Appendix N

Analysis of Hydrologic Variability Sensitivity

This appendix contains a description of the analysis performed to evaluate the potential effects to the hydrologic resources of alternative hydrologic inflow sequences. Two methods for generating future hydrologic inflow sequences with increased hydrologic variability relative to the historical record are described, both using information derived from the most recently published (2007) streamflow reconstructions from tree-ring data. The modeling results using the alternative hydrologic inflow scenarios are compared to the results from the current method used by Reclamation, which is based on the 100-year historical record.

This appendix also includes an attachment, which was an appendix originally published in the Draft EIS of February 2007. The attachment documents the comparison of the same methods as described above applied to streamflow reconstructions from tree-ring data published in 2006. In addition, a third technique was compared at that time that was based on parametric stochastic models. The latter is also included in the attachment.

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N.1 Introduction

This appendix presents the analysis of the sensitivity of the hydrologic resources to alternative hydrologic inflow scenarios. As explained in Section 4.2 of this Final EIS, hydrologic variability was incorporated into the hydrologic modeling using the Index Sequential Method (ISM) (Reclamation 1985; Ouarda et al. 1997) applied to the 100-year natural flow[1] record (1906 to 2005). Two methods were used to generate future hydrologic inflow sequences with increased hydrologic variability relative to the historical record. Although these methods do not explicitly incorporate forecasts of future climate variability, the resulting sequences show a wider range of hydrologic variability, particularly with respect to longer wet and dry periods.

N.2 Development of Two Alternative Hydrologic Inflow Scenarios to Compare with the 1906 to 2005 Natural Flow Record using ISM

In its current configuration, the CRSS model requires monthly natural flows at 29 sites throughout the Colorado River system. There are 20 sites in the Upper Basin (above and including the Lees Ferry Gaging Station in Arizona) and nine sites in the Lower Basin. Natural flows for each of the 29 sites are needed in order simulate the future hydrologic conditions for each alternative hydrologic scenario.

N.2.1 Index Sequential Method Applied to the 1906 to 2005 Natural Flow Record

Under Reclamation current practice, the ISM is used to generate streamflows for input into CRSS. This stochastic method entails a sequential block bootstrap of the observed data, where the block size is determined by the simulation horizon. The ISM cycles through each year in the historic record generating 100 hydrologic sequences (or traces), assuming that the record “wraps around” at the end (i.e., 2005, 1906, 1907). Throughout this appendix, the ISM technique as applied to the 1906 to 2005 natural flow record is referred to as Direct Natural Flow Record (DNF).

Strengths of this method are that it is based on the best available measured data, provides the basis for a quantification of the uncertainty and an assessment of risk with respect to future inflows, and has been widely accepted by stakeholders on the Colorado River. Unfortunately, each trace will only consist of annual and monthly flow magnitudes and sequences that have occurred in the observed record, with the exception of new sequences being generated as a result of the wrap. Therefore, a wider range of plausible future streamflows (including flow magnitudes and wet and dry sequences not seen in the observed record) are not modeled with the ISM method.

[1] Natural flow is the observed flow adjusted for the effects of diversions and the operation of reservoirs upstream of the flow gage. The natural flow record is unbiased by past human development.

N.2.2 Direct Paleo (DP)

This technique uses streamflow reconstructions from tree-ring chronologies directly to generate future hydrologic sequences. The paleo-reconstruction of streamflow is typically based on a model derived from a multiple-linear regression analysis of the tree-ring chronologies that overlap the historical natural flow record. For this study, the sequence 1 paleo-reconstruction from Meko et al. (2007) was used. This paleo-reconstruction provides annual water year flows from year 762 to 2005 on the Colorado River at Lees Ferry. This sequence is of particular interest because it extends into the Medieval Climate Anomaly, a period of time (900 to 1300) when various paleoclimate data indicate hydrologic droughts in the western United States were abnormally widespread (Meko et al. 2007). Remnant preserved wood (tree-rings) were utilized to extend this reconstruction beyond the recent reconstruction described in Woodhouse et al. (2006), which was limited to the period 1492 to 1997.

The major strength of this method is that new sequences not seen in the observed, gaged record are available. One difficulty associated with preparation of tree-ring chronologies and the multiple-linear regression models used for the paleo reconstructions is the accurate representation of the magnitudes of the flows, particularly at the extremes, e.g., at the higher and the lower flows (Woodhouse and Brown 2001). In addition, reconstructions can vary based on the tree-ring samples used as well as the data processing techniques used to generate the streamflows from the tree-ring chronologies. For example, the Meko et al. (2007) paelo reconstruction used in this study is not the first reconstruction completed for Lees Ferry. At least four other streamflows reconstructions (Stockton and Jacoby, 1976; Hildalgo et al., 2000; Hirschboeck and Meko, 2005 and, Woodhouse et al., 2006) are available (see the Attachment A to this appendix) and each reconstruction has a different mean flow for the reconstructed period and each captures differing levels of hydrologic variability. Unfortunately, this makes choosing a particular reconstruction a non-trivial task.

The annual flows at Lees Ferry Gaging Station (site 20) were disaggregated, spatially and temporally, throughout the Colorado River Upper Basin using a nonparametric disaggregation method (Prairie 2006; Prairie et al. 2006). The disaggregation scheme ensures that the flows generated throughout the Upper Colorado River basin are spatially and temporally consistent among the 20 locations that characterize natural flow. The disaggregation method relies on the observed natural flow record (1906 to 2005) to model the spatial and temporal distribution properties of the monthly and annual flow at the 20 locations. From an annual flow at Lees Ferry, the disaggregation scheme temporally disaggregates this annual flow to a monthly time scale then the monthly flow is spatially disaggregated among the 20 Upper Basin sites. During the first step (temporal disaggregation) an annual flow is provided from the Meko et al. reconstruction. This annual flow is ranked among the first K nearest observed natural flows, where K is determined as the square root of the number of years in the observed record (e.g., 100 years). These K nearest observed flows are weighted such that the closed neighbor has the greatest weight and the farthest has the least weight. One of the weighted neighbors is randomly chosen and its corresponding year (termed an “analogue” year) is saved for use during the spatial disaggregation and selection of the Lower Basin flows. The monthly observed flows from the selected year along with the annual flow provided from the reconstruction are incorporated in a conditional probability function that ensures the disaggregated monthly flows sum to the original reconstructed flow. These steps are repeated for each annual flow in the Meko et al. reconstruction. A similar method used for the spatial disaggregation though the analogue year is also used to choose the representative year instead of picking from the K nearest observed flows.

Flows for the nine gages downstream of site 20 were taken from the observed natural flows (1906 to 2005) based on the analogue year that was chosen for the conditional probability function during the Upper Basin disaggregation. For example, if year 1954 was the analogue year chosen during the disaggregation of a given flow in the Upper Basin, then the associated monthly flows for each of the nine downstream sites are resampled from 1954 observed monthly natural flows. This method ensures the downstream sites are both temporally and spatially correlated with each other and with the upstream sites.

These disaggregated flows (1244 years of monthly flows at 29 sites) are chosen with the ISM generating 1244 traces each 53 years in length. As ISM sequentially block bootstraps the disaggregated streamflow data, the generated traces will consist of annual flow magnitudes and sequences that are present in the paleo reconstructed streamflows, with the exception of the sequences created as a result of the wrap.

N.2.3 Nonparametric Paleo Conditioning (NPC)

As previously mentioned, flow magnitudes vary significantly across multiple reconstructions for a particular site (Stockton and Jacoby 1976; Hildalgo et al. 2000; Hirschboeck and Meko 2005, and Woodhouse et al. 2006). However, the paleo-hydrologic state information (i.e., wet or dry), is similar across different reconstructions (Woodhouse et al. 2006). The nonparametric paleo-conditioning technique capitalizes on these observations by first extracting the paleo-hydrologic state information from the streamflow reconstruction and then generating flow magnitudes by conditionally choosing from the historical record (i.e., from historical flows from a wet or dry sequence corresponding to the type of sequence derived from the paleo record).

In essence, this technique combines the strengths of the DNF and Direct Paleo methods. The main drawbacks are that magnitudes not observed in the observed, gaged record can not be generated and the technique is complex and not easily understood by all stakeholders.

For example, to generate a trace, a Markov model fit to the paleo reconstruction is first used to generate a sequence of wet and dry spells over the trace that are representative of spell lengths seen in the paleo reconstruction. The observed record is split into four categories defined by the current and next year’s hydrologic state. These categories include being in a dry state one year and staying in a dry state the next year, or being in a dry state and moving to a wet state, or being in a wet state and moving to a dry state, or lastly being in a wet state and staying in a wet the next year. To choose a flow magnitude for the state sequence, first a flow from the observed record is randomly chosen and its state is determined. The next state is taken from the first value in the state sequence. With these two states the category, from which to choose a flow magnitude is defined. Within the appropriate category all the flows in the category are weighted such that the closest flow magnitude is weighted most and the farthest is weighted least. Then one of the weighted flows is randomly chosen and the flow for the next year is chosen to ensure preservation of the lag-1 correlation observed in the record flows. This chosen flow becomes the next flow and the next state value from the state sequence is used to choose the next flow magnitude. This process is repeated until the end of the state sequence for a given trace is reached. Prairie (2006) provides a detailed description of the conditional choosing technique and its mathematical basis.

