores are contained within the range of 0 to 30%, with #24 – Strawberry River appearing to be an outlier. Upon review of the data for #24, the high pbias scores for the location were determined likely be correct as they appear when there is a very dry year and the forecasting process lags to some extent the deteriorating water supply. The width of the 25/75 percentile box in the box plot is similar in span (30%) for most of the forecast locations. There is a somewhat variable upper tail of the distribution, which is especially visible in the smaller watersheds. Another conclusion from reviewing the graph is the median percent bias exhibits more variability than the width of the 25/75 percentile box.

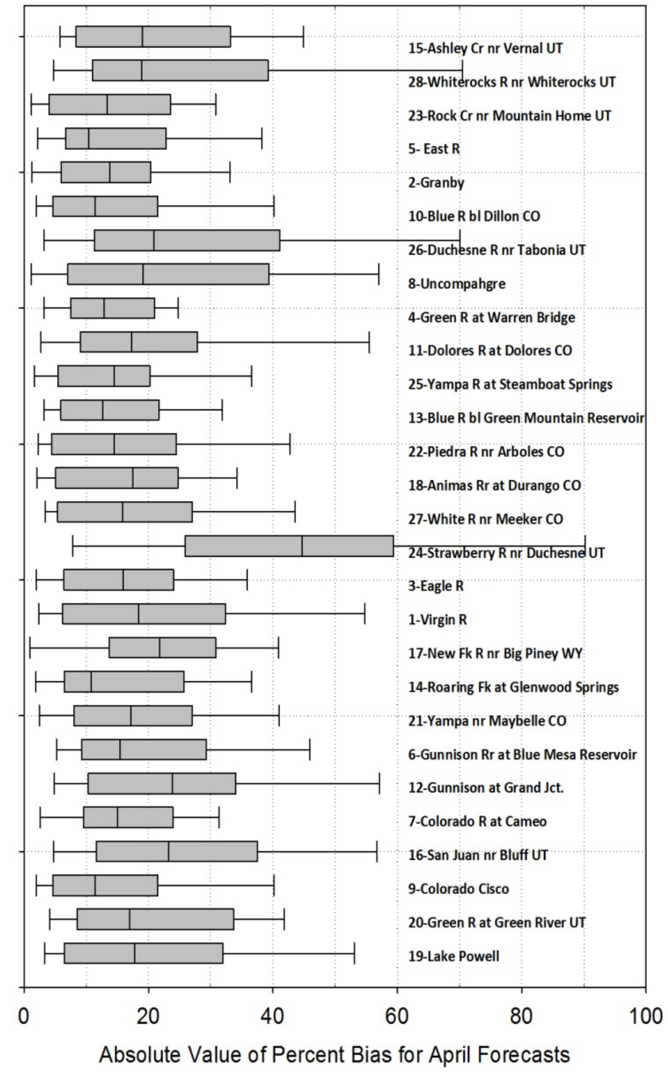

Figure 6. Absolute value of April 1 percent bias arranged by increasing flow; top to bottom

Figure 7 is a two-panel graphic with the distribution of percent bias shown in the lower panel, and the distribution of the absolute value of percent bias in the top panel. Each of the 28 locations is a separate line. The percent bias scores in the lower panel are approximately centered on the median at 0 pbias with a disproportionate increase on the high pbias scores. The traces in the lower panel show the fairly tight distribution of percent bias due to the plus and minus scores. The apparent outlier visible in the negative percent bias score portion of the graphic is again location #24.

The upper panel of Figure 7 shows the distribution of the absolute value of pbias. The graphic shows that approximately 70 percent of the absolute values of percent bias for the individual forecasts are 40 percent or less. Again, one watershed, #24- Strawberry appears as an outlier with high absolute value of pbias scores in the upper panel. The same explanation for the outlier as on Figure 6 seems reasonable. The extensive upper tail in both panels is a more clear visualization of the upper tail appearing in the box graphs of Figure 6.

