AN EVALUATION OF METHODS USED BY DIFFERENT RIVER FORECAST CENTERS TO CALCULATE REASONABLE MAXIMUM AND REASONABLE MINIMUM FORECASTS

by

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INTRODUCTION

The water supply outlook forecasts issued cooperatively by the Soil Conservation Service (SCS), the National Weather Service (NWS), and other Federal and State agencies are defined as follows:

1. Most Probable — That runoff which is expected to occur if precipitation subsequent to the date of forecast is average.
2. Reasonable Maximum — That runoff which is expected to occur if precipitation subsequent to the date of forecast is equal to the amount which is exceeded on the average once in ten years.
3. Reasonable Minimum — That runoff which is expected to occur if precipitation subsequent to the date of forecast is equal to the amount which is exceeded on the average nine out of ten years.

Although each center issuing water supply outlook forecasts adheres to the above definitions, no standardized procedure for making the forecast calculations has been established. This study was initiated to identify the procedures used by the various centers, apply each to some common watersheds using the same predictor variables, and evaluate the results on a common basis. Three methods used by the NWS Fort Worth, Salt Lake City, and Kansas City river forecast centers (RFC's) and two methods used by the Portland SCS West National Technical Center (WNTC) were identified and selected for evaluation. Each of the methods is described, followed by the results from applying each method on two common forecast sites. The information covering the first site, The American Fork River near American Fork, Utah, is given in detail whereas only the results for the other site, The Salt River near Roosevelt, Arizona, are given.

FORECAST METHODOLOGY

Fort Worth RFC Method. The Fort Worth RFC uses a standard multiple regression technique with the reasonable maximum and reasonable minimum defined as the 80 percent confidence interval for a particular estimate assuming that the prediction errors follow a normal distribution with zero mean. The predictor variables are selected from the available hydrologic variables that are correlated with runoff. They include precipitation, antecedent moisture, and snow water equivalent (SWE). It is a straight forward application of ordinary multiple regression techniques.

$$R_{MAX} = Y_{EST} + t \cdot S_E \, SQRT(1 + 1/n + \mathbf{X}^T\mathbf{C}\mathbf{X})$$
$$R_{MIN} = Y_{EST} - t \cdot S_E \, SQRT(1 + 1/n + \mathbf{X}^T\mathbf{C}\mathbf{X})$$

where:

Y_{EST} is the forecast value from the regression equation;
t is the one tailed 90 percent Student t statistic for n-nx-1 degrees of freedom;
S_E is the standard error statistic of the regression equation;
n is the number of observations used in deriving the multiple regression equation;
nx is the number of independent variables in the regression equation;
$\mathbf{X}$ is the reduced independent variable vector for the particular estimate. A reduced independent variable corresponds to its deviation from its mean;
$\mathbf{X}^T$ is the transpose of the $\mathbf{X}$ vector;
$\mathbf{C}$ is the inverse of the $\mathbf{x}^T\mathbf{x}$ matrix used to derive the multiple regression forecast equation;
$\mathbf{x}$ is the n by nx reduced independent variable matrix used to derive the multiple regression estimating equation, and
$\mathbf{x}^T$ is the transpose of the $\mathbf{x}$ matrix.

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Portland WNTC Method. The Portland method is a regression method based on a single equation derived from composite variables indexing winter snow water equivalent, fall precipitation, winter precipitation, spring precipitation, and antecedent moisture. Values for index variables in the regression equation that have not been measured by the time needed to make the forecast are estimated by their respective historical average values. The reasonable maximum and reasonable minimum are calculated by applying an adjustment value determined by the product of the standard error of the reference regression equation and the 90 percent standard normal variate, z. This presumes to define an 80 percent confidence band about a particular point.

Salt Lake City RFC Method. The Salt Lake City method is a regression method similar to the Portland method in that it also uses a single equation for all forecasts. However, the different personnel may use different index variables, with more emphasis typically being placed on NWS stations rather than on SCS snowpack data collection sites. The reasonable maximum and reasonable minimum are obtained by a unique analysis of the historical values of the runoff indexed to antecedent snow water equivalent and precipitation as it accumulates during the forecast season. The rationale for the SLC method attempts to partition the forecast error into that caused by uncertainty of future precipitation and that caused by the procedural error inherent in the regression analysis. This is illustrated in Figures 1 and 2. Figure 1 conceptualizes the two sources of error and illustrates how the error concerning the future precipitation becomes smaller as the forecast season progresses and the procedural error approaches the forecast equation standard error, S_E, computed when the equation was derived, presumably using all available data, including some that is available only at the end of the forecast season. Figure 2 conceptualizes the partitioning of the hydrologic variables used as predictors in the forecast equation into the proportion of the mean data that has been accumulated and that which is yet to occur as the season progresses. The 10 and 90 percent exceedence deciles of the forecast series produced from the historical data provide the upper and lower bound, I_U and I_L, for the reasonable maximum and minimum adjustments. The reasonable maximum and reasonable minimum forecasts are the most probable plus and minus an adjustment term respectively. They are defined as follows:

Reasonable Maximum = Most Probable + R_{MAX} Adjustment Term
Reasonable Minimum = Most Probable - R_{MIN} Adjustment Term