For this study, the paleo hydrologic state information was derived from the sequence 1 paleo reconstruction and coupled with the conditional choosing technique to generate annual water year flows at Lees Ferry were generated. These flows are disaggregated, spatially and temporally, throughout the Colorado River Upper Basin with the nonparametric disaggregation method described in the Section N.2.2. The nine lower sites are resampled as described in Section N.2.2.

The traces generated for the Upper Basin sampling sites can produce monthly flows and sequences that were not seen before and reflect a blend of the hydrologic variability seen in the observed and reconstructed data. The downstream sites 21 to 29 contribute significantly less flow (eight percent of the total calendar year flow) than the upper sites; therefore, choosing from the direct observed natural flows does not adversely affect the ability to model unique and probable flows in the basin as a whole.

As a result of using the hydrologic state information from the paleo reconstruction data the flow sequences in the generated paleo conditioned hydrologies will reflect sequence properties (i.e., wet or dry) characteristic of the paleo reconstruction. The magnitudes of generated flow on a water year basis match the magnitudes in the observed record (1906 to 2005). The inability to generate flow magnitudes beyond those in the observed record can be a shortcoming of this technique although the increased variety of flow sequences is an advantage of this method when compared to some other stochastic hydrologic generation methods.

For these nonparametric paleo conditioned hydrologies, 125 traces, each 53 years in length, were generated for the 29 sites throughout the Colorado River Basin.

N.2.4 Comparison of the Inflow Scenarios

Basic statistics from the three inflow scenarios are shown in Figure N-1. Also presented are the two scenarios based on the Woodhouse et al. 2006 reconstructions analyzed in the Draft EIS and presented in Attachment A to this Appendix N. The statistics are computed from total calendar year flow at Lees Ferry Gaging Station on the Colorado River and include the mean, standard deviation, skew, lag-1 autocorrelation, maximum and minimum. The observed statistic (1906 to 2005) is shown as a blue triangle.

The statistics are shown as “box and whisker” plots that display the inter-quartile range as a box (where 25 percent to 75 percent of the values lie), with the median represented as a vertical line within the box. The five percent to 95 percent range of the values is also shown by the dashed lines typically extending outside the box (i.e., the “whiskers”). One measure of performance of a particular method is its ability to capture the observed statistic within the inter-quartile range. It is not always preferable to capture the observed statistic when considering climate variability. Modeling statistics other than what are exhibited by the observed data allows representation of scenarios that have not occurred in the gauged record but are plausible based on paleo reconstructions.

Each inflow scenario is presented in a row and the six statistics are presented in each column. The observed mean is reproduced well by the DNF and the Meko et al. and Woodhouse et al. NPC as expected. The Meko et al. and Woodhouse et al. Direct-Paleo (DP) scenarios underestimate the observed mean, as expected, because these paleo reconstructions have a lower mean (14.7 and 14.6 million acre-feet [maf], respectively) than the observed period (15.0 maf). The standard deviation which measures the spread of the flow magnitudes is similar to the observed standard deviation for all scenarios except the Meko et al. DP scenario, which has a reduced standard deviation. This most likely results from limited tree-ring data available before A.D. 1200 reducing the variability in the tree ring chronologies. The skew, which measures the overall shift of the flows, is shifted towards lower flows for the DP scenarios while the remaining scenarios exhibit a similar skew to the observed flows. The lag-1 autocorrelation is similar to the observed flow for all inflow scenarios. The observed maximum is not exceeded by the DP scenarios and only slightly exceeded by the Non-parametric Paleo Conditioning (NPC) scenarios. The observed minimum flow is not exceeded by the NPC scenarios while the DP scenarios result in lower minimums. The Meko et al. and Woodhouse et al. DP are able to generate much lower flows than observed, approximately two maf and 3.7 maf lower, respectively, five percent of the time. It was expected the DP would generate lower flows than observed as these are characteristic of Lees Ferry streamflow reconstructions. Paleo reconstructions have consistently shown that the recent period (1906 to 2005) has been a relatively wet period compared with results from multiple reconstructions completed for Lees Ferry. The DP scenarios demonstrate the impact these lower flow magnitudes in the paleo record, which are not seen in the recent observed period, may have on reservoir operations. Information from flow magnitudes is just one aspect of each scenarios statistical properties.

From the hydrologic perspective, the probabilities and durations of wet and dry periods is of interest and a further measure of variability. The probability of wet and dry periods of a given length for the DNF inflow and the two Meko et al., based alternative inflow scenarios are shown in Figure N-2 and Figure N-3 as histograms. Each bar in the histogram depicts the probability for the wet or dry period of a given length. A dry period was defined as consecutive years when the flow in each year is below the median (50^{th} percentile) flow. Similarly, a wet period was defined as consecutive years when the flow in each year is above the median observed flow. In both cases, the length of the period was given by the number of consecutive years in each state.

The DNF inflow scenario contains wet and dry periods of maximum length of five and four years, respectively. The DP scenario based on Meko et al. has an increased variability of wet and dry periods where the maximum lengths are eight and 12 years, respectively. The NPC based on Meko et al. scenario displays the greatest variability with a maximum wet and dry length of 22 and 21 years, respectively.

Figure N-1
Boxplots of Basic Statistics for
Direct Natural Flow (DNF); Direct Paleo (DP) – Meko 2007; Direct Paleo - Woodhouse 2006
Nonparametric Paleo Conditioning(NPC) - Meko 2007; Nonparametric Paleo Conditioning - Woodhouse 2006

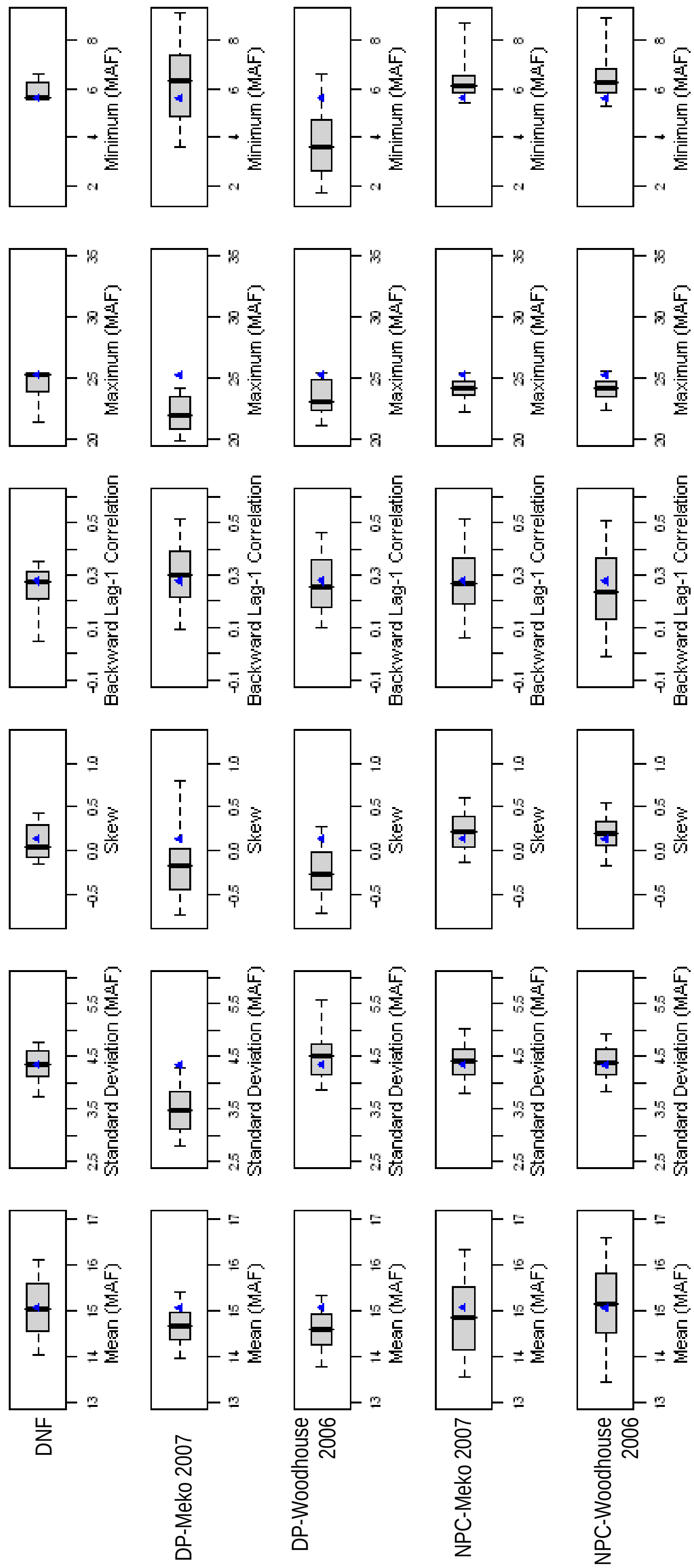


Figure N-2
Histograms of Dry Periods for the Inflow Scenarios
(a) Direct Natural Flow; (b) Direct Paleo – Meko 2007;
and (c) Nonparametric Paleo Conditioning – Meko 2007

