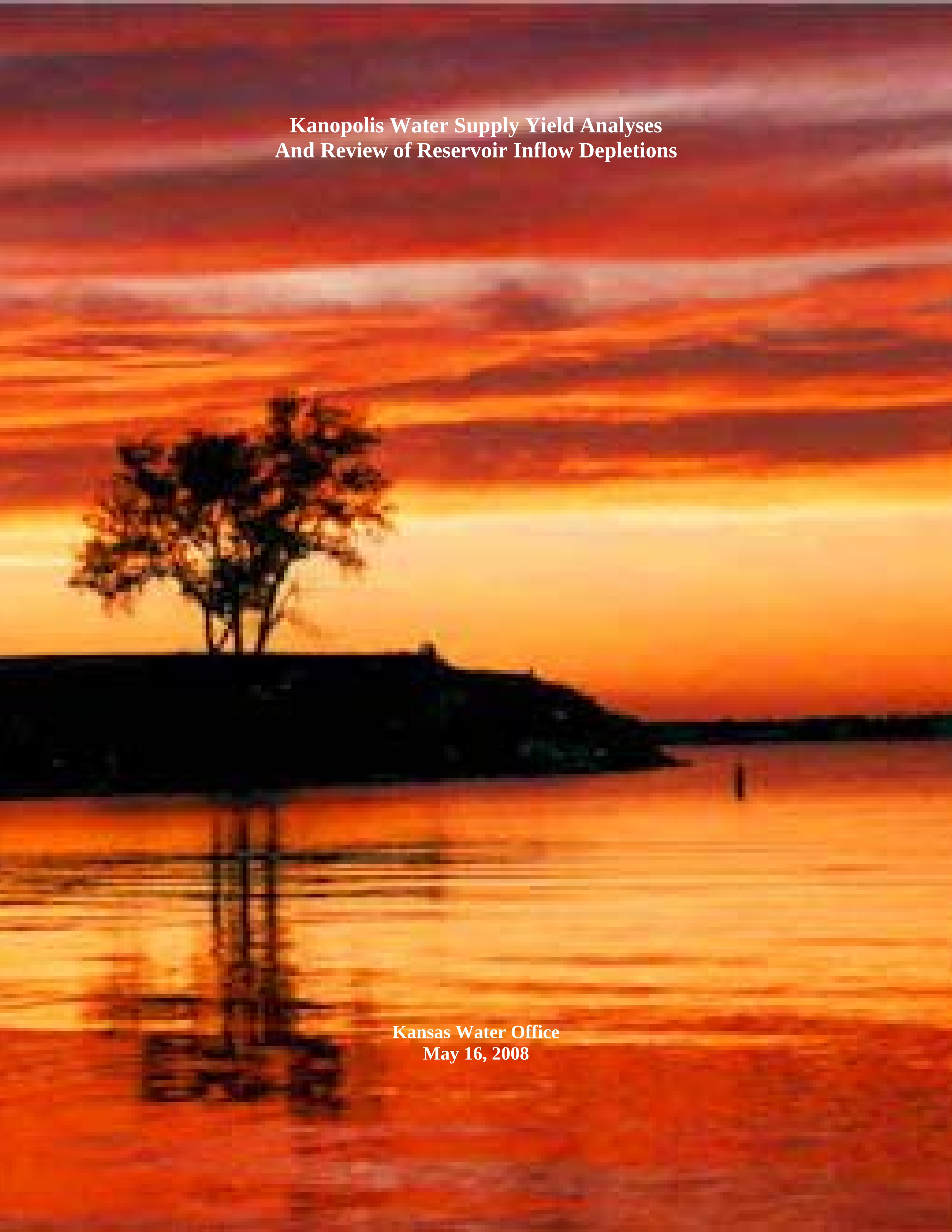

Kanopolis Water Supply Yield Analyses And Review of Reservoir Inflow Depletions

Kansas Water Office
May 16, 2008

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Acknowledgements

The author would like to thank the three anonymous reviewers who spent their valuable time providing thoughts and comments on the methodology used to develop the water supply yield contained in this report.

List of Figures/Tables

Abstract

The Kansas Water Office (KWO) has revised its method of estimating water-supply yields at reservoirs that have experienced large depletions to their inflows over time. This revision utilizes a Monte Carlo simulation technique to characterize the uncertainty in the estimation of future reservoir inflows. Such a technique has been applied to the water-supply yield analysis for Kanopolis Reservoir.

The application of a stochastic approach to estimating inflows to a water-supply yield model changes the way the water-supply yield for Kanopolis Reservoir is expressed. Whereas previous water-supply yield models were math problems with a single solution for a reservoir's water-supply yield, the results from a Monte Carlo simulation generate a probability distribution function for the water-supply yield of Kanopolis Reservoir. This function has been expressed as the probability of equaling or exceeding a water-supply yield projected a specified number of years in the future during a simulated drought.

The Kansas Water Office finds a water-supply yield of **10.1** cubic feet per second or **6.5** million gallons per day maximizes the water-supply benefit to the public and can be reasonably expected to be maintained during a drought with a two percent chance of occurrence in any one year.

Introduction

A reservoir water-supply analysis is an optimization problem solved through the use of a computer model. The setting for this optimization problem is created by artificially aging a reservoir 40 or 50 years. Bathymetric surveys performed at the reservoir through time are used to estimate its sedimentation rate and that information is applied to the anticipated storage in the multi-purpose pool for the future condition. Within the computer model, this temporal reduction to storage is expressed in the modification to a reservoirs area- elevation-capacity table.

This estimate of the physical change to the reservoir's storage is then subjected to the climatic conditions of a drought scenario. The input conditions of this drought scenario are expressed in a water-supply yield model primarily through its effect on expected inflows to the reservoir under its future state. Kansas statute (KSA 82a-1305(a)) defines the drought scenario as a 2% drought and regulation (K.A.R. 98-5-8(a)(3)) further define it by establishing that the 2% drought occurred during 1952-1957. In the optimization problem, the artificially aged reservoir's inflows are subjected to the recorded climatic conditions from 1952-1957. The objective of the optimization problem is to maximize water-supply releases. The primary optimization constraint is that the water-supply pool volume is not allowed to equal zero (dry up). During a water-supply yield analysis, releases from the water-supply pool in the reservoir are made in an iterative fashion until the optimized solution is found.

Kanopolis Reservoir water elevations were lower in 2006 than anticipated, given the climatic conditions in the 6 years leading to the 2006 reservoir water elevations were not as severe as the simulated severe drought conditions that were supplied to the 2002 version of the water-supply yield analysis of Kanopolis Reservoir. In fact, the reported September 2006 elevations of Kanopolis Reservoir approached the simulated minimum elevation from the 2002 Kanopolis water-supply yield analysis (Figure 1). This observation called the projections of the 2002 water-supply yield analysis for Kanopolis Reservoir into question and provided the impetus for review of certain aspects of the Kansas Water Office water-supply yield analysis methodology.

The result of that review created new enhancements to the current yield analysis methodology including a stochastic approach to simulating reservoir inflows in the yield analysis. The Monte Carlo inflow simulation approach to yield analyses is intended to quantify the uncertainty in estimating reservoir inflows. This manner of evaluation makes it possible to estimate probabilities of weathering a specified drought (2% in our case) through a range of water-supply yields. Analysis of the uncertainty of future reservoir inflows for a specified drought condition moves the estimation of water-supply yield from a straightforward math problem to a management decision. Now factors such as public risks or economic consequences can now be weighed by the water resource manager during the decision process of selecting of a water-supply yield.

Yield Model Verification

Figure 1 shows the end of month (EOM) elevations projected by the KWO 2002 water-supply yield model under the required drought scenario (01/1953-09/1957) and a comparable length of time for observed reservoir elevations of the contemporary period (01/2002-09/2006).

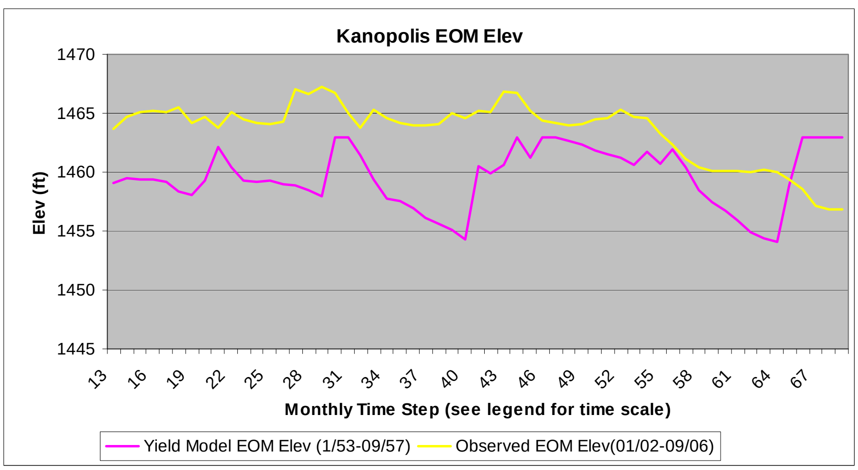


Figure 1: End of Month Elevation Comparison – WS Yield and 2002–2006 Observed

The first issue to review is to determine whether the yield analysis model is functioning properly (model functionality verification). Can we use the observed 01/2002 – 09/2006 inflows, releases and current estimate of the reservoir's area-capacity table in the water-supply yield model and have the model simulated results 'match' the observed results?

Figure 2 compares the observed and model simulated EOM elevations from the 01/2002 – 09/2006 period. Note how well the simulated results reflect the observed elevations[1].

[1] Precipitation to and evaporation from the reservoir surface were not modified from the 01/1953-09/1957 period during the verification step. If these factors were added to the model verification step, we would expect an even better match of the simulated to observed results.

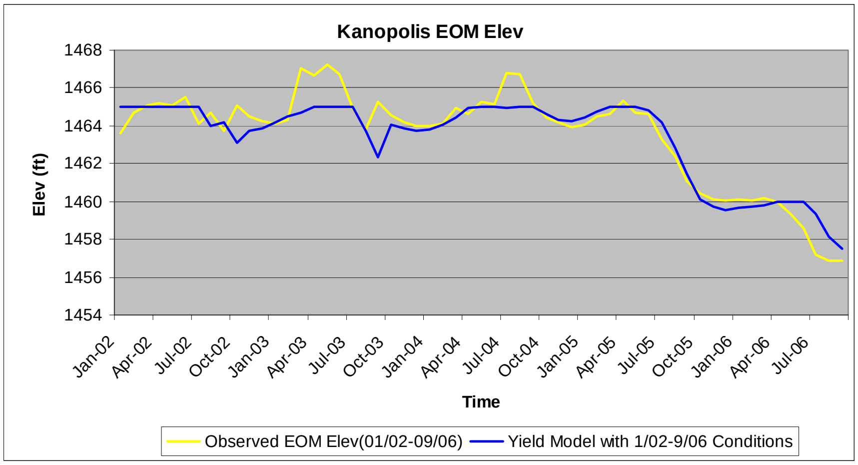


Figure 2: End of Month Elevation Comparison – 2002–2006 Observed and Yield Model

Inflow Review

As previously indicated, the dominant parameter influencing reservoir elevations is reservoir inflows. During the development of a water-supply yield model the streamflows recorded from the required drought condition (1952-1957) are often depleted to represent the effect of various activities in the reservoir's watershed that have occurred since the 1950's. These depletions are an estimate of the expected inflows to a reservoir if a drought, such as the one that occurred during 1952-1957, should occur in the future. If the monthly inflow parameter to the Kanopolis water-supply yield model was not depleted enough for the drought scenario, then we would expect to see the type of issue presented in Figure 1; lower than expected EOM elevation for droughts not as severe as the modeled drought scenario.