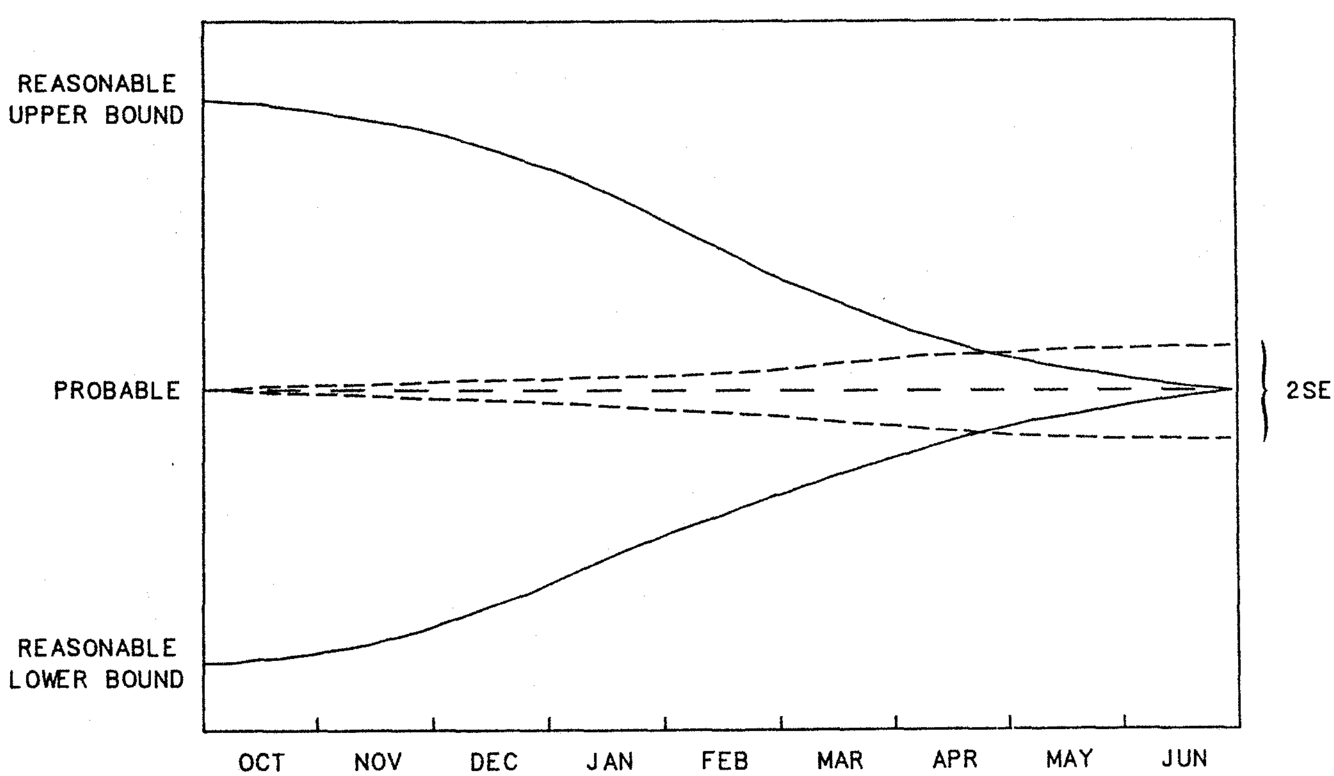

Figure 1. SLC RFC conceptualization of forecast error partitioned into future input data error and procedural error.

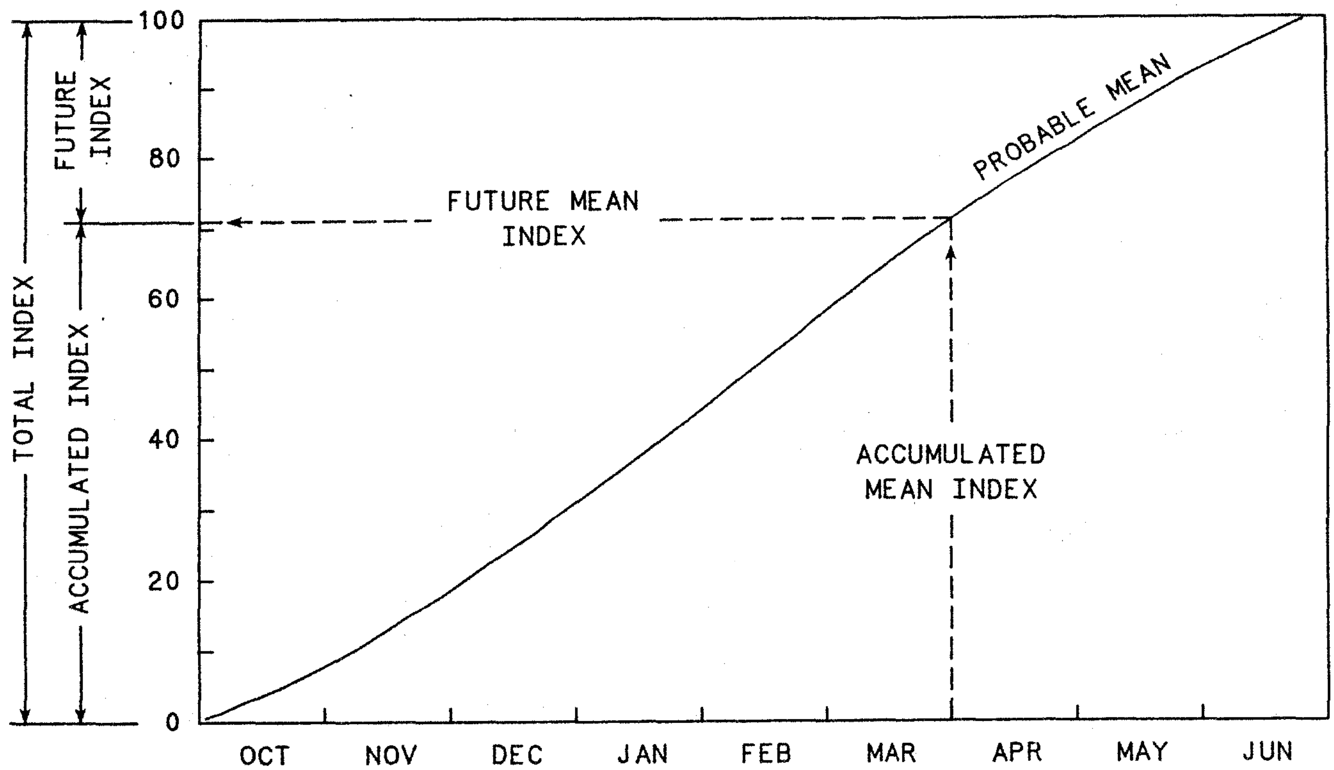

Figure 2. SLC RFC analysis of forecast equation using means.