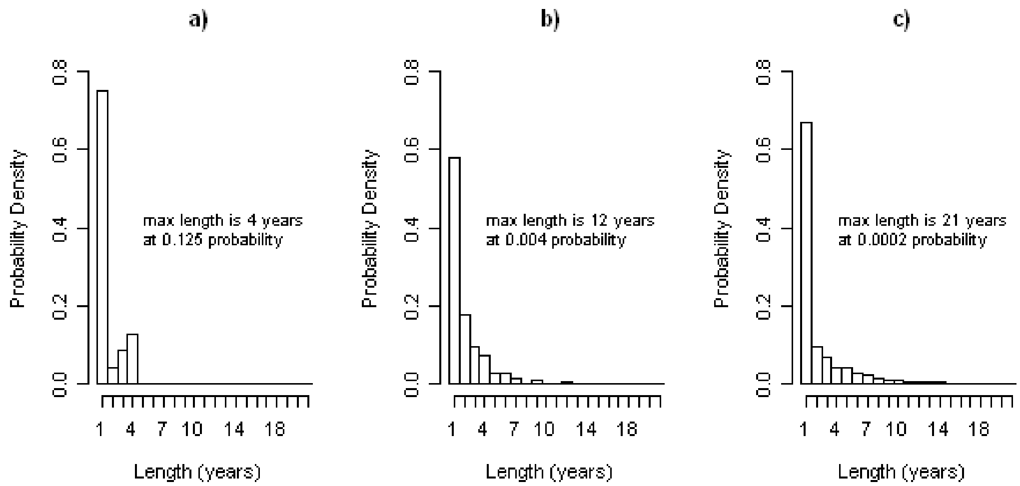


Figure N-3
Histograms of Wet Periods for the Inflow Scenarios
(a) Direct Natural Flow; (b) Direct Paleo – Meko 2007;
and (c) Nonparametric Paleo Conditioning – Meko 2007

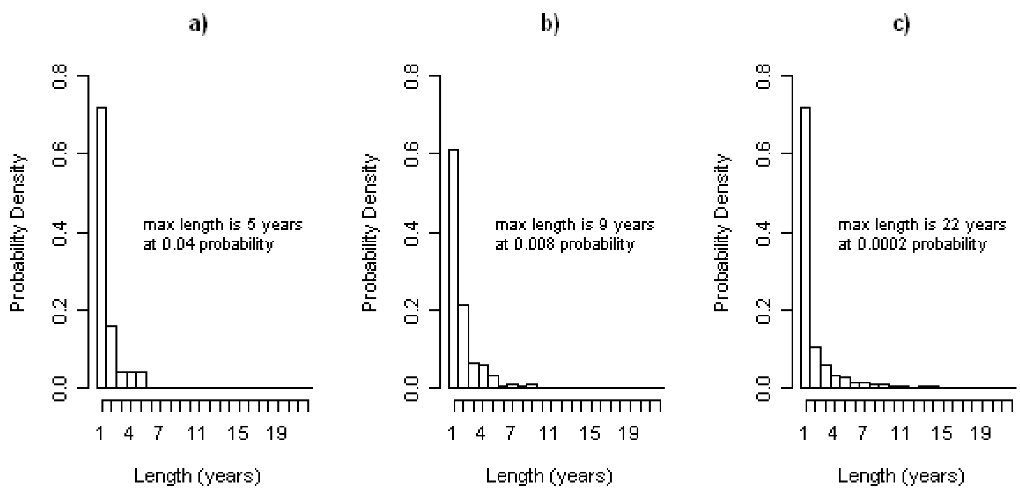


Table N-1 and Table N-2 further present the probability for all dry and wet spells, respectively, for the DNF inflow and the two Meko et al., based alternative inflow scenarios. Spell lengths range from one to 21 years for dry spells or one to 22 years for wet spells. The DNF is developed from the observed record for which the longest dry spell was four years with a 0.125 percent probability. The four-year dry spell has a 0.0697 percent probability with the DP scenario and a 0.0416 percent probability with the NPC scenario. The DP and NPC scenarios exhibit a reduced four-year dry spell as compared with DNF but display a probability of drought lengths beyond the four-year drought. The DP scenario has a 0.0820 percent probability of droughts five years or longer in length. The NPC scenario has a 0.1270 percent probability of droughts five years or longer in length.

Table N-1
Histograms of Dry Periods for the Inflow Scenarios
(a) Direct Natural Flow; (b) Direct Paleo – Meko 2007;
and (c) Nonparametric Paleo Conditioning – Meko 2007

Spell Length (years)	Probability (percent)	Probability (percent)	Probability (percent)
1	0.7500	0.5779	0.6704
2	0.0417	0.1762	0.0951
3	0.0833	0.0943	0.0658
4	0.1250	0.0697	0.0416
5	0.0000	0.0287	0.0388
6	0.0000	0.0287	0.0246
7	0.0000	0.0123	0.0208
8	0.0000	0.0000	0.0119
9	0.0000	0.0082	0.0079
10	0.0000	0.0000	0.0069
11	0.0000	0.0000	0.0044
12	0.0000	0.0041	0.0030
13	0.0000	0.0000	0.0028
14	0.0000	0.0000	0.0018
15	0.0000	0.0000	0.0012
16	0.0000	0.0000	0.0008
17	0.0000	0.0000	0.0010
18	0.0000	0.0000	0.0002
19	0.0000	0.0000	0.0006
20	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0002

Table N-2
Histograms of Wet Periods for the Inflow Scenarios
(a) Direct Natural Flow; (b) Direct Paleo – Meko 2007;
and (c) Nonparametric Paleo Conditioning – Meko 2007

Spell Length (years)	(a) Probability (percent)	(b) Probability (percent)	(c) Probability (percent)
1	0.7200	0.6122	0.7185
2	0.1600	0.2122	0.1028
3	0.0400	0.0612	0.0571
4	0.0400	0.0571	0.0324
5	0.0400	0.0327	0.0265
6	0.0000	0.0041	0.0148
7	0.0000	0.0082	0.0121
8	0.0000	0.0041	0.0103
9	0.0000	0.0082	0.0077
10	0.0000	0.0000	0.0038
11	0.0000	0.0000	0.0047
12	0.0000	0.0000	0.0014
13	0.0000	0.0000	0.0016
14	0.0000	0.0000	0.0018
15	0.0000	0.0000	0.0012
16	0.0000	0.0000	0.0010
17	0.0000	0.0000	0.0008
18	0.0000	0.0000	0.0006
19	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0004
21	0.0000	0.0000	0.0002

The longest wet spells for the DNF scenario are five years in length with a 0.04 percent probability. The DP and NPC again exhibit a slightly reduced five-year wet spell as compared with DNF but display a probability of wet spells beyond five years. The DP scenario has a 0.0245 percent probability of wet spells six years or longer and the NPC scenario has a 0.0627 percent probability of wet spells six years or longer in length.

These dry and wet spell lengths are beyond those exhibited in the observed natural flows and demonstrate the additional hydrologic variability beyond that seen in the recent gaged record that can been attributed to climate variability.

N.3 Results

This section describes the sensitivity of the No Action Alternative and Preferred Alternative to the hydrologic variability provided by the two alternative hydrologic inflow scenarios described in Section N.2. As described in Section 4.2, the modeling assumptions for the Preferred

Alternative are assumed to revert to the assumptions used for the No Action Alternative after 2026.

N.3.1 Percentile Elevations

Figure N-4 presents a comparison of the 90th, 50th, and 10th percentile plots of Lake Powell elevations obtained for DNF and the two alternative hydrologic inflow scenarios, under the No Action Alternative and the Preferred Alternative.

The 90th percentile range of the three hydrologic methods shows smaller variation between the scenarios, largely because Lake Powell is at or near its maximum reservoir capacity.

At the 50th percentile range, the No Action Alternative and Preferred Alternative show little difference except from 2016 to 2030 when the Preferred Alternative is elevated. The DNF and DP track closely throughout the run while the NPC begins lower than either DNF or DP until 2012 when it slightly exceeds both, then drops lower again until the end of the run in 2048.

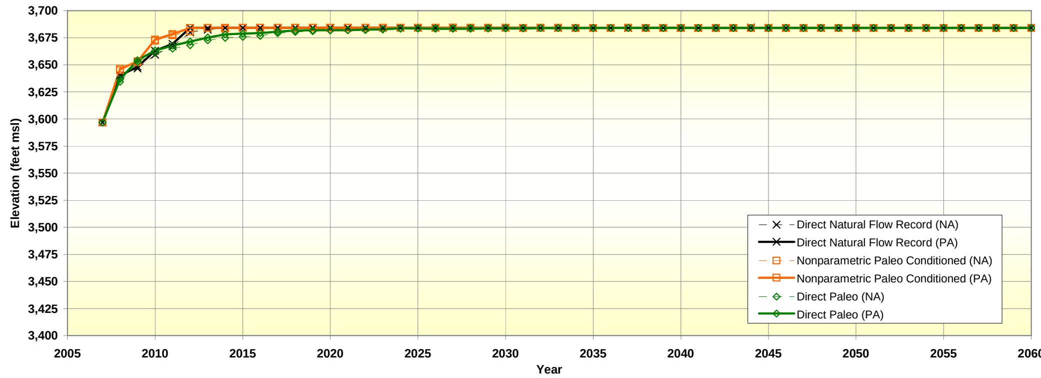
Variation between the various hydrologic inflow methods is highest at the 10th percentile range because Lake Powell is most sensitive to variations in inflow at lower elevations. The higher variability from year to year at the 10th percentile level for the NPC scenario is a result of the different resampling technique used. The DNF and DP hydrologic inflow scenarios are resampled with the ISM, which guarantees year to year hydrologic inflow scenario statistics that are nearly identical. The year to year variation seen in these scenarios results mostly from reservoir operations. The NPC hydrologic inflow scenario is generated with stochastic methods that do not generate identical hydrologic inflow scenario statistics on a year to year basis; although with increased sample size, these scenarios will produce an average year to year statistic which is similar but not identical. This property is present in most stochastic techniques other than ISM.