For the inflow review, we start with an examination of the historic streamflow review. Figure 3 shows the two flow gaging locations that were analyzed: Smoky Hill River near Bunker Hill and Ellsworth (USGS site numbers 06864050 and 04864500, respectively).

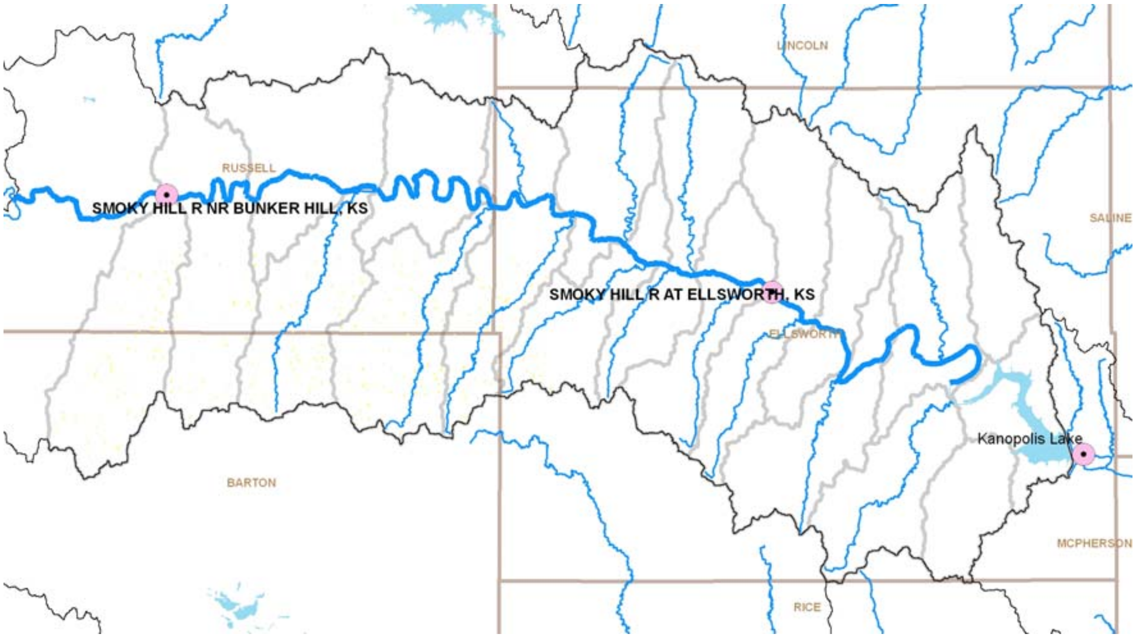
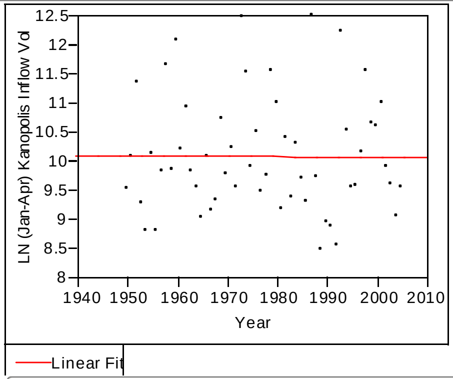


Figure 3: Gaging Station Locations

The streamflows for the Smoky Hill River at Ellsworth were converted to total monthly volumes for the 1950 – 2006 period and scaled to Kanopolis Reservoir inflow volume by proportioning volume to drainage area. These monthly volumes were grouped using a cluster analysis (Ward's Method) into 'flow seasons'. Three primary flow-volume seasons were used from the cluster analysis: January-April, May-July and August-December. A natural log transformation was applied to the three flow seasons from 1950-2006 to get each of the flow-volume seasons to allow the data to follow a normal distribution. Finally, seasonal inflow volume (in acre-feet) was reviewed for a time trend at Kanopolis. The results are shown in Figures 4, 5 and 6.

There was no statistically discernable trend in the seasonal flow volume for the January-April season (Figure 4). A statistically discernable trend was found (alpha = 0.05; Prob > F = 0.0274 from Figure 5) for the May-July season. The trend was declining seasonal flow volumes. The final season, August-December, also showed a declining, statistically discernable trend in seasonal flow volume (Prob > F = 0.0291 from Figure 6). Kendall's tau was run for the same seasonal flow volume data (see bottom of Figures 4, 5 and 6). The results agreed with the parametric test.

Bivariate Fit of LN (Jan-Apr) Kanopolis Inflow Vol By Year



Linear Fit

LN (Jan-Apr) Kanopolis Inflow Vol = 11.085048 - 0.0005097 Year

Summary of Fit

RSquare	0.00007
RSquare Adj	-0.01845
Root Mean Square Error	1.005204
Mean of Response	10.07711
Observations (or Sum Wgts)	56

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.003801	0.00380	0.0038
Error	54	54.563455	1.01043	Prob > F
C. Total	55	54.567256		0.9513

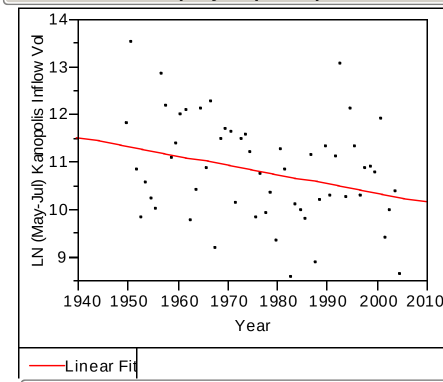
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.085048	16.43474	0.67	0.5029
Year	-0.00051	0.008311	-0.06	0.9513

Kendall Tau b = 0.00; Prob>|Tau b| = 1.00

Figure 4:Inflow Trend (Jan-Apr)

Bivariate Fit of LN (May-Jul) Kanopolis Inflow Vol By Year



Linear Fit

LN (May-Jul) Kanopolis Inflow Vol = 49.39491 - 0.0195227 Year

Summary of Fit

RSquare	0.086902
RSquare Adj	0.069993
Root Mean Square Error	1.041616
Mean of Response	10.78885
Observations (or Sum Wgts)	56

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5.575994	5.57599	5.1393
Error	54	58.588018	1.08496	Prob > F
C. Total	55	64.164012		0.0274

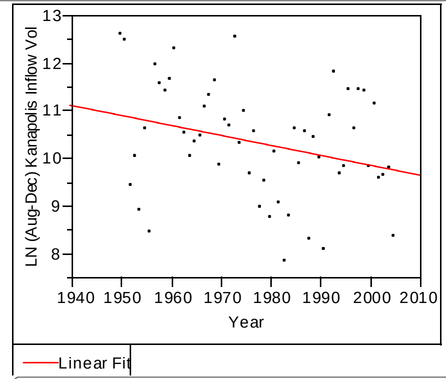
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	49.39491	17.03007	2.90	0.0054
Year	-0.019523	0.008612	-2.27	0.0274

Kendall Tau b = -0.1896; Prob>|Tau b| = 0.039

Figure 5:Inflow Trend (May-Jul)

Bivariate Fit of LN (Aug-Dec) Kanapolis Inflow Vol By Year



Linear Fit

LN (Aug-Dec) Kanapolis Inflow Vol = 51.759995 - 0.0209509 Year

Summary of Fit

RSquare	0.085121
RSquare Adj	0.068179
Root Mean Square Error	1.130555
Mean of Response	10.32953
Observations (or Sum Wgts)	56

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6.421713	6.42171	5.0242
Error	54	69.020409	1.27816	Prob > F
C. Total	55	75.442121		0.0291

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	51.759995	18.4842	2.80	0.0071
Year	-0.020951	0.009347	-2.24	0.0291

Kendall Tau b = -0.2156; Prob>|Tau b| = 0.019

Figure 6:Inflow Trend (Aug-Dec)

This process was repeated for the Smoky Hill River near Bunker Hill (Figures 7, 8, 9 below). There was no statistically discernable trend (at alpha 0.05) in the seasonal flow volume for the January-April season (Prob > F = 0.51 in Figure 7). A statistically discernable trend was found (alpha = 0.05; Prob > F = 0.049 from Figure 8) for the May-July season. The trend was toward declining seasonal flow volumes. The final season, August-December (Figure 9), showed no statistically discernable trend in seasonal flow volume. Kendall's tau, was again run on the seasonal flow volume data (see bottom of Figures 7, 8 and 9). The nonparametric trend test indicated no discernable trend for any of the seasons.

Although modest declines in flow volume at the Bunker Hill gage might be indicated by the trend analysis, what becomes of importance is the comparison of flow volumes at the Bunker Hill and Ellsworth gages. The average annual flow volumes for 1950-2006 at each gage location were calculated by summing the average for the three seasonal periods (Table 1). The average flow volume at Bunker Hill is almost an order of magnitude less than the flow volume at Ellsworth. Therefore, a declining trend in flow volume is proportionately much more significant to the inflows for Kanopolis Reservoirs at Ellsworth than at Bunker Hill. In other words, there never was that much flow volume to begin with at the Bunker Hill gage. Therefore, most of the loss in flow volume must occur below the Bunker Hill location.

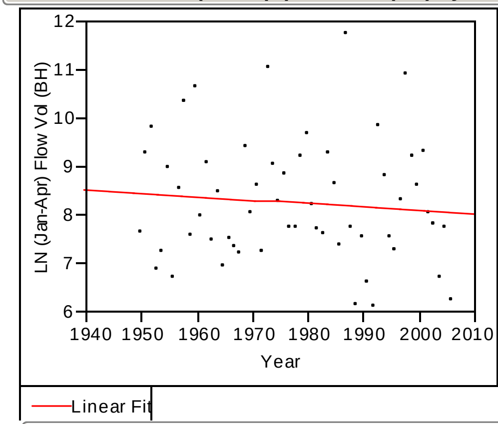
The review of the flow volumes at the Ellsworth and Bunker Hill gage locations indicates a substantial reduction in the gain in flow volume that historically occurred between the two gages on the Smoky Hill River above Kanopolis reservoir. The trend in the reduction in flow volume gain between the two gages by flow season is shown in Figures 10, 11 and 12. Significant declines in the gain between the two gages occurred for the May-July and August-December seasons.

Why would such a large portion of the flow volume decline be associated with this portion of the reservoir's drainage area? Perhaps precipitation in the drainage area has also declined significantly. Perhaps groundwater declines in the area have affected the base flow volume contribution to Kanopolis. Perhaps some other process or practice is intercepting the precipitation that does occur before it becomes inflow to Kanopolis.