The most probable value is calculated in a manner similar to the Portland RFC method and for this study, the same equations and variables were used. The adjustment term used to make the reasonable maximum and minimum forecasts is derived from historical data in the following manner:

Two sources or error are considered in deriving the adjustment terms, the future input data (deviation from the mean), and the error inherent in the forecast relationship (the standard error of the estimating equation). The total mean index, TMI, is defined as the sum of the regression coefficients, b_i, multiplied by their respective variable means, $X(\text{mean})_i$ or

$$TMI = \sum_{i=1}^{nx} b_i \, X(\text{mean})_i$$

The rationale for determining the two portions of the adjustment terms is as follows. The upper and lower deciles, I_U and I_L respectively, of the forecasts generated during the development from the historical data include the extreme range of deviations of the mean as well as the procedural error. The difference between the upper decile and the mean, I_M, establishes the upper increment, and the difference between the lower decile and the mean establishes the lower increment, or

$$\text{The upper decile increment} = I_U - I_M$$
$$\text{The lower decile increment} = I_L - I_M$$

Since the parameters in the estimating equation are time dependent in the sense that they accumulate over time, (for example, the April 1 SWE is an accumulation from the beginning of the snow season and likewise for the precipitation terms), the proportion of their accumulation over the forecast period can be assessed in terms of the total mean index defined above. The complement of the accumulated index is defined as the future index, FI. At any given time, the percent of the total mean index of a forecast relationship that has occurred and the percent of the future index yet to occur can be assessed. With these ideas in mind, the adjustment terms at any given time become:

$$RADJ_{MAX} = p\,(I_U - I_M) + (1-p)\,S_E$$
$$RADJ_{MIN} = p\,(I_L - I_M) - (1-p)\,S_E$$

where:

$RADJ_{MAX}$ is the adjustment term for obtaining the reasonable maximum at a given point in time
$RADJ_{MIN}$ is the adjustment term for obtaining the reasonable minimum at a given point in time
p is the ratio of future mean index to total mean index

I_M is the mean of the historical forecasts
I_U is the upper decile of the historical forecasts
I_L is the lower decile of the historical forecasts
(1-p) is the ratio of the accumulated mean index to the total mean index
S_E is the standard error of the reference equation

Kansas City RFC Method. The Kansas City RFC method is a regression method using a single index parameter composed of weighted monthly hydrologic variables such as precipitation, snow water equivalent, and runoff. The reasonable maximum and minimum adjustments are derived for each month by partitioning the variables of which the index is composed into its known and unknown elements, calculating the index parameter for the historical period as partitioned above, sorting them and then selecting the 90 and 10 percent exceedence values for use in the estimating equation to provide the adjustments for the reasonable maximum and minimum, respectively.

Soil Conservation Service Forecast Error Analysis and Review (FEAR) Method. This is a method for determining the reasonable maximum and minimum based on an analysis of past SCS forecast errors. A normal distribution is fit to the historical series of forecast errors with the 50 percent value adjusted to zero, thus shifting the 90 and 10 percent exceedence values. The resulting 10 and 90 percent exceedence values are used to adjust the most probable forecast value to obtain the reasonable maximum and reasonable minimum.

APPLICATION TO THE AMERICAN FORK RIVER NEAR AMERICAN FORK, UTAH

A data set for conducting the analysis was developed which consisted of the observed values measured on or near the American Fork (AMFK) River basin for the period 1961 through 1986. It is shown as Table 1.

The data for 1961-1985 were used to derive the regression equations and the 1986 data were used to test and compare the results of applying the different methods. The variables in the data set are:

- Y or Q(A-S), the April-September runoff for the American Fork River in 1,000 acre-feet,
- X_1 or Q(N-1), the April-September runoff for the previous year in 1,000 acre-feet,
- X_2 or S(APR), the April 1 Snow Water Equivalent (SWE) for the Timpanogos Divide snow course (Station 11J21) in inches of water,
- X_3 or P(FALL), the sum of three NWS precipitation stations October-November precipitation in inches of water. The three stations are:
  - #1759, Cottonwood Weir
  - #5826, Morgan
  - #8733, Timpanogos Cave
- X_4 or P(WIN), the December-March precipitation for the above three stations,
- X_5 or P(SPR), the April-May precipitation for the above three stations.

Other data included in Table 1 are the April-July runoff for the American Fork River and the January 1, February 1, March 1, and April 1 SWE for the Timpanogos Divide snow course along with their respective 1961-1985 averages.

The five X variables constitute a set of predictor variables for estimating the American Fork runoff, Y. The ordinary multiple regression equation for Y derived from the 1961-1985 data set is the AMFK reference equation:

$$Y = 0.16276\ X_1 + 0.72463\ X_2 + 0.55159\ X_3 + 1.02873\ X_4 + 0.53326\ X_5 - 29.24577$$

The statistics associated with this equation are: the number of observations, n = 25; the degrees of freedom, df = 19; the standard error, S_{ER} = 6.36678; the coefficient of determination, R^2 = 0.870. This equation served as the reference for all except the Fort Worth methods which used only the variables available for making the January, February, March, and April forecasts. A detailed description for deriving each of the forecast equations is given only for the January 1 forecast for each method although the results for all forecast periods are given in the summary tables.