The No Action alternative produces lower reservoir elevations for all the hydrologic inflow scenarios in the early part of the run from 2009 to 2020. The NPC alternative shows a significant drop in reservoir elevation after 2030 that is not displayed by either the DNF or DP scenarios.

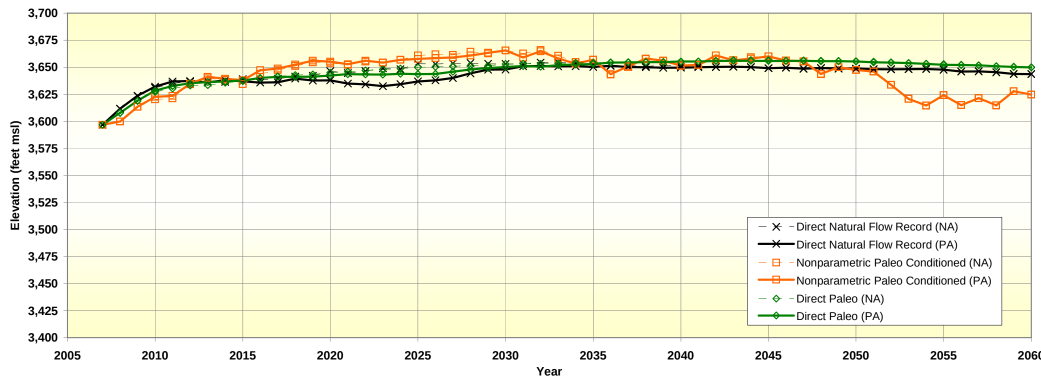
Because Lake Powell is able to make reduced releases at lower reservoir elevations, the Preferred Alternative has the effect of keeping Lake Powell higher (especially through 2017) compared to the No Action Alternative.

Figure N-4
Lake Powell End-of-December Elevations
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
90th, 50th and 10th Percentile Values

90th Percentile



50th Percentile



10th Percentile

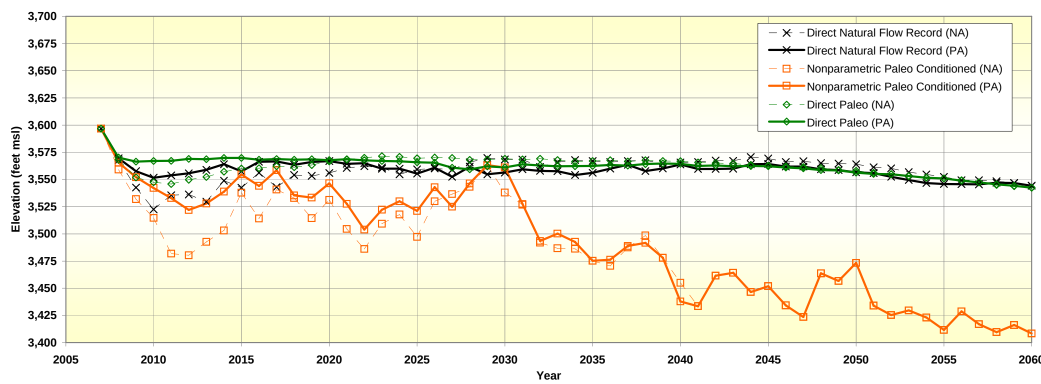
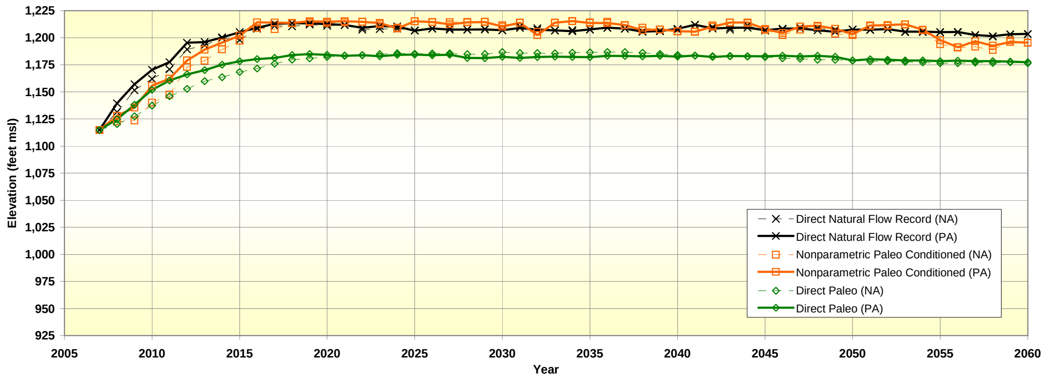


Figure N-5 presents a comparison of the 90th, 50th, and 10th percentile plots of Lake Mead elevations obtained for DNF and the two alternative hydrologic inflow scenarios, operated under the No Action Alternative and the Preferred Alternative. At the 90th and 50th percentiles, DP is generally consistently lower than DNF even though both utilized the same sampling technique because the DP hydrology set has a higher magnitude and droughts of longer duration. At the 90th and 50th percentiles, NPC is generally higher than DNF due to higher magnitude and longer duration wet cycles in the two data sets.

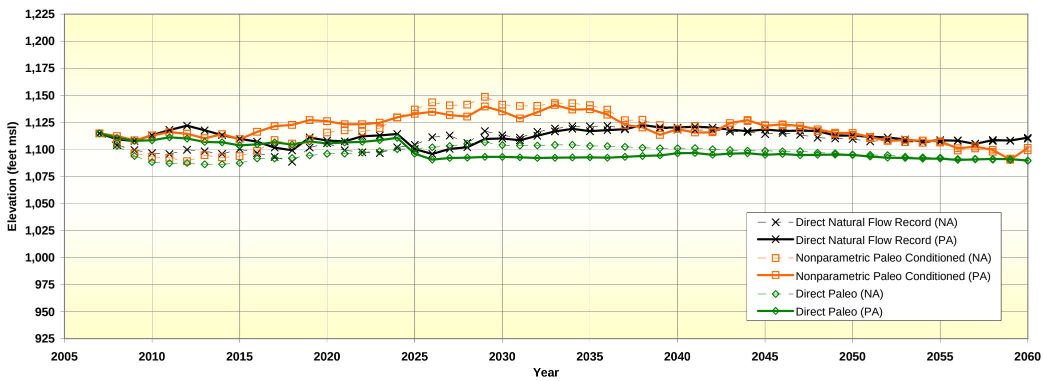
At the 90th percentile, the No Action Alternative is generally lower until 2020 when the two alternatives track similarly. At the 50th percentile, the No Action Alternative is again generally lower through the interim period. From 2027 to 2045, the No Action Alternative is higher than the Preferred Alternative after which the two alternatives track similarly. At the 10th percentile, the Preferred Alternative is the lowest compared to the No Action Alternative with the NPC hydrologic inflow scenario through about 2020. This behavior is due to the low inflows into Lake Powell under this scenario of which the effect can be seen at the Lake Powell 10th percentile in Figure N-4. In contrast to the NPC and DNF scenarios, under the DP scenario the Lake Powell elevation is generally higher under the Preferred Alternative than under the No Action Alternative during the interim period. Lake Powell elevation is highest at the 10th percentile under the DP scenario, and more significantly the Preferred Alternative is closest to elevation 3,575 feet msl. Above this elevation, Lake Powell must release 8.23 maf or for balancing (resulting in higher Lake Mead elevations) and below this elevation, Lake Powell reduces releases to 7.48 maf.

Figure N-5
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
90th, 50th and 10th Percentile Values

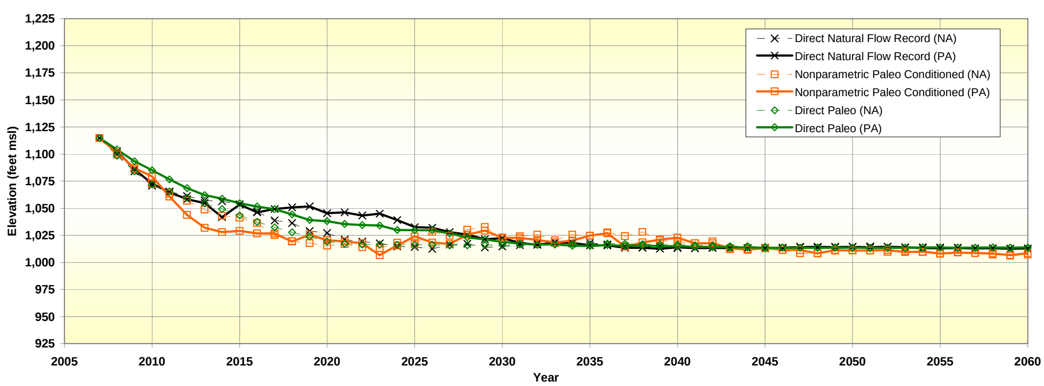
90th Percentile



50th Percentile



10th Percentile



N.3.2 Extreme Drought Single Trace Analysis

Figure N-6 presents the 25-year running mean from sequence 1 of the paleo reconstruction published by Meko et al. (2007). The lowest 25-year period in the paleo reconstruction extends from A.D. 1130 to 1154. During this period the mean flow is 84 percent of the mean observed natural flow from 1906 to 2005. The lowest 25-year period in the observed flow (1953 to 1977) is 87 percent of the observed mean.