Inflow Depletion: Contributing Factors Review

Four precipitation stations in the Kanopolis drainage area were reviewed for trends. Figure 13 shows the location of each of these stations. The monthly precipitation (in inches) at each of the four stations was compiled for each of the same seasons as the flow volume analysis (January-April, May-July and August-December). A natural log transformation was applied to the precipitation seasonal totals from 1950-2006 to get each of them to follow a normal distribution. Finally, these seasonal totals were reviewed for trend through time.

Bivariate Fit of LN (Jan-Apr) Flow Vol (BH) By Year



Linear Fit

LN (Jan-Apr) Flow Vol (BH) = 21.538018 - 0.0067193 Year

Summary of Fit

RSquare	0.007876
RSquare Adj	-0.01016
Root Mean Square Error	1.263101
Mean of Response	8.247321
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Square	Mean Squar	F Ratio
Model	1	0.696550	0.69655	0.4366
Error	55	87.748391	1.59543	Prob > F
C. Total	56	88.444941		0.5115

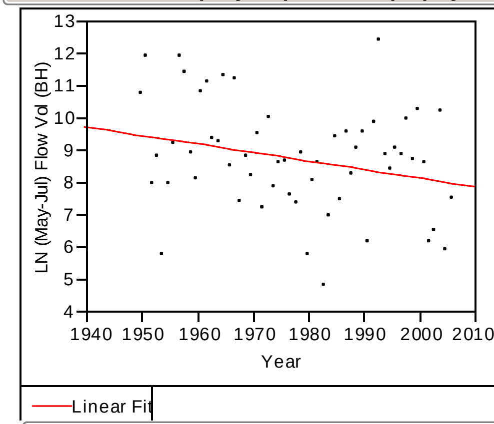
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	21.538018	20.11522	1.07	0.2890
Year	-0.006719	0.010169	-0.66	0.5115

Kendall Tau b = -0.0451; Prob>|Tau b| = 0.62

Figure 7: BH Inflow Trend (Jan-Apr)

Bivariate Fit of LN (May-Jul) Flow Vol (BH) By Year



Linear Fit

LN (May-Jul) Flow Vol (BH) = 60.948893 - 0.0264012 Year

Summary of Fit

RSquare	0.068624
RSquare Adj	0.05169
Root Mean Square Error	1.629005
Mean of Response	8.727354
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Square	Mean Squar	F Ratio
Model	1	10.75366	10.7537	4.0524
Error	55	145.95114	2.6537	Prob > F
C. Total	56	156.70480		0.0490

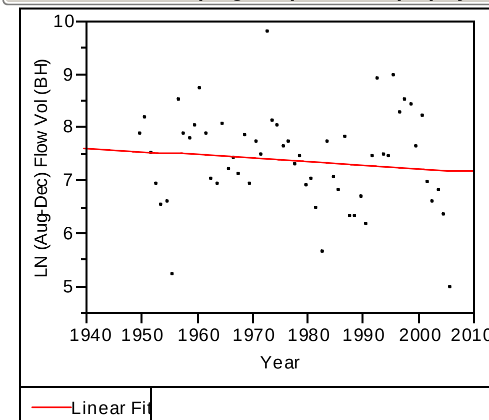
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	60.948893	25.94233	2.35	0.0224
Year	-0.026401	0.013115	-2.01	0.0490

Kendall Tau b = -0.1391; Prob>|Tau b| = 0.1265

Figure 8: BH Inflow Trend (May-Jul)

Bivariate Fit of LN (Aug-Dec) Flow Vol (BH) By Year



Linear Fit

LN (Aug-Dec) Flow Vol (BH) = 20.021015 - 0.0063991 Year

Summary of Fit

RSquare	0.013855
RSquare Adj	-0.00408
Root Mean Square Error	0.904197
Mean of Response	7.36363
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Square	Mean Squar	F Ratio
Model	1	0.631750	0.631750	0.7727
Error	55	44.966436	0.817572	Prob > F
C. Total	56	45.598186		0.3832

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	20.021015	14.39957	1.39	0.1700
Year	-0.006399	0.00728	-0.88	0.3832

Kendall Tau b = -0.1205; Prob>|Tau b| = 0.1862

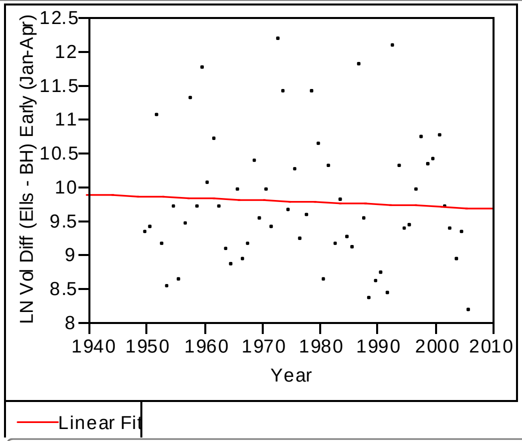
Figure 9: BH Inflow Trend (Aug-Dec)

Mean Flow Volumes For Two Locations on Smoky Hill R.

	Jan-Apr	May-Jul	Aug-Dec	Annual
1950-2006	Mean Flow Vol (AF)	Mean Flow Vol (AF)	Mean Flow Vol (AF)	Mean Flow Vol (AF)
Bunker Hill	3,817	6,169	1,578	11,564
Ellsworth	23,792	48,477	30,593	102,862
Flow Vol Gain (AF)	**19,975**	**42,308**	**29,016**	**91,298**

Table 1: Mean Flow Volume Comparison – Bunker Hill and Ellsworth

LN Vol Diff (Ells - BH) (Jan-Apr) By Year



Linear Fit

LN Vol Diff (Ells - BH) Early (Jan-Apr) = 15.813054 - 0.0030483

Summary of Fit

RSquare	0.002692
RSquare Adj	-0.01544
Root Mean Square Error	0.982656
Mean of Response	9.783598
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.143355	0.143355	0.1485
Error	55	53.108746	0.965614	Prob > F
C. Total	56	53.252101		0.7015

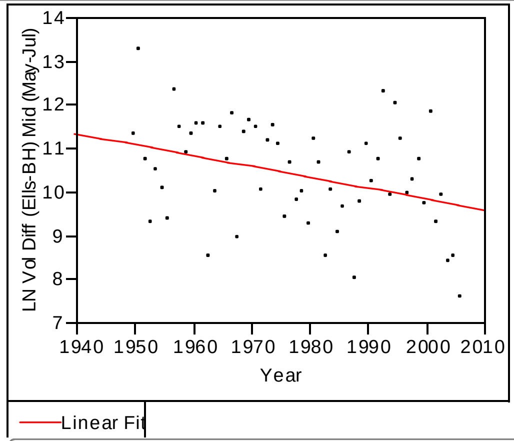
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.813054	15.64906	1.01	0.3167
Year	-0.003048	0.007911	-0.39	0.7015

Kendall Tau b = -0.0213; Prob>|Tau b| = 0.82

Figure 10: Ch in Flow Trend (Jan-Apr)

LN Vol Diff (Ells-BH) (May-Jul) By Year



Linear Fit

LN Vol Diff (Ells-BH) Mid (May-Jul) = 59.885393 - 0.0250192

Summary of Fit

RSquare	0.123221
RSquare Adj	0.10728
Root Mean Square Error	1.117763
Mean of Response	10.3974
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	9.657323	9.65732	7.7296
Error	55	68.716702	1.24939	Prob > F
C. Total	56	78.374025		0.0074

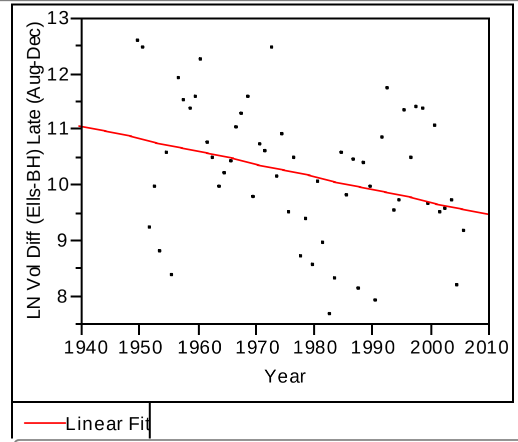
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	59.885393	17.80067	3.36	0.0014
Year	-0.025019	0.008999	-2.78	0.0074

Kendall Tau b = -0.2143; Prob>|Tau b| = 0.02

Figure 11: Ch in Flow Trend (May-Jul)

LN Vol Diff (Ells-BH) (Aug-Dec) By Year



Linear Fit

LN Vol Diff (Ells-BH) Late (Aug-Dec) = 55.376038 - 0.0228408

Summary of Fit

RSquare	0.097946
RSquare Adj	0.081545
Root Mean Square Error	1.160931
Mean of Response	10.197
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	8.048796	8.04880	5.9720
Error	55	74.126900	1.34776	Prob > F
C. Total	56	82.175696		0.0178

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	55.376038	18.48813	3.00	0.0041
Year	-0.022841	0.009347	-2.44	0.0178

Kendall Tau b = -0.2318; Prob>|Tau b| = 0.01

Figure 12: Ch in Flow Trend (Aug-Dec)

Figure 13: Precipitation Station Locations

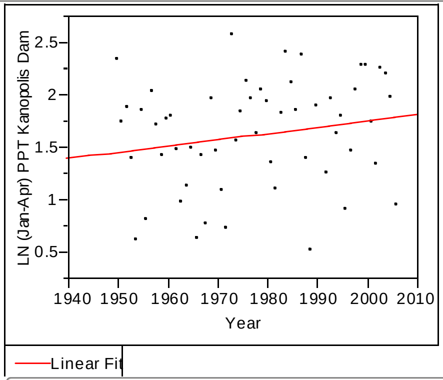
Figures 14, 15 and 16 show the bivariate fit of seasonal total precipitation at the Kanopolis Dam station from 1950 – 2006. No statistically discernable trend (at alpha = 0.05) could be found for any of the previously defined inflow seasons at this station.

Figures 17, 18 and 19 are for the Ellsworth climate station, which is located in the subwatershed of interest. Again, no discernable trend occurs. This lack of trend is repeated for the two remaining stations located above the Bunker Hill stream gage; Loretta (Figures 20, 21 and 22) and Hays 1S (Figures 23, 24 and 25).

This review of precipitation for trend certainly does not indicate that a decline in seasonal flow volume could be explained by a concomitant decline in precipitation volume for the same period. Therefore, processes and/or practices must be intercepting the volume of precipitation before it becomes inflow to Kanopolis reservoir.

Three general processes/practices could be involved in inflow interception. The first could be from direct diversion of surface water or indirectly, via base flow volume declines from groundwater use. Figure 26 shows the location of all points of diversion located in the drainage between the Bunker Hill gage and Kanopolis Dam. There are about 1,600 AF in total appropriations for all these points of diversion. 2001 water use (a relatively dry year) totaled about 675 acre-feet. Since 675 acre-feet of water use is a fraction of one percent of the estimated average annual volume inflow gain from the Bunker Hill to Ellsworth gages locations (91,298 AF from Table 1), water use in the subwatershed certainly could not be a contributing factor of any significance to the flow volume loss to between those gages.