Fort Worth RFC Method. The Fort Worth method is an application of the ordinary least squares multiple regression technique. Thus, a separate regression equation is developed for each of the four forecast times using only those variables that are available to the forecaster when the forecast must be issued. The January 1 forecast equation and its associated statistics is now considered.

Table 1: Data set for American Fork River forecast evaluations.

YEAR	SNOW WATER EQUIVALENT STATION 11J21 (TD) JAN	FEB	MAR	APR	REGRESSION VARIABLES FOR AMERICAN FORK FORECAST QAJ	Y Q(A-S)	X1 Q(N-1)	X2 S(APR)	X3 P(FALL)	X4 P(WIN)	X5 P(SPR)
1961	6.2	5.3	6.5	10.8	7.6	9.1	23.8	10.8	13.09	12.07	5.56
1962	14.0	19.0	27.3	30.7	34.1	37.9	9.1	30.7	15.08	29.66	16.47
1963	0.8	7.4	12.2	15.3	22.0	25.3	37.9	15.3	4.91	20.03	17.35
1964	6.6	13.2	16.6	17.1	29.2	33.2	25.3	17.1	11.65	21.38	22.77
1965	17.0	24.9	27.4	27.1	36.5	41.8	33.2	27.1	11.68	34.42	19.31
1966	14.7	18.0	21.1	21.8	24.2	27.1	41.8	21.8	9.86	19.58	9.95
1967	18.8	27.2	29.7	31.8	36.9	45.0	27.1	31.8	11.06	29.53	23.02
1968	8.1	13.8	21.3	25.3	33.1	37.9	45.0	25.3	8.28	27.69	23.25
1969	10.8	29.7	42.8	44.7	56.2	61.4	37.9	44.7	11.99	33.81	8.55
1970	7.1	11.9	13.0	18.3	24.4	28.3	61.4	18.3	12.56	24.74	16.75
1971	15.6	17.1	20.5	17.7	28.9	32.9	28.3	17.7	19.04	25.77	13.77
1972	19.6	24.6	23.8	19.2	26.5	29.7	32.9	19.2	20.14	22.07	11.15
1973	13.1	17.6	23.9	29.6	37.4	42.9	29.7	29.6	18.12	26.33	13.47
1974	8.5	14.5	17.2	18.2	26.3	29.2	42.9	18.2	12.60	23.05	15.16
1975	7.5	14.5	22.7	32.2	45.0	52.3	29.2	32.2	13.57	30.46	19.43
1976	12.8	15.4	25.2	27.0	21.6	24.6	52.3	27.0	14.64	22.02	9.59
1977	0.3	3.6	5.0	7.9	8.1	9.9	24.6	7.9	3.80	15.66	19.42
1978	7.7	15.1	24.2	33.0	45.8	51.9	9.9	33.0	7.69	36.21	19.76
1979	15.5	21.7	27.2	31.4	27.5	31.6	51.9	31.4	10.28	22.59	6.20
1980	3.0	23.2	35.2	40.2	49.0	55.5	31.6	40.2	11.17	39.73	13.98
1981	7.6	11.2	12.8	17.2	18.7	21.9	55.5	17.2	10.92	22.10	20.63
1982	5.4	20.0	23.0	38.6	51.9	59.6	21.9	38.6	20.44	41.35	13.61
1983	16.0	20.7	26.1	34.2	58.8	69.6	59.6	34.2	14.06	35.12	21.27
1984	15.4	16.8	21.3	22.8	52.7	59.4	69.6	22.8	17.94	28.68	15.60
1985	18.3	21.2	22.8	25.2	33.8	38.3	59.4	25.2	22.20	20.71	14.50
1986	14.0	18.0	31.7	33.5	59.3	65.8	38.3	33.5	19.31	33.87	23.39
1961-1985 Average	10.82	17.10	21.95	25.49	33.45	38.25	37.67	25.49	13.07	26.59	15.62

Explanation of Column Headings

11J21 (TD) is first of month SWE for the Timpanogos Divide Snow Course in inches
QAJ is the April-July runoff for the American Fork River in 1000 acre-feet
Q(A-S) is the April-September runoff for the American Fork River in 1000 acre-feet
Q(N-1) is the previous years QAS for the American Fork River in 1000 acre-feet
S(APR) is the April 1 SWE for the Timpanogos Divide Snow Course in inches of water
P(FALL) is the sum of the October-November precipitation for the Cottonwood Weir, Morgan, and Timpanogos Cave weather stations in inches
P(WIN) is the sum of the December-March precipitation for the above three stations
P(SPR) is the sum of the April-May precipitation for the above three stations

January 1 forecast. The variables available for making the January 1 forecast consist of the previous year's runoff, Q(N-1), the January 1 snow water equivalent, TD(JAN), and the fall precipitation, P(FALL). The January forecast equation derived from the 1961-1985 data is as follows:

$$Q(A\text{-}S) = -0.00902\ Q(N\text{-}1) + 0.26485\ TD(JAN) + 0.84905\ P(FALL) + 24.62931$$

The statistics associated with the Fort Worth January equation are: n = 25, df = 21, S_E = 15.96505, and R^2 = 0.098. The covariance matrix is:

$$C = \begin{bmatrix} 1.7423E\text{-}04 & -1.2127E\text{-}04 & -9.0893E\text{-}06 \\ -1.2127E\text{-}04 & 2.0162E\text{-}03 & -1.3124E\text{-}03 \\ -9.0893E\text{-}06 & -1.3124E\text{-}03 & 2.8215E\text{-}03 \end{bmatrix}$$

The rows and columns correspond to the order in which the variables occur in the equation, i.e., row and column 1 correspond to Q(N-1), row and column 2 to TD(JAN), and row and column 3 to P(FALL). The variable averages for the 1961-1985 reference period are required for calculating the 80 percent confidence interval about a prediction and are given in Table 1. The results of applying the January equation to the 1986 data are given below and are also included in Table 3 with the summary of results.