Figure N-6
Annual Natural Flow at Lees Ferry
Meko et al. sequence 1 Reconstruction
25 Year Running Mean

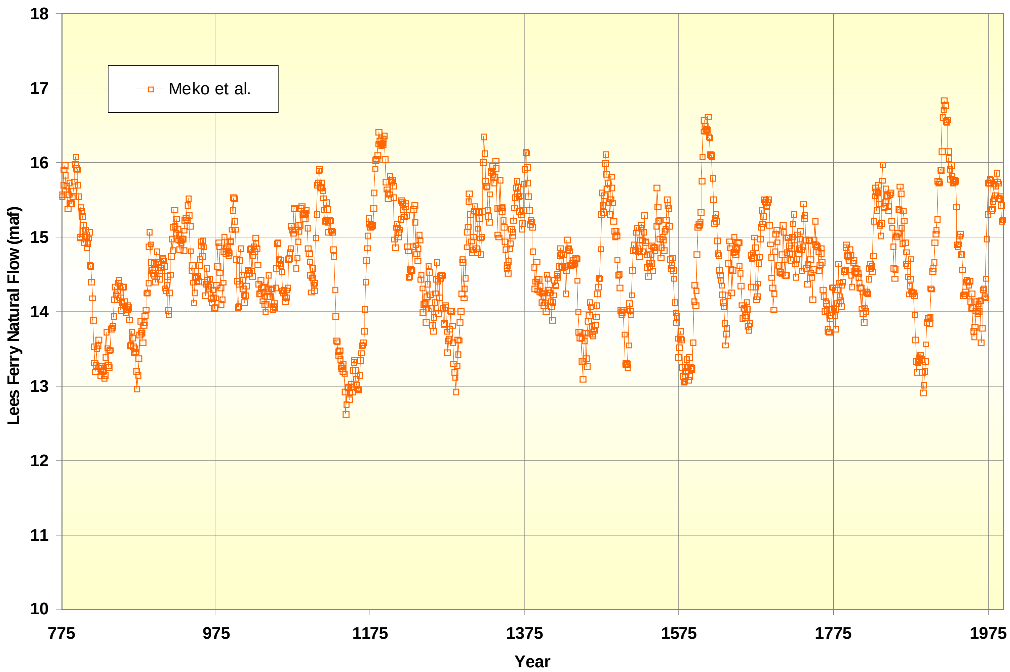


Figure N-7 presents the annual natural flow at Lees Ferry from trace 369 for DP. This trace is an identical input to both the No Action Alternative and the Preferred Alternative simulations. This trace is resampled directly from the Meko et al. paleo reconstruction and begins with the A.D. 1130 to 1154 lowest 25-year period thereby, including the flow sequence with the most extreme 25-year drought exhibited in the paleo reconstruction. This period falls within the timeframe of the Medieval Climate Anomaly, a period when many paleoclimate records have demonstrated severe hydrologic droughts in the western United States (Meko et al. 2007). During the first 25 years of trace 369, not all flows are below the mean observed flow (15.1 maf). Multiple years are above the mean observed flow, though the majority of years are below the mean in these first 25 years.

Figure N-7
Annual Natural Flow at Lees Ferry
Single trace using Meko et al. Reconstruction for
No Action Alternative (NA) and Preferred Alternative (PA)
Hydrology start year is 1130 from Meko et al. Reconstruction

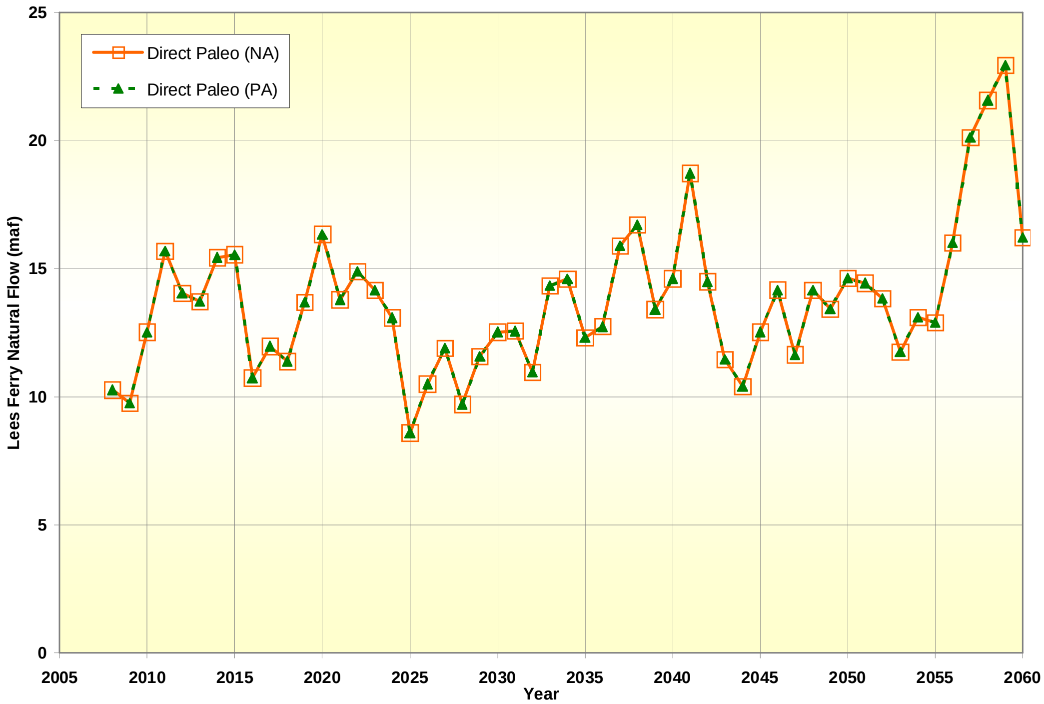
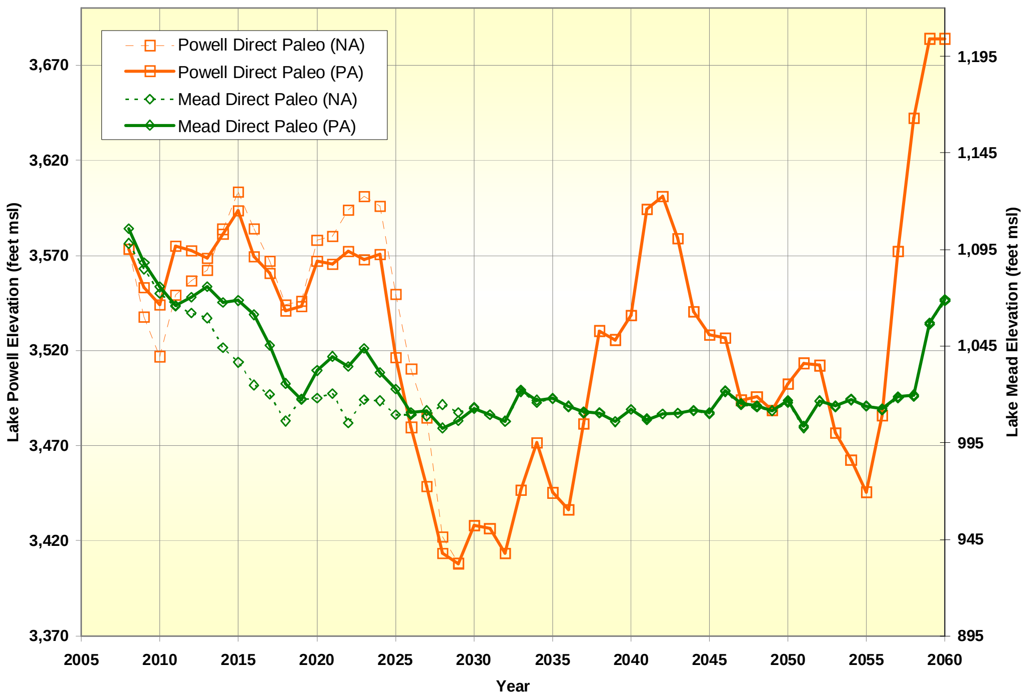


Figure N-8 presents end-of-December elevations of Lake Powell and Lake Mead resulting from trace 369 for DP.

Figure N-8
End-of-December Elevations
Comparison of Single Trace using Meko et al. Reconstruction for
No Action Alternative (NA) and Preferred Alternative (PA)
Hydrology Start Year is 1130 from Meko et al. Reconstruction



Given the current initial conditions a continuing drought further draws down Lake Mead though the Preferred Alternative maintains higher elevations at Lake Mead as a result of balancing releases from Lake Powell. Under the Preferred Alternative, Lake Powell is initially higher due to the ability to reduce releases below 8.23 maf. However, as Lake Mead's elevation is drawn down, Lake Powell provides water through balancing releases and is also eventually drawn down near the end of the interim period. During the higher Lake Powell reservoir elevations centered on 2042 and 2059 the natural flows were substantially increased, thereby building reservoir storage at Lake Powell.

Figure N-9 presents the annual natural flow at Lees Ferry from trace 50 for NPC. This trace is an identical input to both the No Action Alternative and the Preferred Alternative simulations. This trace is not directly resampled from the paleo reconstruction but uses the reconstruction to conditionally choose the observed natural flows generating dry spells not seen before but statistically plausible given the paleo reconstruction's spell length properties. The trace begins with the lowest 25-year period generated from the NPC hydrologic inflow scenarios. During this period the mean flow is 80 percent of the mean observed natural flow from 1906 to 2005. In this trace the natural flows exhibit increased variability of extreme low flows compared to the single trace presented in Figure N-7. In Figure N-7, the lowest annual flow is 8.6 maf while in Figure N-9, the lowest flow is 5.7 maf. The lower flows exhibited by the NPC trace allow further understanding of the impacts that periods of extreme low flows may have on reservoir operations.