Bivariate Fit of LN (Jan-Apr) PPT Kanopolis Dam By Year



Linear Fit

LN (Jan-Apr) PPT Kanopolis Dam = -10.0992 + 0.0059229 Year

Summary of Fit

RSquare	0.037046
RSquare Adj	0.019214
Root Mean Square Error	0.507559
Mean of Response	1.614857
Observations (or Sum Wgts)	56

Analysis of Variance

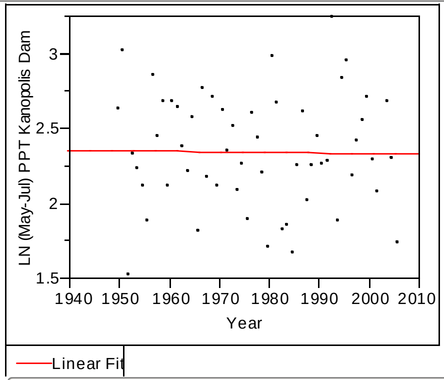
Source	DF	Sum of Square	Mean Squar	F Ratio
Model	1	0.535185	0.535185	2.0775
Error	54	13.911266	0.257616	Prob > F
C. Total	55	14.446451		0.1553

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-10.0992	8.127497	-1.24	0.2194
Year	0.0059229	0.004109	1.44	0.1553

Figure 14: Dam PPT Trend (Jan-Apr)

Bivariate Fit of LN (May-Jul) PPT Kanopolis Dam By Year



Linear Fit

LN (May-Jul) PPT Kanopolis Dam = 2.9814111 - 0.0003239 Year

Summary of Fit

RSquare	0.000198
RSquare Adj	-0.01832
Root Mean Square Error	0.380609
Mean of Response	2.340875
Observations (or Sum Wgts)	56

Analysis of Variance

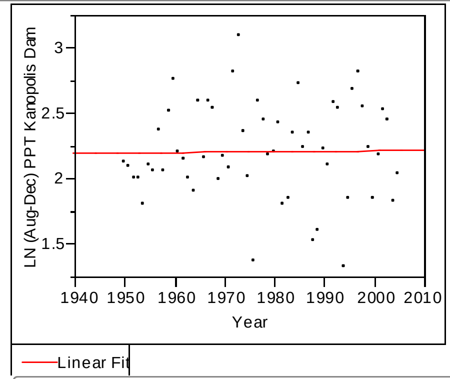
Source	DF	Sum of Square	Mean Squar	F Ratio
Model	1	0.0015519	0.001552	0.0107
Error	54	7.8226003	0.144863	Prob > F
C. Total	55	7.8241521		0.9179

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.9814111	6.188858	0.48	0.6319
Year	-0.000324	0.003129	-0.10	0.9179

Figure 15: Dam PPT Trend (May-Jul)

Bivariate Fit of LN (Aug-Dec) PPT Kanopolis Dam By Year



Linear Fit

LN (Aug-Dec) PPT Kanopolis Dam = 1.6337237 + 0.0002914 Year

Summary of Fit

RSquare	0.000171
RSquare Adj	-0.01834
Root Mean Square Error	0.367185
Mean of Response	2.209875
Observations (or Sum Wgts)	56

Analysis of Variance

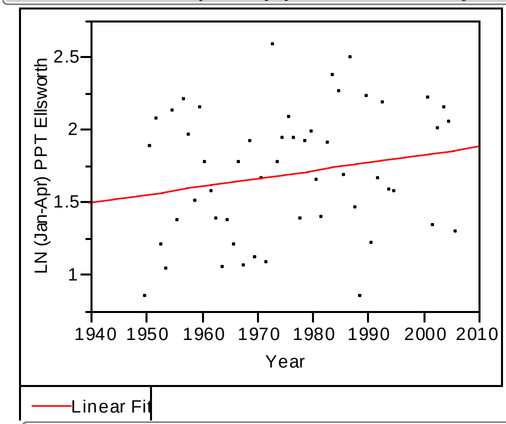
Source	DF	Sum of Square	Mean Squar	F Ratio
Model	1	0.0012419	0.001242	0.0092
Error	54	7.2805222	0.134824	Prob > F
C. Total	55	7.2817641		0.9239

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.6337237	6.003344	0.27	0.7866
Year	0.0002914	0.003036	0.10	0.9239

Figure 16: Dam PPT Trend (Aug-Dec)

Bivariate Fit of LN (Jan-Apr) PPT Ellsworth By Year



Linear Fit

LN (Jan-Apr) PPT Ellsworth = -9.21969 + 0.0055245 Year

Summary of Fit

RSquare	0.04089
RSquare Adj	0.021707
Root Mean Square Error	0.435156
Mean of Response	1.697154
Observations (or Sum Wgts)	52

Analysis of Variance

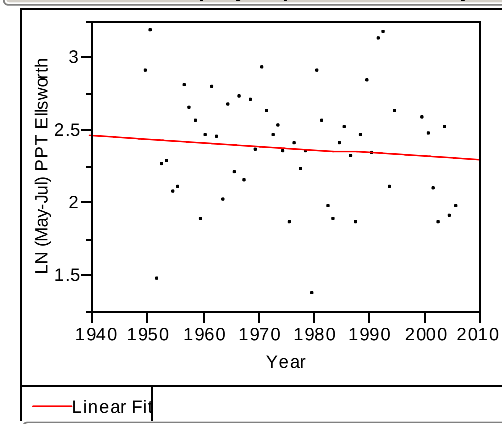
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.4036500	0.403650	2.1316
Error	50	9.4680528	0.189361	Prob > F
C. Total	51	9.8717028		0.1505

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-9.21969	7.47746	-1.23	0.2233
Year	0.0055245	0.003784	1.46	0.1505

Figure 17: Ellsworth PPT Trend (Jan-Apr)

Bivariate Fit of LN (May-Jul) PPT Ellsworth By Year



Linear Fit

LN (May-Jul) PPT Ellsworth = 7.0851689 - 0.0023816 Year

Summary of Fit

RSquare	0.0095
RSquare Adj	-0.00992
Root Mean Square Error	0.399829
Mean of Response	2.377906
Observations (or Sum Wgts)	53

Analysis of Variance

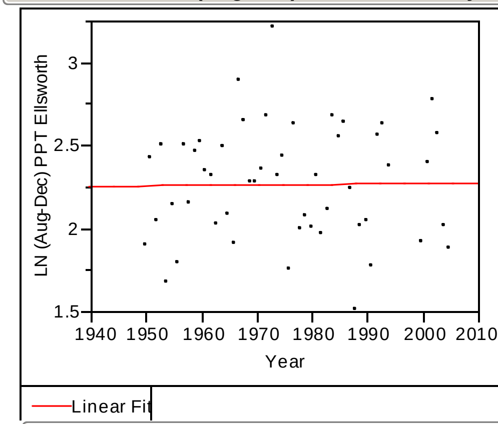
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0782001	0.078200	0.4892
Error	51	8.1530364	0.159863	Prob > F
C. Total	52	8.2312365		0.4875

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.0851689	6.730603	1.05	0.2974
Year	-0.002382	0.003405	-0.70	0.4875

Figure 18: Ellsworth PPT Trend (May-Jul)

Bivariate Fit of LN (Aug-Dec) PPT Ellsworth By Year



Linear Fit

LN (Aug-Dec) PPT Ellsworth = 1.7182208 + 0.0002766 Year

Summary of Fit

RSquare	0.000163
RSquare Adj	-0.02024
Root Mean Square Error	0.346022
Mean of Response	2.264765
Observations (or Sum Wgts)	51

Analysis of Variance

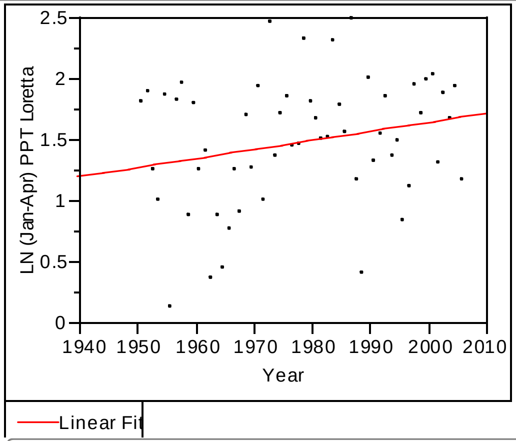
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0009592	0.000959	0.0080
Error	49	5.8668440	0.119732	Prob > F
C. Total	50	5.8678032		0.9290

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.7182208	6.10658	0.28	0.7796
Year	0.0002766	0.003091	0.09	0.9290

Figure 19: Ellsworth PPT Trend (Aug-Dec)

Bivariate Fit of LN (Jan-Apr) PPT Loretta By Year



Linear Fit

LN (Jan-Apr) PPT Loretta = -13.13083 + 0.007386 Year

Summary of Fit

RSquare	0.053507
RSquare Adj	0.03598
Root Mean Square Error	0.511314
Mean of Response	1.482411
Observations (or Sum Wgts)	56

Analysis of Variance

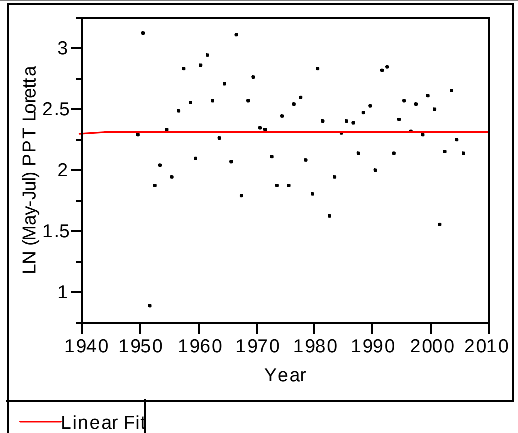
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.798115	0.798115	3.0527
Error	54	14.117856	0.261442	Prob > F
C. Total	55	14.915972		0.0863

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-13.13083	8.364036	-1.57	0.1223
Year	0.007386	0.004227	1.75	0.0863

Figure 20: Loretta PPT Trend (Jan-Apr)

Bivariate Fit of LN (May-Jul) PPT Loretta By Year



Linear Fit

LN (May-Jul) PPT Loretta = 1.9376799 + 0.0001895 Year

Summary of Fit

RSquare	0.00006
RSquare Adj	-0.01812
Root Mean Square Error	0.408377
Mean of Response	2.312561
Observations (or Sum Wgts)	57

Analysis of Variance

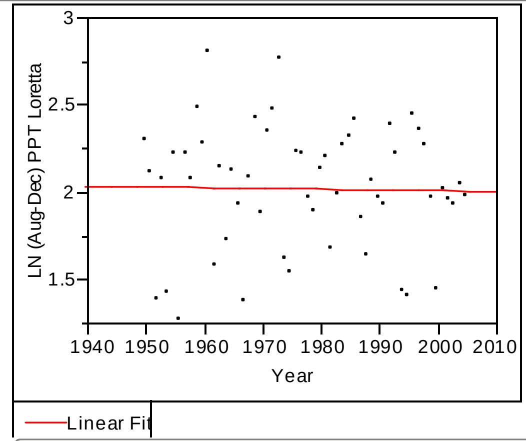
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0005542	0.000554	0.0033
Error	55	9.1724479	0.166772	Prob > F
C. Total	56	9.1730020		0.9542