The most probable runoff	44.39 thousand acre-feet
Reasonable maximum	66.72 thousand acre-feet
Reasonable minimum	22.05 thousand acre-feet

The Reasonable maximum and minimum are the 90 and 10 percent exceedence values assuming the residual errors follow a normal distribution with a mean of zero and a standard deviation of S_E.

Portland WNTC Method. The Portland method uses a single regression equation developed from the set of variables that provide the greatest correlation with runoff. Data for variables that are unknown at the time the forecast must be made are estimated from either some other variable that is known or from the historical mean of the particular unknown variable. The five variable reference equation for the American Fork River provides the basis for the Portland method from which each of the monthly forecast equations are derived. The January 1 forecast equation and its results are now developed.

<u>January 1 Forecast</u>. The equation for making the January 1 forecast uses the previous year's runoff, January 1 SWE, and fall precipitation as predictor variables. Since the reference equation requires April 1 SWE, winter precipitation, and spring precipitation, these variables must be estimated. The April 1 SWE is estimated from the January 1 value by multiplying the January 1 SWE by the ratio of the average April 1 to January 1 SWE. The unknown precipitation variables are estimated by their respective average values. The January 1 forecast equation is:

$$Q(A\text{-}S) = 0.16276\ Q(N\text{-}1) + 0.72463(25.49/10.82)\ TD(JAN) + 0.55159\ P(FALL) + 1.02873(26.59) + 0.53326(15.62) - 29.24577$$

which upon collecting terms reduces to:

$$Q(A\text{-}S) = 0.16276\ Q(N\text{-}1) + 1.70710\ S(JAN) + 0.55159\ P(FALL) + 6.43768$$

Using this as a forecast model on the 1961-1985 data set, the various statistics for the equation were obtained. They are: $n = 25$, $df = 21$, $S_E = 18.38662$, $R^2 = 0.068$.

Since this is not an explicit regression model, the Covariance matrix, C, is not defined. The adjustment for obtaining R_{MAX} and R_{MIN} is similar to that for the Fort Worth method except that instead of using the Student t statistic, the Portland WNTC uses the standard normal deviate, z, and ignores the term involving C. In addition, S_{ER} for the reference equation is used instead of the true S_E for the actual equation used. Thus, the equations for the reasonable maximum and reasonable minimum become:

$$R_{MAX} = Y_{EST} + z \cdot S_{ER}\ SQRT(1 + 1/n)$$
$$R_{MIN} = Y_{EST} - z \cdot S_{ER}\ SQRT(1 + 1/n)$$

The results of applying the Portland method equations to the 1986 data are included in Table 3 of the summary and conclusions.

Salt Lake City RFC Method. The derivation of the adjustment terms for applying the Salt Lake City RFC procedure to the American Fork River Basin using the AMFK reference equation parameters is given in Table 2.

The forecast equations for the four forecast dates are identical to the equations used in the Portland WNTC method. However, the reasonable maximum and minimum forecasts are different as described above. The results for the Salt Lake City RFC method are included in Table 3.

The discrepancy between the confidence interval for the reasonable maximum and minimums is caused by not calculating and using the actual standard error of each forecast equation. Instead, only the standard error of the reference equation is used along with the future and accumulated index partitioning of the historical 10 and 90 percent forecast deciles. The Portland WNTC method exhibits the same thing because it uses only the reference equation standard error in calculating the reasonable maximum and minimum forecasts.

Table 2. Computation of the Reasonable Maximum and Reasonable Minimum Adjustment Terms for the American Fork River Basin Forecast Model using the Salt Lake City RFC Method.

TMI = 0.16276X1 + 0.72463X2 + 0.55159X3 + 1.02873X4 + 0.53326X5
where the X's are the historical means from the development period
TOTAL MEAN INDEX, TMI = 67.49

	TIME PERIOD					
Variable	OCT-DEC 31	JAN 1	FEB 1	MAR 1	APR 1	MAY-SEP 30
X1	6.13					
X2		7.84	4.55	3.52	2.56	
X3	7.21					
X4		6.98	6.24	6.14	7.99	
X5						8.33
MONTHLY INDEX	13.34	14.82	10.79	9.66	10.55	8.33
ACI	13.34	28.16	38.95	48.61	59.16	67.49
FI	54.15	39.33	28.54	18.88	8.33	0
p in %	80.23	58.28	42.29	27.97	12.34	0
1-p in %	19.77	41.72	57.71	72.03	87.66	100.00

Upper Decile = 59.89 - 38.25 = +21.64
Lower Decile = 16.02 - 38.25 = -22.23

	JAN 1	FEB 1	MAR 1	APR 1
Upper Increment Adjustment p(21.64)	12.61	9.15	6.05	2.67
Lower Increment Adjustment p(-22.23)	-12.96	-9.40	-6.22	-2.74
Standard Error Adjustment (1-p)(6.367)	2.66	3.67	4.59	5.58

Total Adjustment to be added each month to the probable forecast

	JAN 1	FEB 1	MAR 1	APR 1
Reasonable Maximum Adj	15.27	12.82	10.64	8.25
Reasonable Minimum Adj	-15.62	-13.07	-10.81	-8.32

Kansas City RFC Method. The Kansas City RFC method regresses a single index variable against the runoff being forecast. The same variables used in the previous methods were used to calculate the index variable, C_{INDEX}. These include the previous year's runoff, the April snow water equivalent, and the fall, winter, and spring precipitation. The weighting coefficients for these five variables used in calculating the C index were the regression coefficients resulting from an ordinary multiple regression application on the American Fork 1961-1985 data set. The C index equation is:

$$C_{INDEX} = 0.16276\ Q(N\text{-}1) + 0.72463\ S(APR) + 0.55159\ P(FALL) + 1.02873\ P(WIN) + 0.53326\ P(SPR)$$

The regression equation used for the Kansas City forecasts is:

$$Y = 1.00000\ C_{INDEX} - 29.24577$$

The statistics associated with this equation are $C_{INDEX}(MEAN) = 67.498$, $n = 25$, $df = 23$, $S_E = 5.78672$, $R^2 = 0.870$. This is the basic equation for the Kansas City forecast procedure. The monthly forecasts are made by substituting mean values for parameters unknown at the time of the forecast in the index equation and calculating an index value which is then used in the forecast equation to make the monthly forecast.