Figure N-9
Annual Natural Flow at Lees Ferry
Single trace using Nonparametric Paleo Conditioning with
Meko et al. Reconstruction for No Action Alternative (NA) and Preferred Alternative (PA)

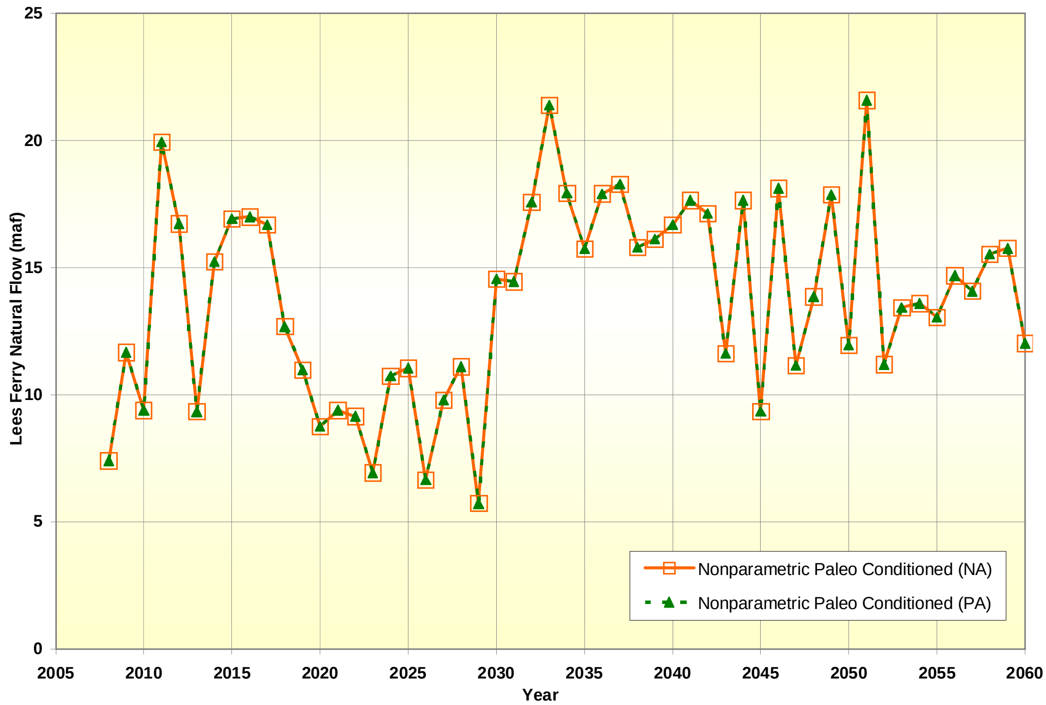
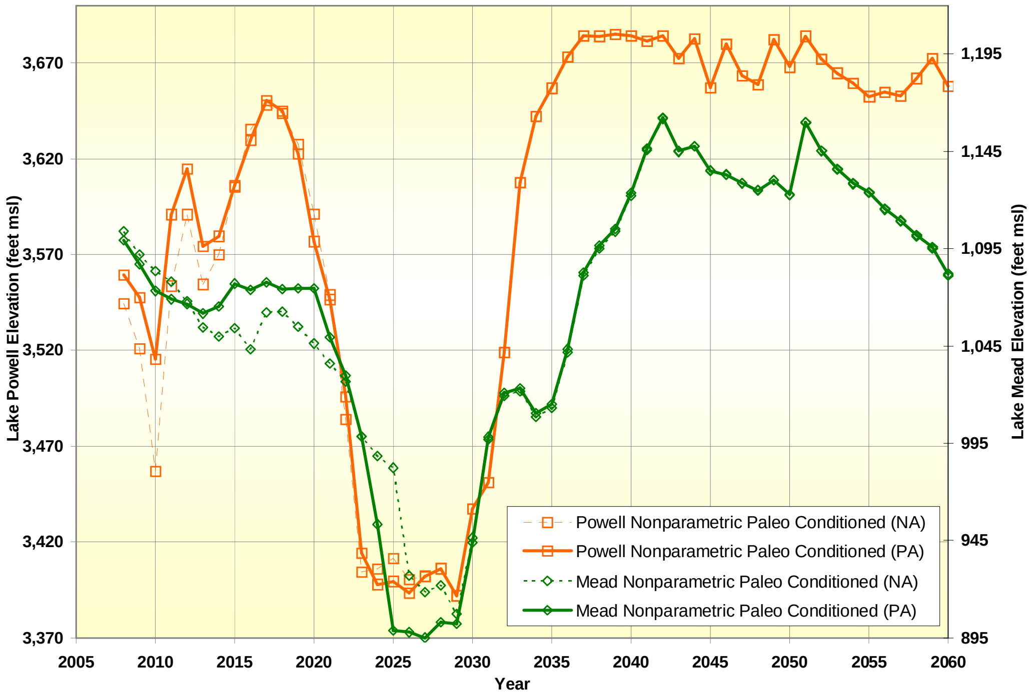


Figure N-10 presents end-of-December elevations of Lake Powell and Lake Mead from trace 50 for NPC.

Figure N-10
End-of-December Elevations
Comparison of Single Trace using Nonparametric Paleo Conditioning with
Meko et al. Reconstruction for No Action Alternative (NA) and Preferred Alternative (PA)



The initial natural flows shown in Figure N-10 are low but increase above the mean observed flow by 2011 increasing elevations at both Lake Powell and Lake Mead. Beginning in 2018, natural flows are below the mean observed flow and remain below until 2032. Under this sustained dry spell, Lake Mead is drawn down to dead pool (895 feet msl) by 2027 and Lake Powell is taken to 3,392 feet msl by 2029 under the Preferred Alternative. The increased drawdown seen under the Preferred Alternative is a result of the modeling assumption that includes a maximum shortage amount of 600 kaf[2] while the No Action Alternative includes absolute protection of Lake Mead at elevation 1,000 feet msl[3], which can result in shortages as large as 3,300 kaf which prevent the reservoirs from dropping to the elevations seen under the Preferred Alternative. When natural flows rebound above the mean observed flow again in 2032, both reservoirs recover.

N.3.3 Probability of Being Below Key Elevations

Figure N-11 presents a comparison of the likelihood of Lake Powell end-of-December elevations being at or below the minimum power pool (elevation 3,490 feet msl) for DNF and for the two alternative hydrologic inflow scenarios. DNF shows nearly no chance of

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[2] As noted in Section 2.7, the Preferred Alternative includes a provision for appropriate consultations regarding additional shortages when Lake Mead is below 1,025 feet msl. For modeling purposes, it was assumed that shortages of 600 kaf would continue to be applied for Lake Mead elevations below 1,025 feet msl.

[3] Modeling assumptions used in the Preferred Alternative allowed a maximum shortage of approximately 3,300 kaf, resulting in the inability to absolutely protect Lake Mead elevation 1,000 feet msl.

Lake Powell elevations falling below minimum power pool. NPC indicates the highest likelihood of occurrence at 26 percent, followed by the DP (five percent), and DNF (one percent). During the interim period, for all inflow scenarios, the probability of Lake Powell falling below elevation 3,490 feet msl is less under the Preferred Alternative due to the ability of Lake Powell to make reduced releases at lower reservoir elevations.

Figure N-11
Lake Powell End-of-December Elevations
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Percent of Values Less Than or Equal to Elevation 3,490 feet msl

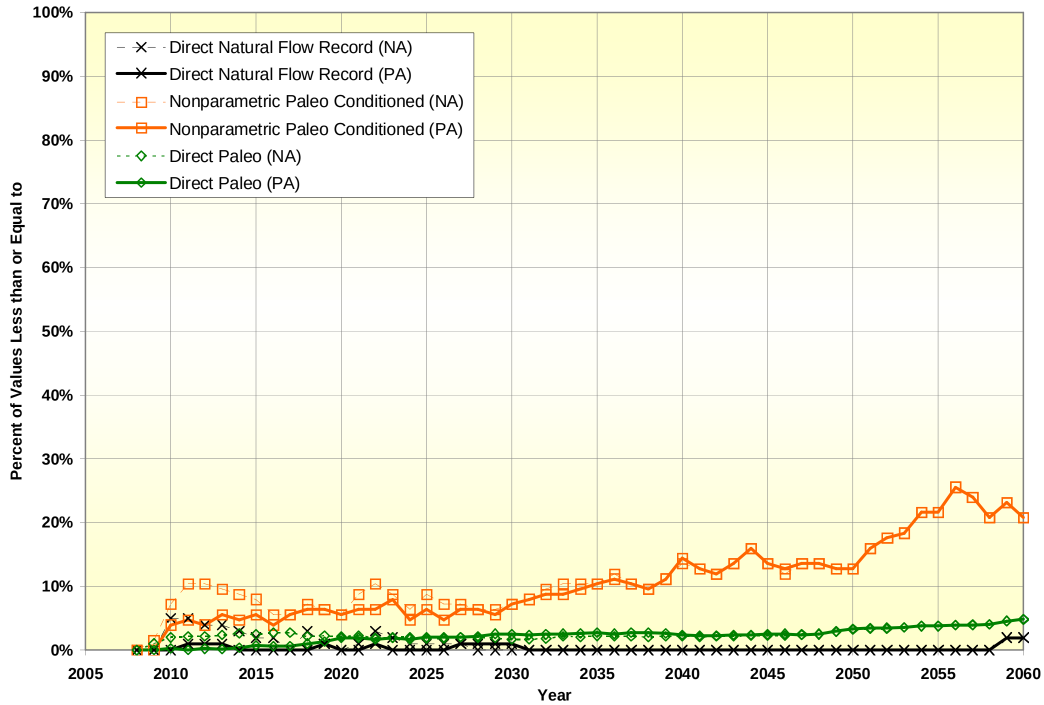


Figure N-12 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below the minimum power pool (elevation 1,050 feet msl) for DNF and for the two alternative hydrologic inflow scenarios. NPC generally shows the highest chance of being below minimum power pool until 2017, when the No Action Alternative with DP and DNF indicate a higher likelihood. After 2028, the NPC generally indicates the lowest likelihood for most years.