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.9376799	6.503509	0.30	0.7669
Year	0.0001895	0.003288	0.06	0.9542

Figure 21: Loretta PPT Trend (May-Jul)

Bivariate Fit of LN (Aug-Dec) PPT Loretta By Year



Linear Fit

LN (Aug-Dec) PPT Loretta = 2.8530217 - 0.0004214 Year

Summary of Fit

RSquare	0.000375
RSquare Adj	-0.01814
Root Mean Square Error	0.358246
Mean of Response	2.019714
Observations (or Sum Wgts)	56

Analysis of Variance

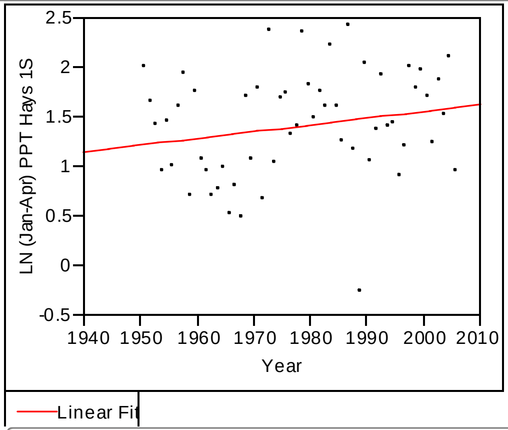
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0025979	0.002598	0.0202
Error	54	6.9303875	0.128341	Prob > F
C. Total	55	6.9329854		0.8874

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.8530217	5.857209	0.49	0.6282
Year	-0.000421	0.002962	-0.14	0.8874

Figure 22: Loretta PPT Trend (Aug-Dec)

Bivariate Fit of LN (Jan-Apr) PPT Hays 1S By Year



Linear Fit

LN (Jan-Apr) PPT Hays 1S = -12.09869 + 0.0068261 Year

Summary of Fit

RSquare	0.042601
RSquare Adj	0.024871
Root Mean Square Error	0.532646
Mean of Response	1.406839
Observations (or Sum Wgts)	56

Analysis of Variance

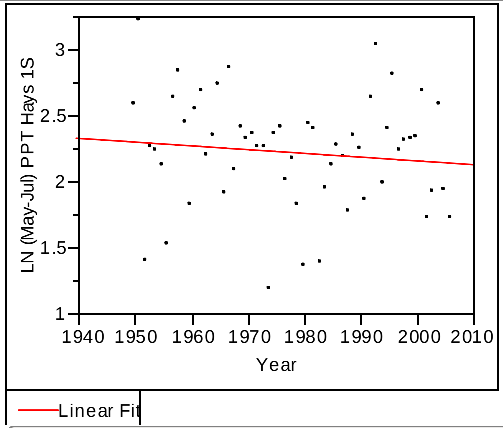
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.681703	0.681703	2.4028
Error	54	15.320446	0.283712	Prob > F
C. Total	55	16.002150		0.1270

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-12.09869	8.71299	-1.39	0.1707
Year	0.0068261	0.004404	1.55	0.1270

Figure 23: Hays PPT Trend (Jan-Apr)

Bivariate Fit of LN (May-Jul) PPT Hays 1S By Year



Linear Fit

LN (May-Jul) PPT Hays 1S = 7.5809284 - 0.0027082 Year

Summary of Fit

RSquare	0.011469
RSquare Adj	-0.0065
Root Mean Square Error	0.421094
Mean of Response	2.224123
Observations (or Sum Wgts)	57

Analysis of Variance

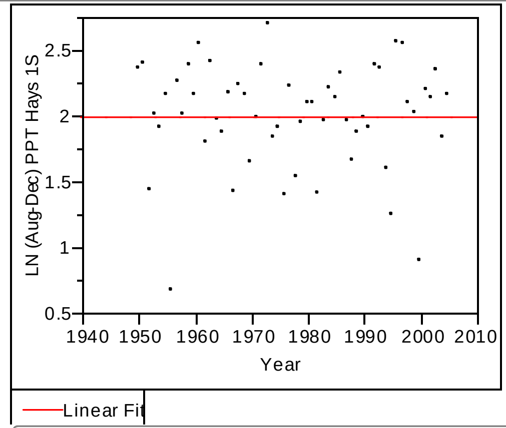
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.1131537	0.113154	0.6381
Error	55	9.7526204	0.17732(	Prob > F
C. Total	56	9.8657741		0.4278

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.5809284	6.706035	1.13	0.2632
Year	-0.002708	0.00339	-0.80	0.4278

Figure 24: Hays PPT Trend (May-Jul)

Bivariate Fit of LN (Aug-Dec) PPT Hays 1S By Year



Linear Fit

LN (Aug-Dec) PPT Hays 1S = 2.1990875 - 0.0001033 Year

Summary of Fit

RSquare	0.000018
RSquare Adj	-0.0185
Root Mean Square Error	0.403287
Mean of Response	1.994714
Observations (or Sum Wgts)	56

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0001563	0.000156	0.0010
Error	54	8.7825672	0.16264(	Prob > F
C. Total	55	8.7827234		0.9754

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.1990875	6.593601	0.33	0.7400
Year	-0.000103	0.003334	-0.03	0.9754

Figure 25: Hays PPT Trend (Aug-Dec)

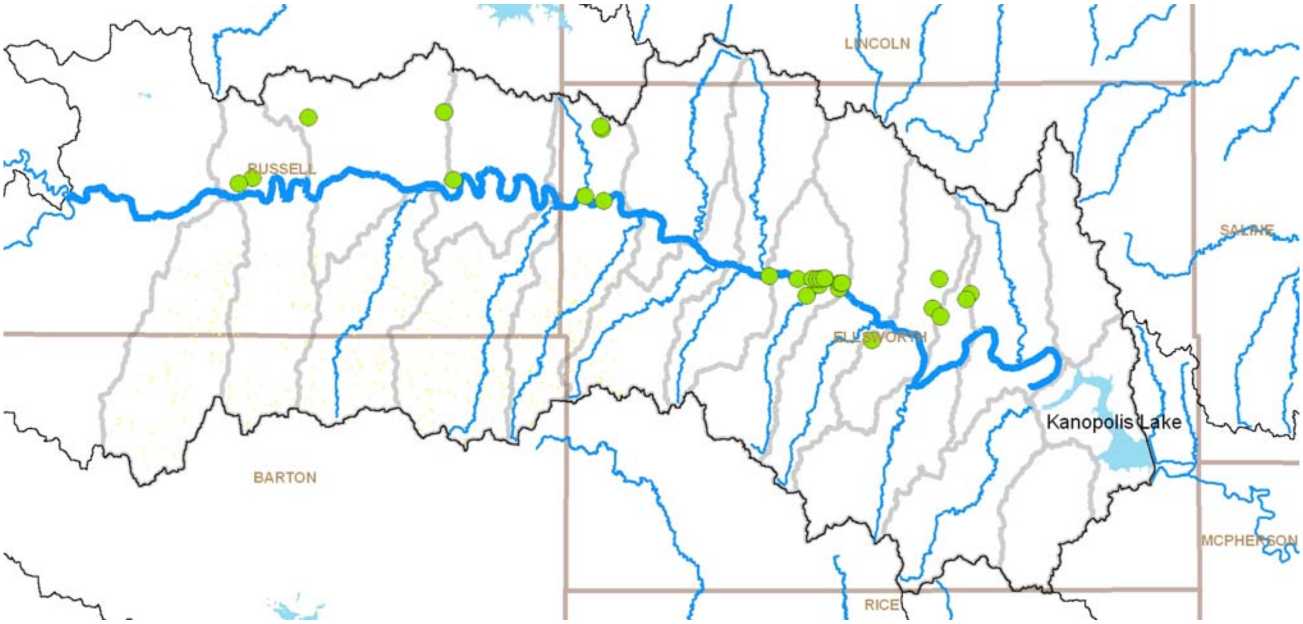


Figure 26: Points of Diversion in Watershed

The other two practices fall into the general classification of runoff management. The first is a possible increase in the use of small watershed impoundments between 1950 and 2006. The second is land surface practices that enhance soil moisture collection/retention (conservation tillage practices) and reduce soil erosion caused by runoff (terracing, buffer strips, grassed waterways). Although both of these practices could increase ground-water recharge and, thus, later base flow, a greater amount of water is expected to be lost to surface water and soil moisture evaporation and to plant transpiration. More study would be needed to determine the relative impact from each of the runoff management practices.

Reservoir Inflow Summary

Since 1950 there has been a significant reduction to the flow volume gain between the Bunker Hill and Ellsworth gages (Figure 11 and 12). This loss has reduced the volume of inflow to Kanopolis reservoir. There has been no concomitant reduction in precipitation volume in the area to explain this flow volume decline. Total annual water use from all sources in the area of interest is a fraction of one percent of the average annual flow volume. The effects of runoff management practices installed since 1950 have not been assessed as far as their relative contribution to this loss. One result of these practices is likely a factor in causing the reduction to inflow volumes to Kanopolis Reservoir.

Inflow Depletion Estimation for Yield Analyses

As previously mentioned, the inflow to a water-supply yield model is one of the most sensitive parameters in the yield optimization problem. If the method of inflow depletion overestimates the monthly volumes entering a reservoir during the drought period, then the water-supply yields can be overestimated. Previous reservoir yield analyses performed by the Kansas Water Office have generally split the period of flow record and compared total inflow volumes of a historic period versus a more modern period of the same time length to determine the inflow depletion fraction that is applied to observed volumes from the regulation-defined 2% drought period (1952-1957). More recently, the Kansas Water Office has applied the annual trend in reservoir inflow, using only years with less normal precipitation, in an attempt to more accurately estimate inflow depletions for a yield analyses (Wilson Reservoir Water Supply Yield Analysis, KWO 2004).

Since these yield analyses are run on a monthly time step and we have already shown that the inflows and their depletions have varied (at least) seasonally through time (Figures 4 - 12), why limit the depletion method to annual declines or fractional declines estimated from gross volumetric changes that compare large segments of time? The relationship between various climatic factors, moisture indices, and monthly inflows of a more recent period (remember we have shown that inflows have declined over time but precipitation has not) can be used to estimate inflows for the historical drought period used in the yield analysis for Kanopolis Reservoir.

Twelve multiple regression models were created, one for each month's inflow, using data from a recent drought period, 2000 through 2006. A stepwise regression process was utilized. In each case the following factors were candidates for use in the regression model to predict the current month's (Month) inflow:

1. Precipitation (Ellsworth) for Month
2. Precipitation ((Loretta + Hays 1S) / 2) for Month
3. Palmer Hydrologic Drought Index (Region 5) for Month
4. Palmer Drought Severity Index (Region 5) for Month
5. Palmer "Z" Index (Region5) for Month
6. Factors 1 through 5 for the previous month (Month -1)
7. Inflow from Month -1 (previous month's inflow)
8. Factors 1 through 5 for Month -2 and Inflow Month -2

The step-wise regression technique established the 12 monthly multiple regression models shown in Table 2. Adjusted R-Squares for these multiple regressions ranged from 0.62 to 0.98. Notice that in most of the monthly regression models a previous month's inflow was found to be a significant factor in predicting the current month's inflow. These equations established a relationship between predictors (climatic and previous flow volume conditions) and the current month's inflow. These relationships are based upon a more recent drought period (data from 2000 – 2006) so when we simulate a historic drought such as that that occurred in the 1950's we can estimate more accurately inflows in response to that drought condition.