The reasonable maximum and minimum forecasts are obtained by calculating the C index values for each forecast time from the 1961-1985 data set, ranking them, and obtaining the deviation of the 10 and 90 percent deciles from the index mean of 67.498 as adjustments to be added to the forecast C index. The adjusted indexes are then used in the above regression equation to provide the reasonable maximum and minimum forecasts.

January 1 Forecast. The predictor variables available for the January 1 forecast include the previous year's runoff, the January 1 SWE used to estimate the April 1 SWE, and the fall precipitation. The other variables needed to calculate the C index are estimated by their respective 1961-1985 averages. Substituting the averages for the unknown variables in the equation for calculating the C index yields the following:

$$C_{JAN} = 0.16276\ Q(N\text{-}1) + 1.70710\ TD(JAN) + 0.55159\ P(FALL) + 35.68345$$

Using this relationship to calculate the January 1 series of C indexes for the 1961-1985 period, the 10 and 90 percent deciles were obtained. Their deviations from the mean C index are +16.662 and -17.862 respectively. Using 1986 data, the C index is 76.468. Applying the forecast equation to the January forecast index values results in the following 1986 January 1 forecast with a complete summary of results included in Table 3.

Most probable runoff = 47.22 thousand acre-feet
Reasonable maximum = 66.88 thousand acre-feet
Reasonable minimum = 29.54 thousand acre-feet

In order to assess the actual confidence level of the reasonable maximum and minimum forecasts, the actual statistics of the forecast equation in terms of the runoff must be known. These were derived by substituting the January C index estimating equation into the Kansas City forecast equation and calculating the applicable statistics using the 1961-1985 data set. The January 1 forecast equation is:

$$Y = 0.16276\ Q(N\text{-}1) + 1.70710\ TD(JAN) + 0.55159\ P(FALL) + 6.43768$$

with equation statistics of $n = 25$, $df = 21$, $S_E = 18.38662$, and $R^2 = 0.068$. Performing an analysis similar to that used with the Portland and Salt Lake City methods, the actual confidence levels of the 1986 reasonable maximum and minimum forecasts are 80.8 and 17.6 percent respectively.

SCS FEAR Method. The Soil Conservation Service has analyzed the forecast accuracy of many of its water supply forecast sites by fitting a normal distribution to the historical forecast errors. The Portland WNTC supplied the available analysis results for the American Fork River site. The January forecast record was not long enough for analysis, but the February 1, March 1, and April 1 ten and ninety percent exceedence values as a percent of the mean runoff were supplied. The values provided were: February 1 forecast, +41.0 and -41.0 percent; March 1 forecast, +30.1 and -30.0 percent; and April 1 forecast, +25.9 and -25.9 percent of the mean flow for the reasonable maximum and reasonable minimum adjustments respectively.

The results of using the FEAR analysis values for forecasting the 1986 reasonable maximum and minimum runoff with the Portland WNTC forecast equations are summarized in Table 3.

SUMMARY AND CONCLUSIONS

The forecast results of the study are summarized in Tables 3 and 4 and displayed in Figures 3 and 4. The Fort Worth RFC method is the only one that provides true 90 percent confidence level reasonable maximum forecasts and 10 percent confidence level reasonable minimum forecasts based on the assumptions of linear regression analysis. The Portland WNTC method produced confidence levels about the most probable forecast value that varied considerably from the 90 and 10 percent levels for each 1986 runoff forecast, 66.9 to 89.3 for the reasonable maximum and 10.7 to 33.1 for the reasonable minimum. The Salt Lake City RFC procedure produced confidence levels, varying from 66.9 to 87.3 percent for the reasonable maximum and 12.5 to 32.0 percent for the reasonable minimum. The Kansas City RFC method was the most erratic producing confidence levels from 76.5 to 100.0 percent for the reasonable maximum and 0.2 to 17.6 percent for the reasonable minimum. The SCS FEAR method produced confidence levels for the 1986 data that varied from 81.7 to 91.3 percent and from 8.7 to 18.4 percent for the reasonable maximum and minimum respectively.

It is apparent that the different reasonable maximum and minimum forecast methods are indeed not equivalent although each purports to provide a range within which the actual runoff will fall 80 percent of the time. Using recognized statistical methods, this study has identified the differences in the methods and has demonstrated them for the 1986 forecasts in Figures 3 and 4.

Table 3. 1986 Forecast Results for the American Fork River, Utah, Site.
(Observed April-September runoff = 65.8 thousand ac-ft.)