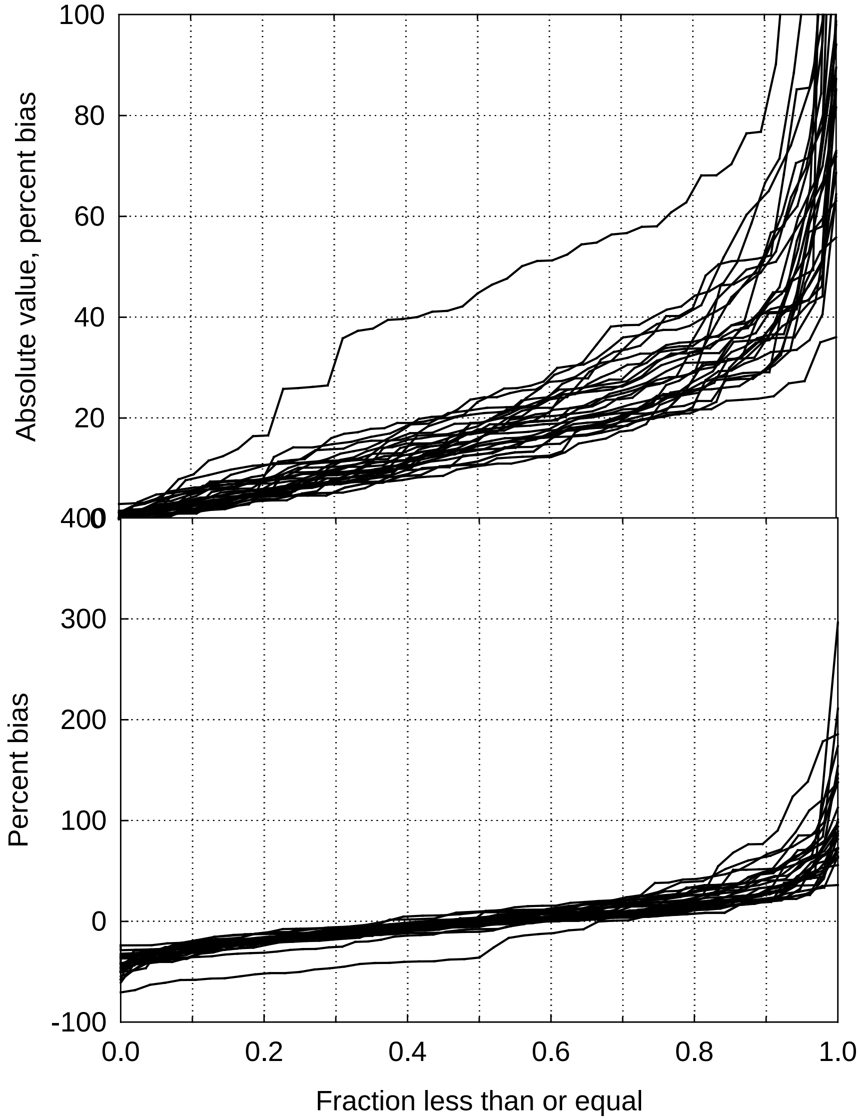

Figure 7. Percent Bias and Absolute Value of Percent Bias distributions

Figure 8 shows the distribution of percent bias for low, mid and high flows on six representative watersheds. The box plot is interpreted similarly as discussed for Figure 6. The pbias scores for the low flow years have considerable variability, with the median varying from nearly zero to nearly 40%. There are long upper tails for the pbias in low flow years, primarily due to the magnification of the error when dividing by a smaller observed flow. The percent bias for mid flow years exhibits the tightest distribution, with the median around zero. For the high flow forecast years, the median percent bias is negative, roughly around -20%. The high flow pbias also exhibit a tight distribution with the 10th percentile about -40%.

CONCLUSIONS

This investigation has illustrated several important characteristics of watersheds and runoff forecasts within the Colorado River Basin. The data assembled for the study presented an opportunity to calculate the runoff yield for twenty-eight of the watersheds. A strong relationship between increasing watershed yield and increasing watershed elevation was demonstrated. In addition, a relationship between increasing watershed area and increasing runoff

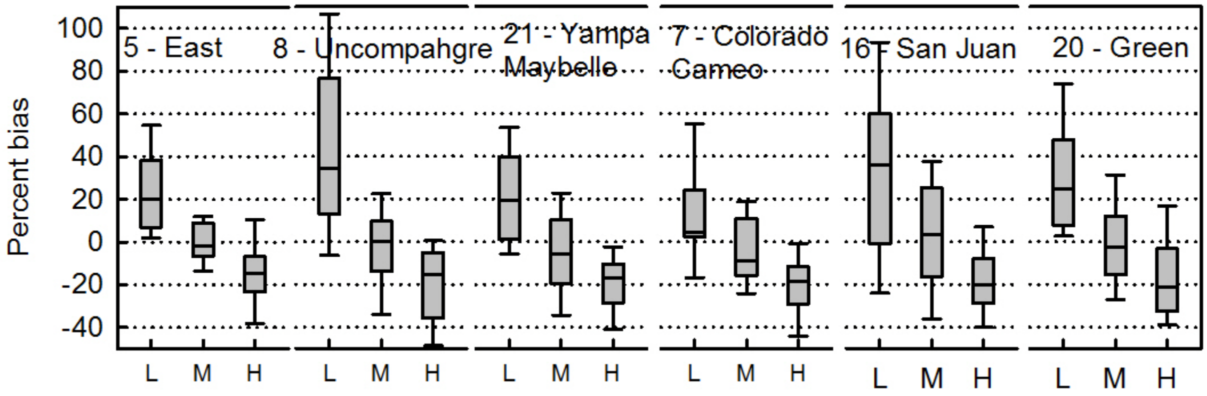

Figure 8. Percent Bias for selected watersheds

was shown but with a decreasing contribution to runoff as the size increased. This may be due to increasing areas of low runoff that are included in the watershed as the size of the watershed increases. Examination of the percent bias time series for two of the watersheds indicated strongly that forecasts in wet years tend to under forecast runoff. Conversely, forecasts in dry years tend to over forecast runoff. Forecasts for mid flow years are shown to be somewhat challenging as the year may end up slightly wet or dry and the forecasting process is expected to reflect that result. Investigation of the percent bias for the various watersheds shows that 70% of the absolute values of pbias scores are 40 percent or less. This similarity between watersheds would be expected as all the forecasts use similar types of information although the forecast locations are different and with different physical characteristics at each watershed.

One interesting observation is the absence of any trend toward decreasing percent bias through the advance of the historical record. This observation stands in contrast to the years of increasing institutional experience in forecasting runoff and the advance of computational machinery. A possible explanation could be that the percent bias measures the human contribution to the forecasting process, which leads to the production of conservative forecasts that are familiar and useful to water resource decision makers.

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