The Preferred Alternative generally shows a lower likelihood for both the DNF and DP inflow scenarios until 2028 when these scenarios show the highest likelihood for most years.

Figure N-12
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Percent of Values Less Than or Equal to Elevation 1,050 feet msl

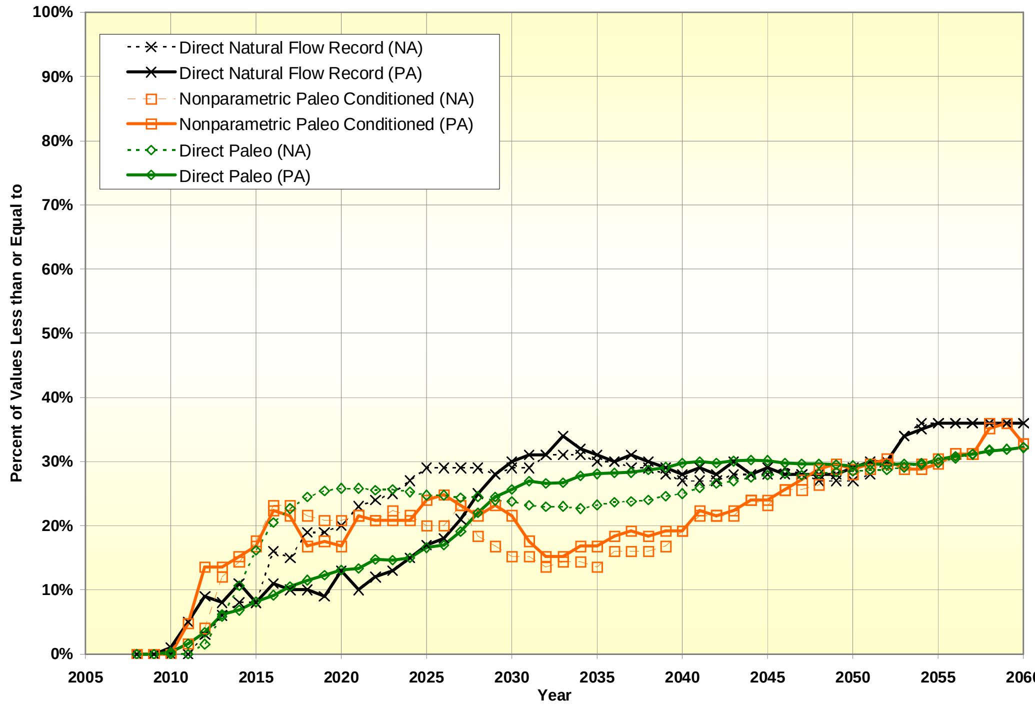


Figure N-13 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below 1,025 feet msl for DNF and for the two alternative hydrologic inflow scenarios. NPC generally shows the highest likelihood of falling below elevation 1,025 feet msl until 2020, when the No Action Alternative with DP and DNF indicate a higher likelihood. After 2028, the NPC generally indicates the lowest likelihood until 2050, when NPC again shows the highest likelihood.

The Preferred Alternative generally shows a lower likelihood for both the DNF and DP hydrologic inflow scenarios until 2033, when these scenarios show slightly higher likelihood until 2050, when NPC generally shows a higher likelihood.

Figure N-13
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Percent of Values Less than or Equal to Elevation 1,025 feet msl

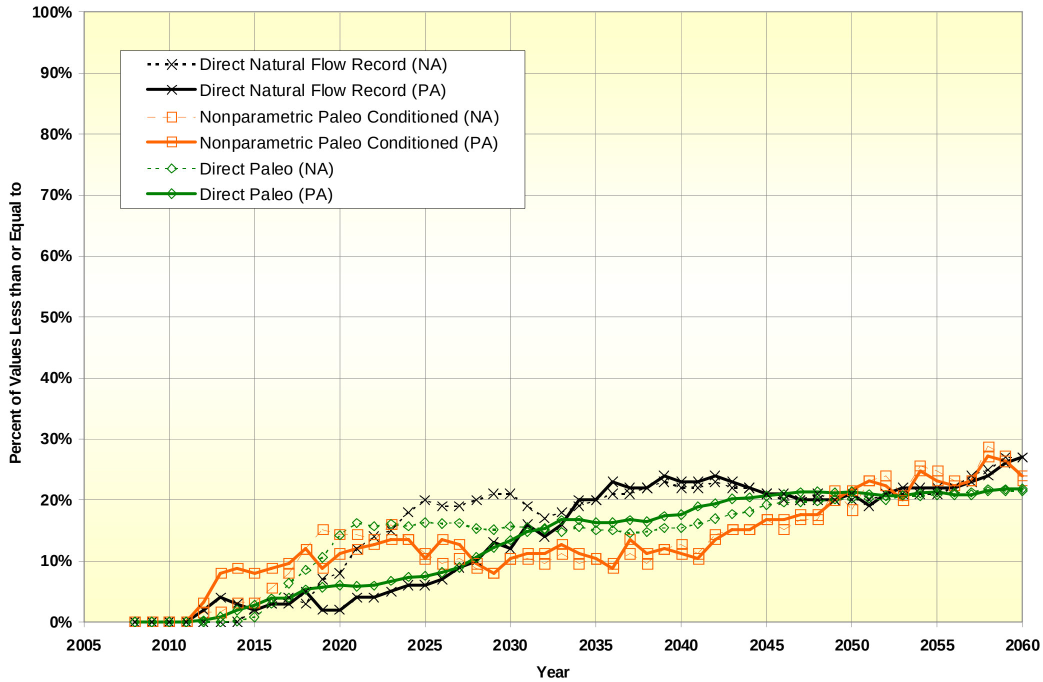
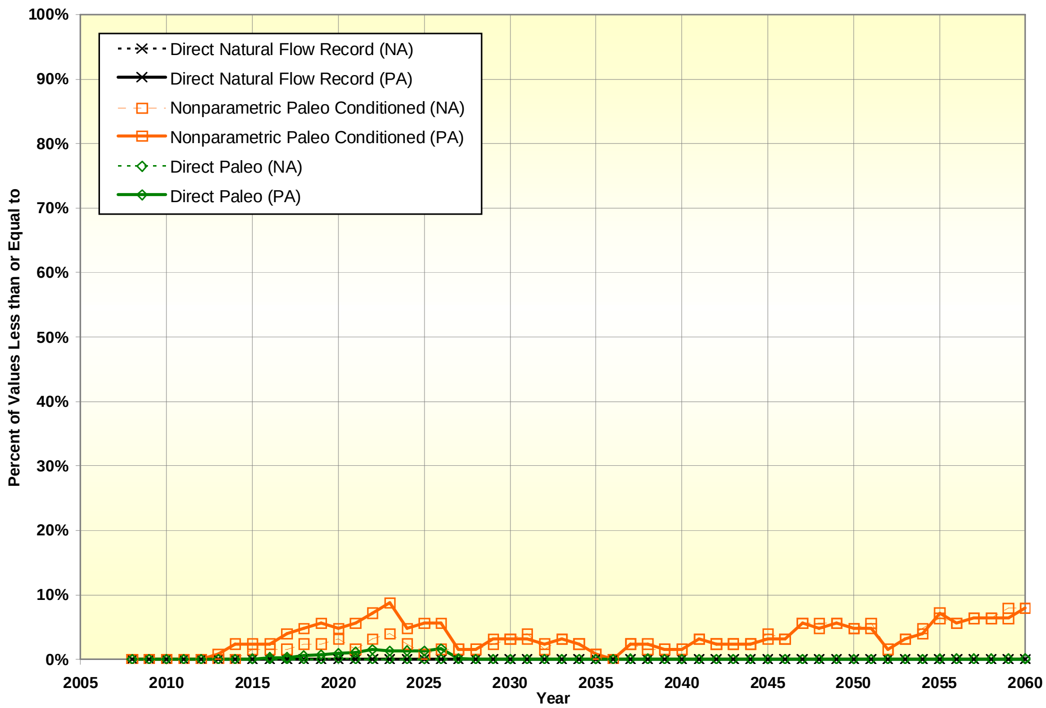


Figure N-14 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below 1,000 feet msl (the elevation of Southern Nevada Water Authority's lower intake) for DNF and for the two alternative hydrologic inflow scenarios. DNF shows no chance of Lake Mead elevations being below 1,000 feet msl. NPC indicates the highest likelihood of occurrence at nine percent in 2023 under the Preferred Alternative, followed by the No Action Alternative (eight percent), and the DP Preferred Alternative (two percent).