FORECAST DATE	MOST PROBABLE 1000 AC-FT	REASONABLE MAXIMUM 1000 AC-FT	REASONABLE MINIMUM 1000 AC-FT	CONFIDENCE LEVELS MAXIMUM PERCENT	CONFIDENCE LEVELS MINIMUM PERCENT
		FORT WORTH RFC METHOD			
JAN 1	44.39	66.72	22.05	90.0	10.0
FEB 1	40.56	58.64	22.48	90.0	10.0
MAR 1	53.82	69.89	37.75	90.0	10.0
APR 1	54.74	64.10	45.39	90.0	10.0
		PORTLAND WNTC METHOD			
JAN 1	47.22	55.54	38.90	66.9	33.1
FEB 1	42.77	51.09	34.45	72.5	27.5
MAR 1	50.00	58.32	41.68	74.4	25.6
APR 1	55.09	63.41	46.77	87.5	12.5
		SALT LAKE CITY RFC METHOD			
JAN 1	47.22	62.49	31.60	78.8	20.7
FEB 1	42.77	55.59	29.70	82.0	17.5
MAR 1	50.00	60.64	39.19	79.8	19.8
APR 1	55.09	63.34	46.77	87.3	12.5
		KANSAS CITY RFC METHOD			
JAN 1	47.22	66.88	29.54	80.8	17.6
FEB 1	42.77	54.70	26.80	80.3	12.8
MAR 1	50.00	59.18	36.30	76.5	14.2
APR 1	55.09	76.42	32.80	99.7	0.2
		SCS FEAR METHOD			
JAN 1	47.22	NOT AVAILABLE - INSUFFICIENT DATA			
FEB 1	42.77	58.45	27.09	86.7	13.3
MAR 1	50.00	61.51	38.52	81.7	18.4
APR 1	55.09	65.00	45.18	91.3	8.7

Table 4. 1986 Forecast Results for the Salt River, Arizona, Site.
(Observed April-May runoff = 139.5 thousand ac-ft.)

FORECAST DATE	MOST PROBABLE 1000 AC-FT	REASONABLE MAXIMUM 1000 AC-FT	REASONABLE MINIMUM 1000 AC-FT	CONFIDENCE LEVELS MAXIMUM PERCENT	CONFIDENCE LEVELS MINIMUM PERCENT
		FORT WORTH RFC METHOD			
FEB 1	229.16	392.79	65.53	90.0	10.0
MAR 1	194.53	309.11	79.94	90.0	10.0
APR 1	189.21	260.76	117.66	90.0	10.0
		PORTLAND WNTC METHOD			
FEB 1	168.07	231.20	104.94	68.2	31.8
MAR 1	190.61	253.74	127.48	74.6	25.4
APR 1	189.21	252.34	126.08	89.3	10.7
		SALT LAKE CITY RFC METHOD			
FEB 1	168.07	246.66	102.51	72.1	31.2
MAR 1	190.61	232.34	146.06	66.9	32.0
APR 1	189.21	237.49	140.93	83.1	16.9
		KANSAS CITY RFC METHOD			
FEB 1	168.07	364.16	0.08	92.4	10.8
MAR 1	190.61	395.52	0.00	97.9	2.8
APR 1	189.21	480.19	2.62	100.0	0.1
		SCS FEAR METHOD			
NOT AVAILABLE - INSUFFICIENT RECORD FOR RELIABLE ANALYSIS					

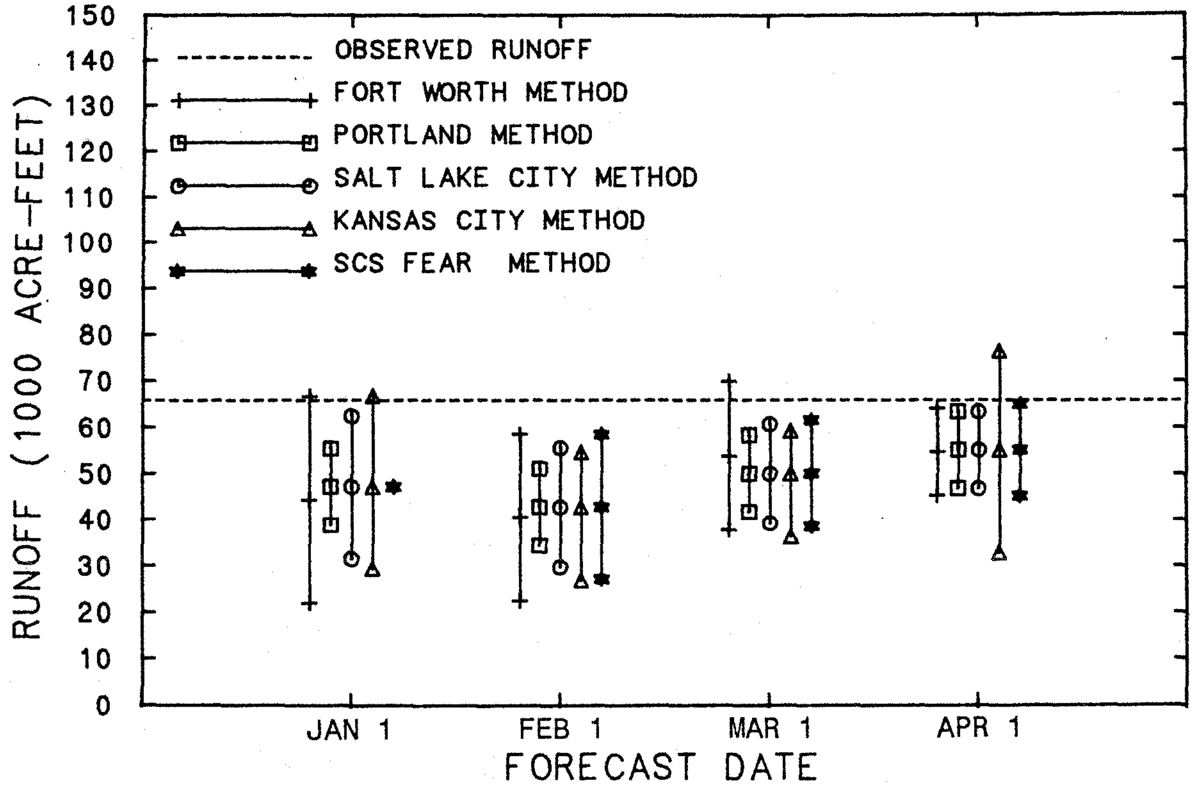

Figure 3. 1986 Reasonable Maximum and Minimum Forecast Results for the American Fork River, Utah, Site.