By using the 12 regression models in Table 2, we can apply the modern relationship between climatic factors and inflows to the historical conditions of the 1952 – 1957 drought to adjust the observed 1952 – 1957 Kanopolis inflows for the water-supply yield analysis. To adjust January 1952 inflows for the water-supply yield simulation, the recorded monthly inflow for November 1951 was used in the January regression equation (see Table 2) to estimate the depletion to the historically observed inflow. To estimate depletion to the February 1952 inflow, we used the calculated January inflow from the previous step and the observed January 1952 precipitation. From February 1952 forward we ceased using actual inflows from the historic period and substitute, where prescribed by Table 2, the depleted inflows calculated using the equations from the previous months. However, during this process we continued to use the climatic variables and moisture indices (precipitation and the Palmer "Z" Index) from the defined drought period. We continued to solve the depletion to monthly inflows until we reached the end of the drought period. These steps generated depleted inflows for the 1952 – 1957 drought period for input into the Kanopolis water-supply yield model.

Again, the intent of the monthly inflow regression equations is to simulate a modern inflow response to the climate conditions of the 1952-1957 drought.

For comparison purposes, Figure 27 shows the observed 1952-1957 inflows to Kanopolis (red line), the depleted inflows as estimated by the monthly multiple regression equations (green line), and the depleted inflows that were used in the 2002 Kanopolis Yield Analysis model (blue line). On average the 2002 Kanopolis Yield Model depleted observed 1952-1957 inflows by about 30%. Notice in Figure 27 that the regression model often predicts smaller inflows (greater depletion) than the 2002 Kanopolis water-supply yield model. Volumetrically, over the six-year modeled drought period, the regression equations from Table 2 predict that inflows will a little less than half of the volume that the 2002 Kanopolis yield model uses and about a third of the actual historic volume for the defined drought period, 1952-1957.

Solving the 2002 Kanopolis water-supply yield model by substituting the regression calculated monthly inflows for the published inflows used in that model produced a yield of 5.9 MGD (9.2 cfs) for the year 2040. This is a bit less than half of the published water-supply yield from the 2002 water-supply yield analysis of Kanopolis Reservoir.

Kanopolis: Multiple Regression Monthly Inflow Equations

	Intercept		Previous Inflow 1		PPT 1		PPT 2		Palmer "Z" Index	Adj. R^2
January										
LN Jan Inflow =	2.01282	+	0.77455 LN Nov Inflow (Lag -1)	+		+		+		0.98
St Err	0.32186		0.04222							
February										
LN Feb Inflow =	-0.56750	+	1.01247 LN Jan Inflow	+	0.53436 SqRt Feb PPT (Ellsworth)	+		+		0.93
St Err	1.12718		0.15230		0.19114					
March										
LN Mar Inflow =	-0.50754	+	0.90895 LN Feb Inflow	+	1.06751 SqRt Mar PPT (Ellsworth)	+		+		0.93
St Err	1.05522		0.12586		0.20002					
April										
LN Apr Inflow =	4.85499	+	0.39928 LN Mar Inflow	+		+		+	0.45288 ZNDX Feb (R5)	0.83
St Err	2.08694		0.24933						0.12550	
May										
LN May Inflow =	1.36039	+	0.57289 LN Apr Inflow	+	1.43664 SqRt May PPT (Ellsworth)	+		+		0.82
St Err	1.72684		0.23833		0.52189					
June										
LN Jun Inflow =	2.15283	+	0.46199 LN May Inflow	+	1.56639 SqRt May PPT (L,H)	+		+		0.9
St Err	1.30242		0.25327		0.74557					
July										
LN Jul Inflow =	3.69136	+		+	2.07057 SqRt Jul PPT (Ellsworth)	+	0.93364 SqRt May PPT (Ellsworth)	+		0.79
St Err	1.02723				0.57186		0.58122			
August										
LN Aug Inflow =	2.12148	+		+	0.92173 SqRt Aug PPT (Ellsworth)	+	2.97812 SqRt Jul PPT (Ellsworth)	+		0.62
St Err	2.58659				0.64153		1.04965			
September										
LN Sep Inflow =	8.72326	+		+		+		+	0.78387 ZNDX Sep (R5)	0.7
St Err	0.33840								0.20197	
October										
LN Oct Inflow =	0.09150	+	0.67874 LN Sep Inflow	+	1.28358 SqRt Oct PPT (Ellsworth)	+		+		0.87
St Err	1.15668		0.11331		0.22966					
November										
LN Nov Inflow =	-0.93416	+	0.95717 LN Oct Inflow	+	1.40484 SqRt Nov PPT (Ellsworth)	+		+		0.83
St Err	1.46431		0.17023		0.47302					
December										
LN Dec Inflow =	1.96607	+	0.75871 LN Nov Inflow	+		+		+		0.87
St Err	0.88019		0.12073							

Table 2: Regression Equations Applied to Deplete Historic Inflows

1952 – 1957 Monthly Inflows (Kanopolis)

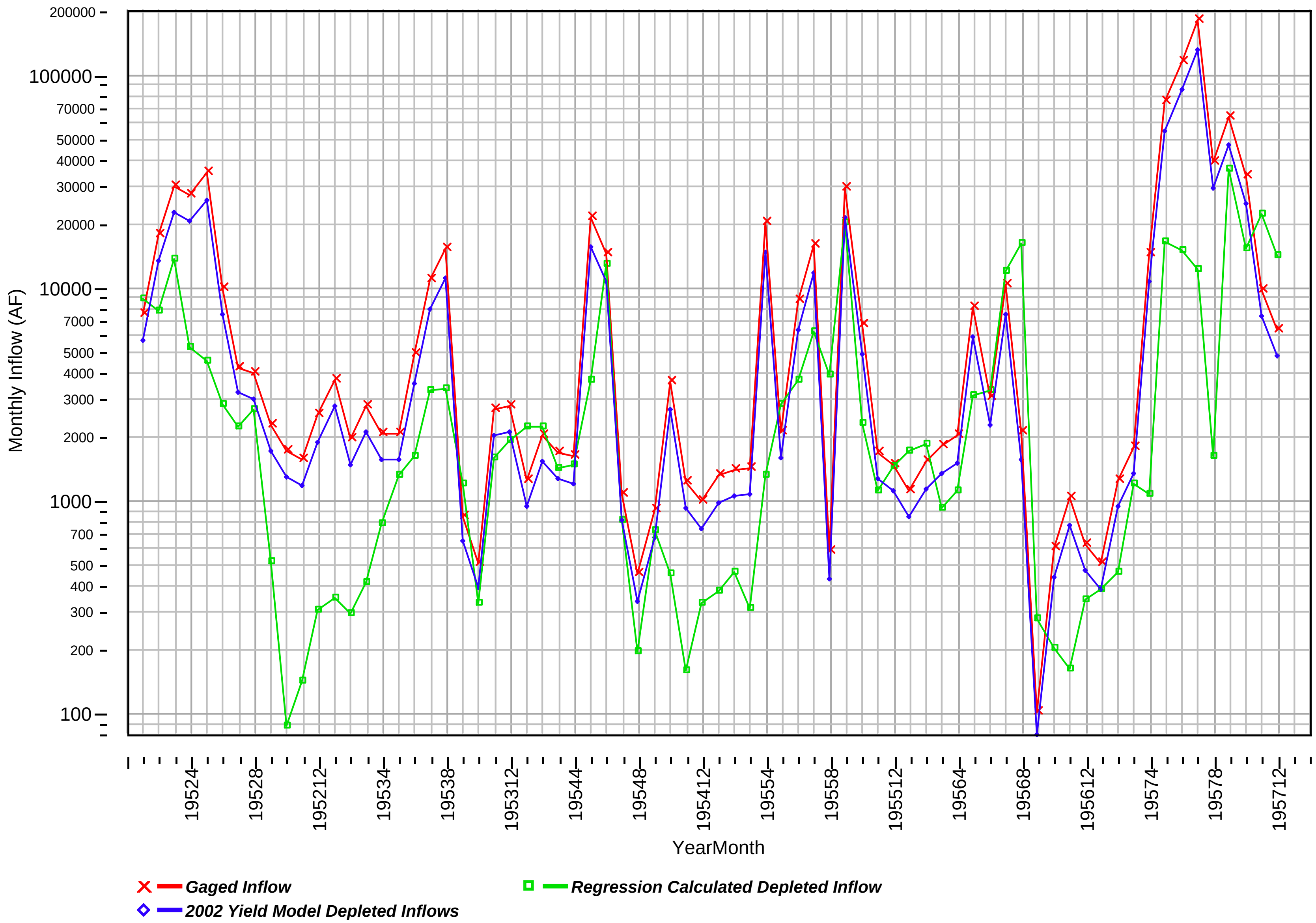


Figure 27: Inflow Comparisons – Observed, 2002 Water Supply Yield Model and Depleted Inflows Derived from Regression Eqns in Table 2

2008 Kanopolis Water-Supply Yield Model

Changes in Sedimentation Rates

In October 2007, the Kansas Biological Survey performed a bathymetric survey of the Kanopolis Reservoir multi-purpose pool. The results of this survey indicated that the rate of sediment accumulation in the reservoir was lower for the past 14 years than the previous 43 years. This reduced the period of record average sedimentation rate for the reservoir. As previously explained, the most recent bathymetric survey available is used to estimate the current sedimentation rate of the reservoir and that information is used to project the storage in the multi-purpose pool for the modeled future storage condition. Since the most recent bathymetric survey (2007) has reduced the reservoir's average sedimentation rate (using survey data from 1950 and 2007) from the rate used in the 2002 KWO water-supply yield analysis for Kanopolis (which used the estimated sedimentation rate from 1950 and 1993 data), the area-elevation-capacity tables were adjusted for the projected future storage of the reservoir for the KWO 2007 water-supply yield analysis of Kanopolis. The projected volume of the reservoir at the top of the multi-purpose pool is about 9,000 AF greater in 2040 using the most current sedimentation rate estimate than the volume used in the 2002 KWO yield analysis. If all other parameters were held the same between the 2002 and 2007 versions of the Kanopolis water-supply yield models, the 2007 model with its greater projected future storage should also have a greater water supply yield.

Changes to Reservoir Inflows: Stochastic Approach

Previously, we used November 1951 inflows as a starting condition for the series of regression equations (Table 2) applied to deplete inflows to Kanopolis reservoir. However, a more accurate model of expected future conditions would use the November inflows observed from more modern period (1977-2005) as the starting condition for our series of regression equations.