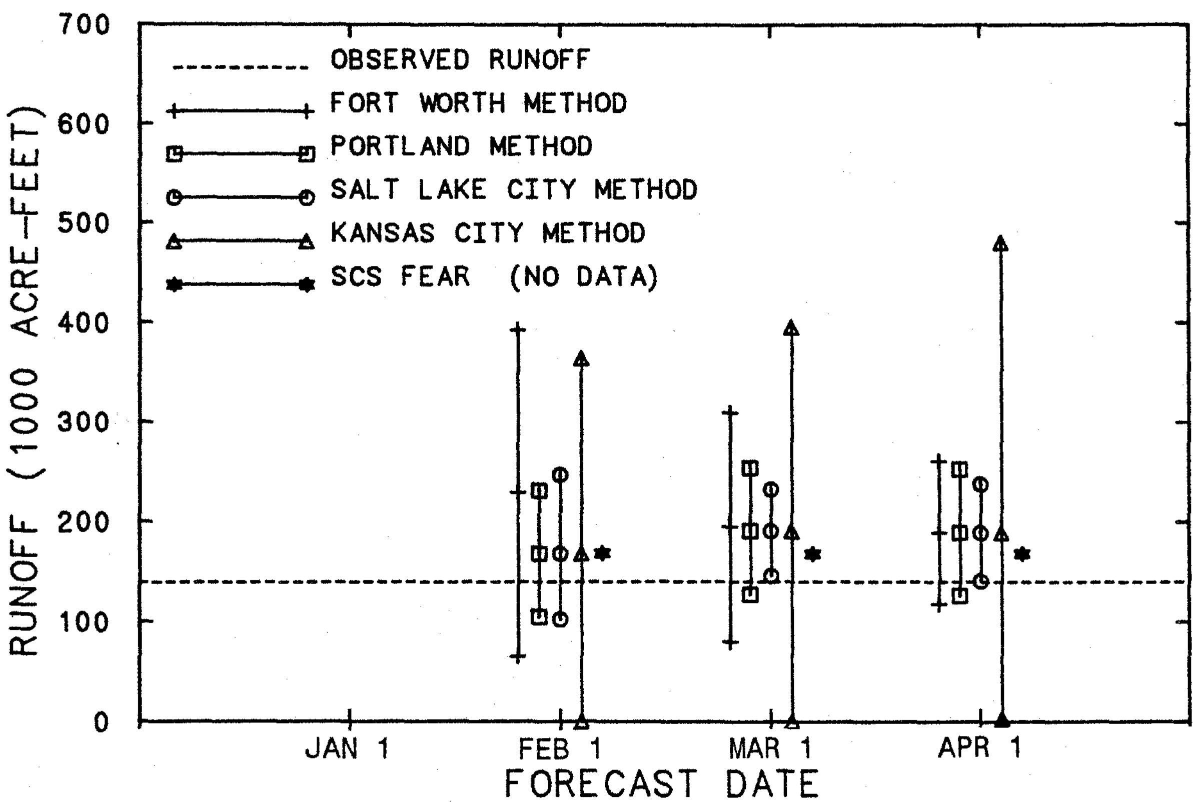

Figure 4. 1986 Reasonable Maximum and Minimum Forecast Results for the Salt River, Arizona, Site.

RECOMMENDATIONS

The following recommendations are made as a result of this study:

1. A standardized procedure for determining the reasonable maximum and minimum forecasts should be established and used by all of the RFC's.

2. The Fort Worth RFC method is preferred because it employs generally accepted statistical methods in defining the reasonable maximum and minimum forecasts. One drawback to its immediate application may be the lack of the required statistics for the current forecast equations or models. Updated forecast equations could be derived for which the required statistics would be available or a post analysis of the current equations could be performed to provide the required statistics.

3. An alternative form of the SCS FEAR analysis could also prove useful. Use the standard error of the relationship between the observed runoff and the historically forecast runoff to calculate the adjustment terms for obtaining the reasonable maximum and minimum forecasts. The adjustment would be:

$$R_{ADJ} = \pm\ t\ S_E\ SQRT[1 + 1/n + (Y_{EST} - \bar{Y}_{EST})^2/SY^2]$$

where:

t	is the one tailed 90 percent Student t statistic for n-2 degrees of freedom.
n	is the number of previous forecasts analyzed in developing the S_E statistic.
S_E	is the standard error obtained from regressing the observed flows against the historical forecasts.
Y_{EST}	is the particular estimate about which the adjustment is to be made.
$\bar{Y}_{EST}$	is the mean of the historical forecasts used to determine S_E.
SY^2	is the sum of the squared deviations of the historical forecasts from their mean.

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REFERENCES

Apley, T. (1979) *Method Used in Computing Reasonable Minimum Reasonable Maximum Flows from SCS Forecast Flows.* Letter to Bernie Shafer outlining the methods used by the Kansas City RFC. November 16, 1979. 3 pages.

Huber, A. L. (1989) *Water Supply Forecast Reasonable Maximum - Reasonable Minimum Study.* ARS-SCS Cooperative Study Technical Report NWWRC 89-4. September 30, 1989. 23 pages.

Shafer, B. A. and J. M. Huddleston. (1986) *A Centralized Forecasting System for the Western United States.* Proceedings of the 54th Annual Meeting Western Snow Conference, April 15-17, 1986, Phoenix, Arizona. pp 61-70.

Unknown *Determination of Maxs and Mins for Water Supply Forecast at River Forecast Center Fort Worth, Texas.* Undated, unpublished two page procedural note.

Unknown *Reasonable Maximum and Reasonable Minimum Computation.* Undated, unpublished procedural report from the Salt Lake City RFC. 11 pages.