As a first step in the revision of the water-supply yield analysis methodology, the distribution of November inflows from 1977-2005 is used to randomly generate 100 starting conditions to the defined 2% drought period.

Recall that we could not explain *all* the variation in monthly inflows for the modern period when we developed our multiple regression equations in Table 2 (nor would we expect to in such a complex system). Since we could only explain between 62 and 98 percent of this variation (from the adjusted R-Squares in Table 2) we are not completely certain that we identified the correct values for our predictor coefficients in our regression equations. A range of most likely values for these coefficients is provided by using the standard error associated with each coefficient (see standard errors (St Err) below each predictor coefficient in Table 2). We can use a uniform random distribution to vary each predictor's coefficient in a range defined by that coefficient's standard error. An upper limit to monthly inflows was established by bounding the maximum monthly flow volume to the observed volumes reported at the USGS Ellsworth gaging station during the 1952-1957 drought. The yield during the 2% drought period of the reservoir is calculated based upon the resulting inflows. Estimating inflows in this manner is intended to capture much of the uncertainty in our estimate of depletions to the observed inflows at Kanopolis Reservoir for the 1952-1957 drought.

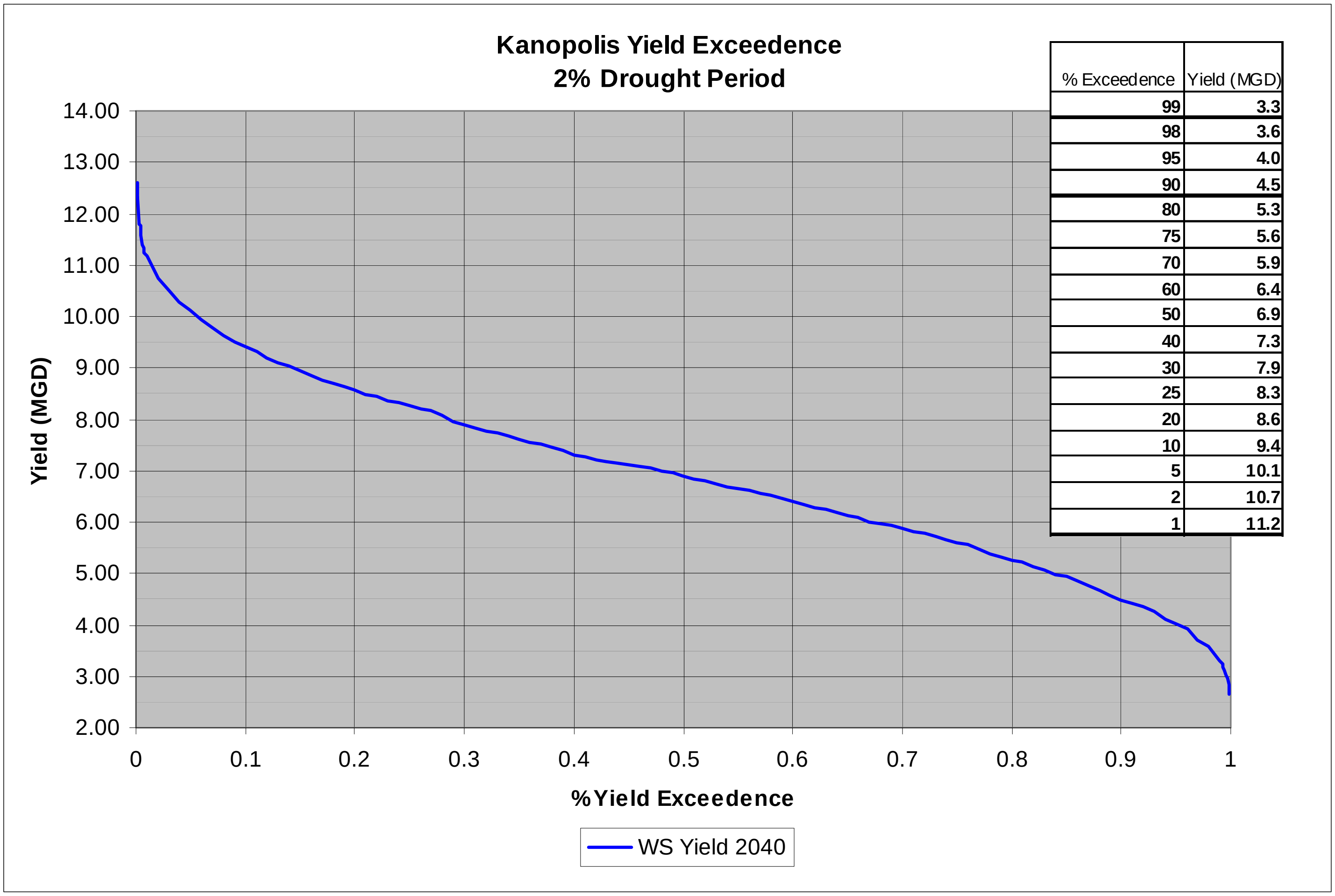
The next step to the refinement of the water-supply yield analysis methodology is, for each one of the 100 starting conditions generated from the first step, randomly generate inflows from the range defined by the standard error of the predictor coefficient. Those generated monthly inflows are then limited, if necessary, at an upper bound to the observed monthly inflows reported during the 1952-1957 drought. This process is repeated another 14 times for each of the 100 starting conditions. This creates 15 different inflow depletion runs for each of the 100 starting conditions.

The final step is to calculate the reservoir's water-supply yield by treating each of the 15 depletion runs for each of the 100 starting conditions (100*15 = 7,500 yields) as a separate solution to the optimization problem. By using all 1,500 yield solutions we can create Figure 28, a water supply yield exceedence curve.

Figure 28 shows that, with the new stochastic method of estimating water-supply yield, there is no longer a single yield value for the 2% drought period for Kanopolis[2]. What was once a single, unique solution is now expressed as a continuum of solutions. This continuum of solutions captures the uncertainty in the reservoir inflow predictions from the hydrologic system above the reservoir as it is subjected to the prescribed drought period. The selection of the 'reasonable' yield for the system has changed from a mathematical solution to a management decision. The level of uncertainty, and the risks associated with that uncertainty, can be considered during the selection of the yield value for the reservoir during the yield selection process.

From Figure 28, we find that none of the 1,500 yields calculated from the 2007 yield analysis for the year 2040 equaled or exceeded the 2002 version of published yield of 12.9 MGD for that same year. Primary yield exceedence values for 2040 are provided in the table inset of Figure 28.

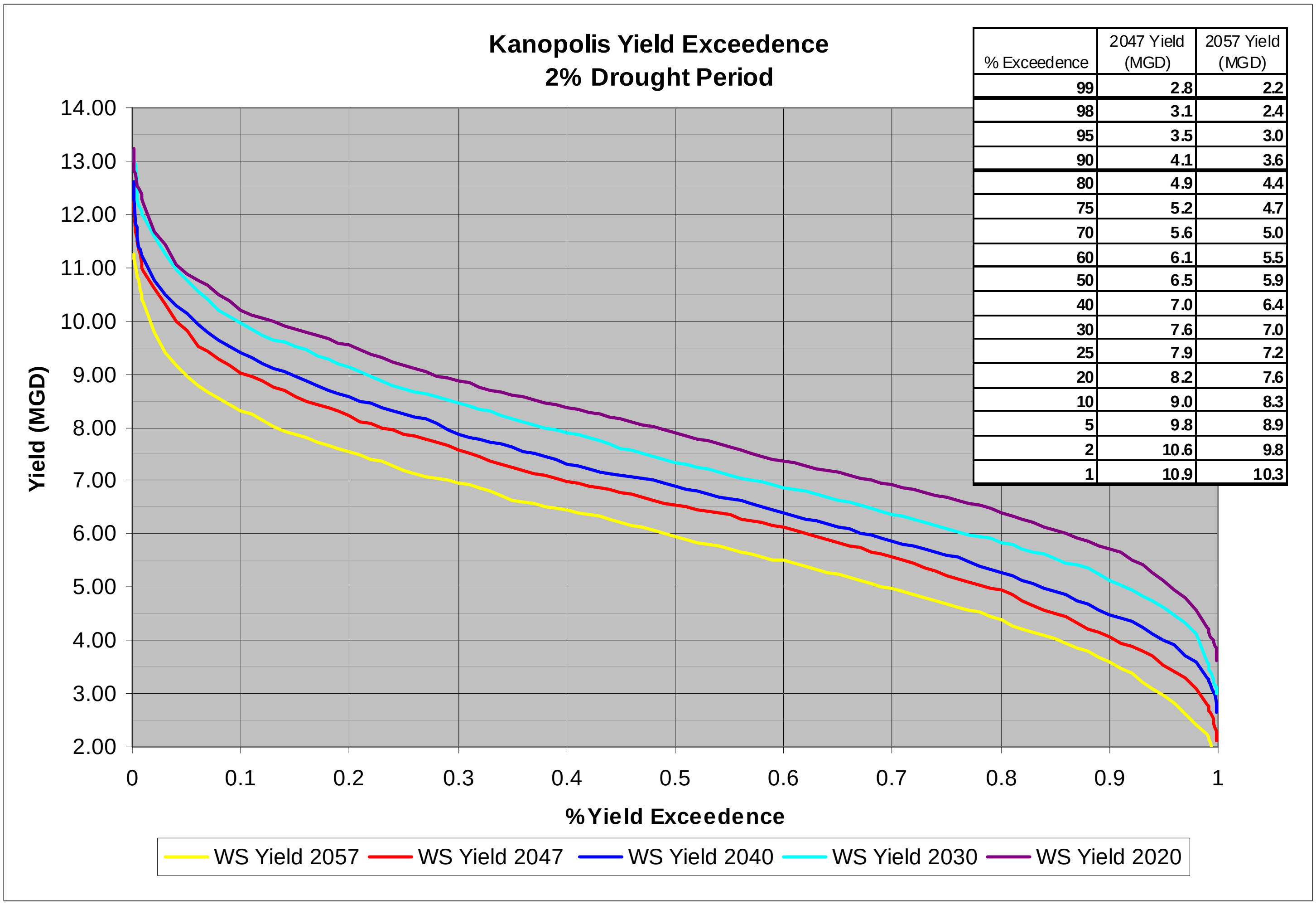
[2] In reality, to think that there ever was a single yield value for the drought period having a 2% chance of occurrence is a fundamental problem with previous yield analysis methods. The system is too complex with too many variables to think of calculating yield as a straightforward math problem with a single solution.



% Exceedence	Yield (MGD)
99	3.3
98	3.6
95	4.0
90	4.5
80	5.3
75	5.6
70	5.9
60	6.4
50	6.9
40	7.3
30	7.9
25	8.3
20	8.6
10	9.4
5	10.1
2	10.7
1	11.2

Figure 28: Kanopolis Yield Exceedence Curve (Year = 2040)

The yield exceedence curves for additional selected years are shown in Figure 29. The table inset in Figure 29 indicates that 40 years in the future (year 2047) half of the simulated yields equaled or exceeded 6.5 MGD. That same yield exceedence is reduced to 5.9 MGD 50 years in the future.



% Exceedence	2047 Yield (MGD)	2057 Yield (MGD)
99	2.8	2.2
98	3.1	2.4
95	3.5	3.0
90	4.1	3.6
80	4.9	4.4
75	5.2	4.7
70	5.6	5.0
60	6.1	5.5
50	6.5	5.9
40	7.0	6.4
30	7.6	7.0
25	7.9	7.2
20	8.2	7.6
10	9.0	8.3
5	9.8	8.9
2	10.6	9.8
1	10.9	10.3

Figure 29: Kanopolis Yield Exceedence Curves for Various Years

Fitting a regression line to chart select yield exceedences through time produces Figure 30. Since reservoir yields are based upon projected reservoir conditions 40 years in the future (K.A.R. 98-5-8 (a)(4)), a graph like Figure 30 would be beneficial between those times when water supply yield analyses are performed for an individual reservoir. Application of such a yield exceedence value curve through time would only be valid if the parameters input to the yield model have not changed since the last time a water-supply yield model was performed on a reservoir (K.A.R. 98-5-8(b)).

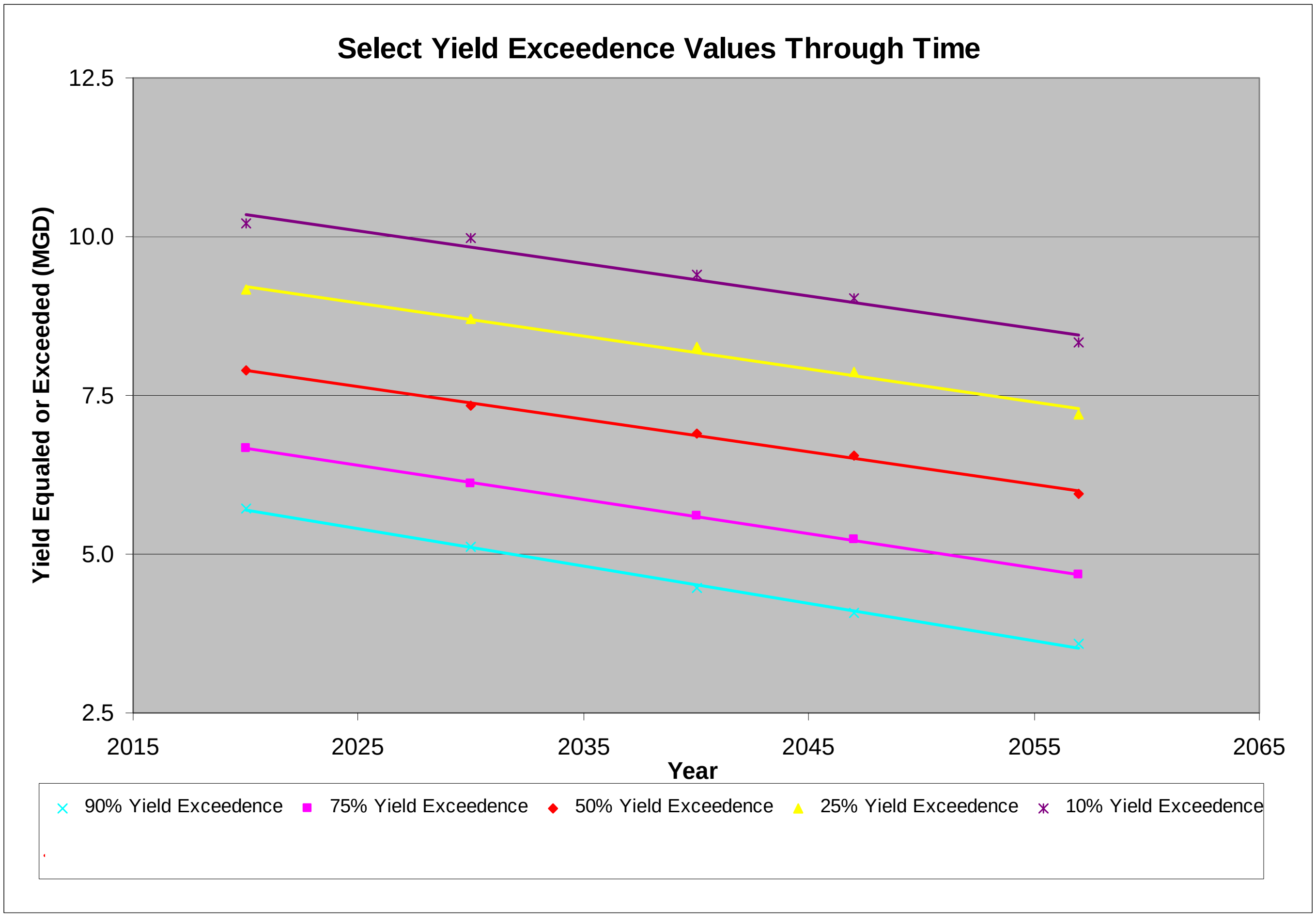


Figure 30: Kanopolis Water Supply Yields for Various Percent Exceedences Through Time

Conclusion: Water-Supply Yield Selection for Kanopolis Reservoir

As previously mentioned, the establishment of a reservoir's water-supply yield is now a process in risk assessment. Risks and benefits are discussed and weighed during the resource management decision process of selecting a water-supply yield. On March 14, 2008, the KWO recommended a water-supply yield for Kanopolis Reservoir of 13.9 cubic feet per second or 9.0 million gallons per day for consideration of the Public Water Supply Subcommittee of the Kansas Water Authority. Based upon public comments received during the March 17, through April 17, 2008, comment period, the regression equations in Table 2 were revised to more accurately simulate the Kanopolis inflows during the 2000-2006 drought. The most significant change to the yield analysis was created with the assumption that simulated monthly inflows for the water-supply yield analysis would not exceed the reported monthly inflows from the 1952-1957 drought. The result of this assumption reduced the yield exceedence curves from the first draft analysis. The KWO recommends a water-supply yield for Kanopolis Reservoir of **10.1** cubic feet per second or **6.5** million gallons per day based upon the results of this evaluation. The KWO believes this yield maximizes the water-supply benefit to the public yet can still be reasonably expected to be maintained during a drought with a two percent chance of occurrence in any one year (K.A.R. 98-5-8(a)(2)). The KWO published the yield recommendation for final public comment on April 30, 2008. The public comment period is 15 days (April 30, 2008, through May 15, 2008). Written comments and KWO responses to those comments from the March 17 through April 17, 2008, comment period are included in Appendix A of this report. Any additional comments received before the final public comment deadline of May 15, 2008, (and KWO responses to those comments) will also be included in Appendix A of the final report.

Appendix A

Public comments and KWO response

The equations in Table 2 of the 3/17/08 version of yield analysis overestimate inflow to Kanopolis by more than twice the flow recorded at the Ellsworth gage for the 2005-2006 period.

> *Agree. The KWO has revised the regression equations in Table 2 based upon climatic factors and inflows for the 2000-2006 period with the intent of more accurately simulating the estimated inflows for the most recent drought of record. This revision has greatly improved the predicted v. observed results for the period in question.*
>
> *As a point of clarification to this comment - KWO notes that the flow recorded at the Ellsworth gage is not used directly in the water-supply yield model as inflow to Kanopolis. The drainage area at the Ellsworth gage is approximately 7,580 mi^2. The drainage area for Kanopolis reservoir is reported as 7,857 mi^2. The anticipated difference in flow volumes between these two drainage areas is accounted for by proportioning the difference in the two areas to the unit area flow at the gaged location.*

Are there provisions to review the yield analysis on some type of schedule?

> *The KWO generally updates a water-supply yield analysis if new information is available to update or improve the projection accuracy of the water-supply yield model. The text on page 22 and Figure 30 in this report are provided as guidance on this issue.*

The effects that evaporation may have on the water supply yields mentioned in Appendix B as a contributor- Should this be examined more in-depth?

> *Although the yield model has some sensitivity to evaporation, the effect of changes to evaporation rates are not nearly as great on the yield of this reservoir as inflows to the reservoir. Because of this, KWO has emphasized improvements to the method of depleting inflows at this time over improvements to evaporation estimates. As outlined in Appendix B, additional work could be done to improve our understanding of the evaporation component. However, the sensitivity analysis indicates that this will result in only a marginal change. A larger question is what will the effect of climate change have on temperature in the region and therefore evaporation from reservoirs. Additional research outside of the yield analysis quantifying the impacts will need to be completed before we can appropriately incorporate any changes.*

The decline of base flow in the river is examined between the Bunker Hill gauging station and the Ellsworth gauging station. The effects of runoff management are discussed, but noted that more study work is needed to determine the relative impact from each of the runoff management practices. Could it have an effect on the yield?

> *Stream flow depletions due to runoff management measures would reduce the yield of a reservoir.*

Is more study work on this issue planned?

At this time, no additional study is planned by the KWO. Both the state and federal governments have supported watershed and land surface erosion management measures in all areas of our state. Although runoff has most likely declined in the drainage area between the Bunker Hill gage and the Ellsworth gage, the flip side is that the rate of sediment accumulation has likely declined with it. Less sediment means more storage available today and in the future. The KWO is working with the Kansas Water Research Institute to evaluate a number of sediment research issues. Among those is the question of the effectiveness of various runoff management practices. That research will hopefully provide additional information on the sediment reduction potential of various measures as well as possible water supply implications. In any case it is not anticipated that the KWO will support or endorse removal of runoff management measures.

It is documented that the flow in the river have declined, but the reason has not been confirmed. Can we be sure we are at the lowest flows??

We cannot be sure. Because of this uncertainty, reservoir yield models are updated periodically and new (and hopefully improved) water-supply yields are established. The intent of the update is to capture the flow decline trends that may not have been accounted for in previous yield models.

Does the yield decrease over time?

Yes, as it relates to sediment accumulation in the yield model. Since sediment accumulates in reservoirs through time, the water-supply storage volume available in reservoirs declines through time. This causes the water-supply yield to decline through time.

Appendix B

Additional Enhancements to Water Supply Yield Analyses for the Future

Besides inflow, the two other most sensitive parameters in a water-supply yield analysis can be based upon regressions. One is the evaporation rate from the surface of the reservoir and the other is the sedimentation rate used to reduce the size of the water-supply storage volume through time. In the same way that the predictor coefficients for each monthly inflow depletion regression equation were allowed to vary by each of the standard errors associated with each coefficient, we can also vary the predictor coefficients of the regression equations for the evaporation and sedimentation rates.

Regulation has defined the 2% drought upon which Kansas water-supply yields are estimated as occurring during 1952-1957. However, even during the severe drought in the 1950's there were timely inflows that occurred (Figure1 shows that the elevation of the reservoir occasionally recovered after periods of decline) which would affect the optimization problem of estimating a reservoir's water-supply yield. Since computing power is now relatively[3] inexpensive, the optimization problem of estimating yield can easily be extended beyond 1952-1957. Why confine the yield solution to just 1952-1957 conditions when the conditions for the entire 1950-2006 period can now be included in the optimization problem without much additional effort? Extending the period beyond 1952-1957 would only make the stochastic yield solution method more robust in its estimate of the distribution of water-supply yields.

[3] Relative to 1996 when the regulation was developed which defines the 2% drought period.