Figure N-14
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Percent of Values Less Than or Equal to Elevation 1,000 feet msl



N.3.4 Lower Basin Shortage

Figure N-15 shows the probability of shortage in the Lower Basin under the No Action Alternative and the Preferred Alternative obtained for DNF and the two alternative hydrologic inflow scenarios. The higher variability observed with the NPC method is a function of the resampling technique. The Preferred Alternative exhibits a lower probability of shortage until 2026 when the No Action Alternative has a generally lower probability. The highest probability of shortage for each alternative occurs after 2055 with the following approximate values: DNF, 69 percent; DP, 82 percent; and NPC, 78 percent.

Figure N-15
Lower Basin Shortages
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Probability of Occurrence

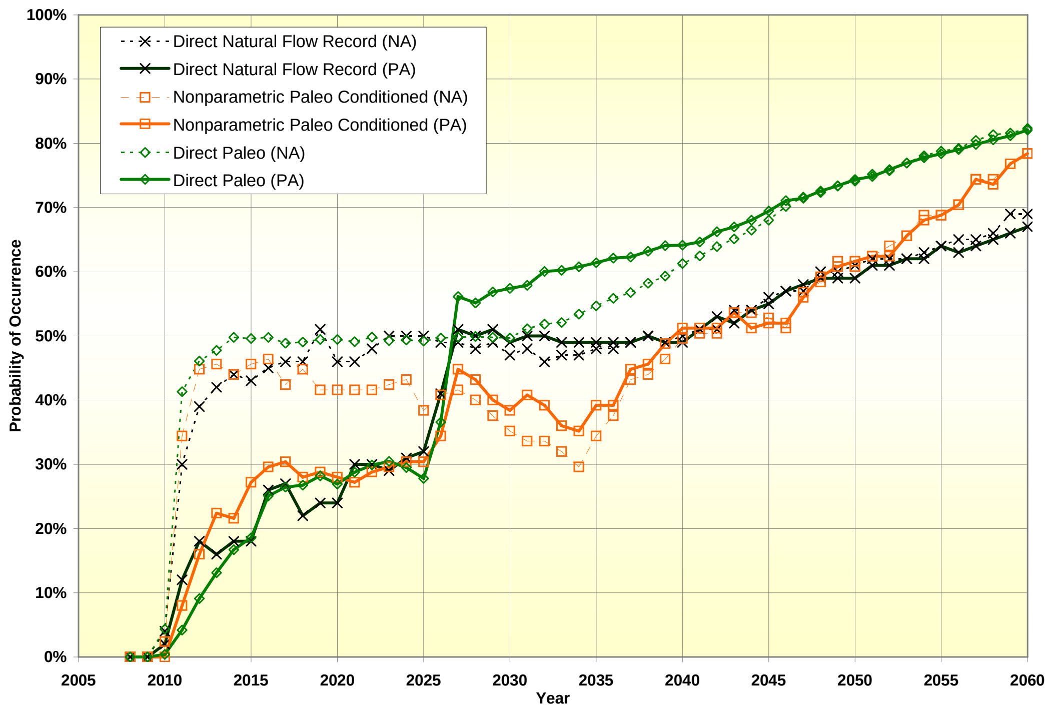


Figure N-16 shows the cumulative distribution of shortages over the interim period. Under the No Action Alternative, for all inflow scenarios, the magnitude of most shortages is about 500 kaf. Under the Preferred Alternative, for the DNF and DP scenarios, most shortages are about 400 kaf. With the NPC scenario, about fifty percent of the shortage amounts are 400 kaf while fifty percent are 500 kaf and above, up to 859 kaf. A shortage of 859 kaf under the Preferred Alternative indicates that Lake Mead elevation was below 1,000 feet msl for the entire year resulting in no delivery to SNWA. The No Action Alternative with both the DP and NPC scenarios reaches a maximum shortage of 3.3 maf, the maximum shortage using current modeling assumptions. With the DNF scenario, the maximum shortage in the No Action Alternative is much lower at about 1.9 maf.

Figure N-16
Cumulative Distribution of Lower Basin Shortages
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
2008 to 2026

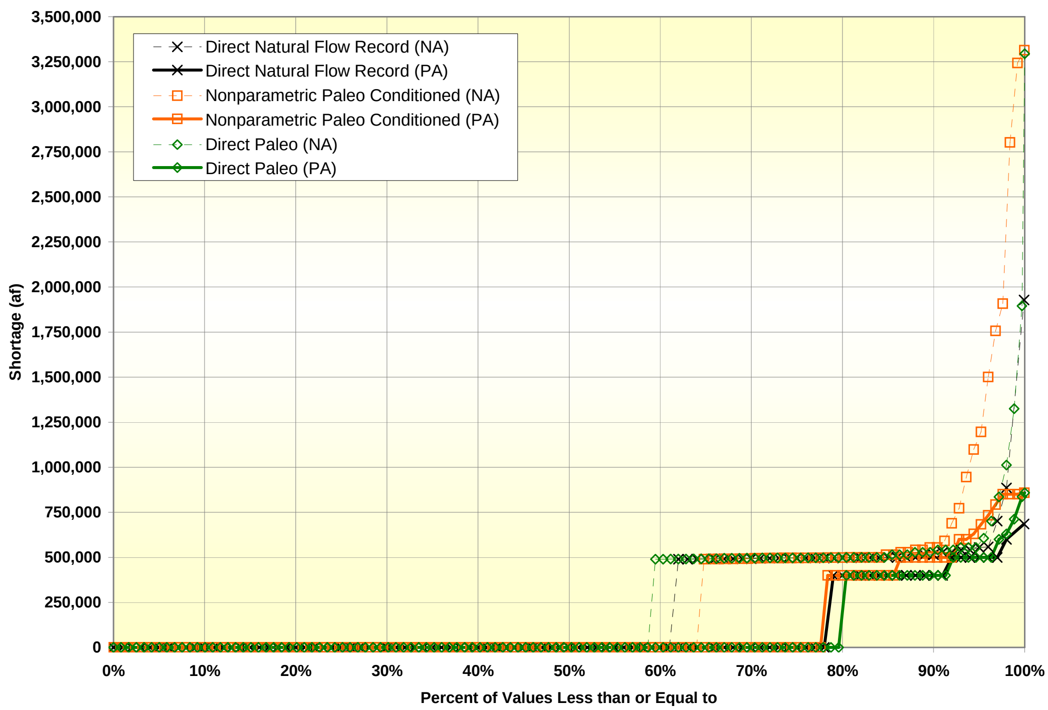
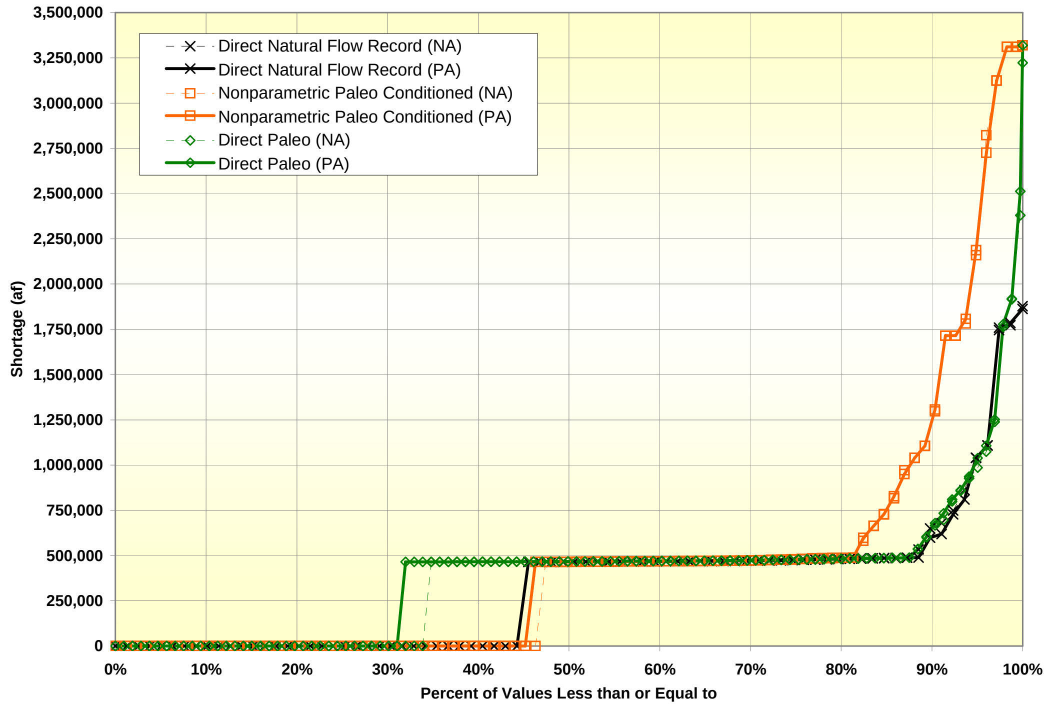


Figure N-17 shows the cumulative distribution of shortages from 2027 through 2060. During this period the shortage strategy for both the No Action Alternative and the Preferred Alternative is identical and includes absolute protection of Lake Mead elevation 1,000 feet msl. For all inflow scenarios most of the shortages are about 500 kaf, however shortages of this amount occur approximately fifteen percent more often with the DP inflow scenario. Shortages above 500 kaf occur about ten percent more often under the NPC scenario. Both the DP and NPC scenarios reach a maximum shortage of 3.3 maf, while the DNF scenario reaches a maximum shortage much lower at about 1.9 maf.

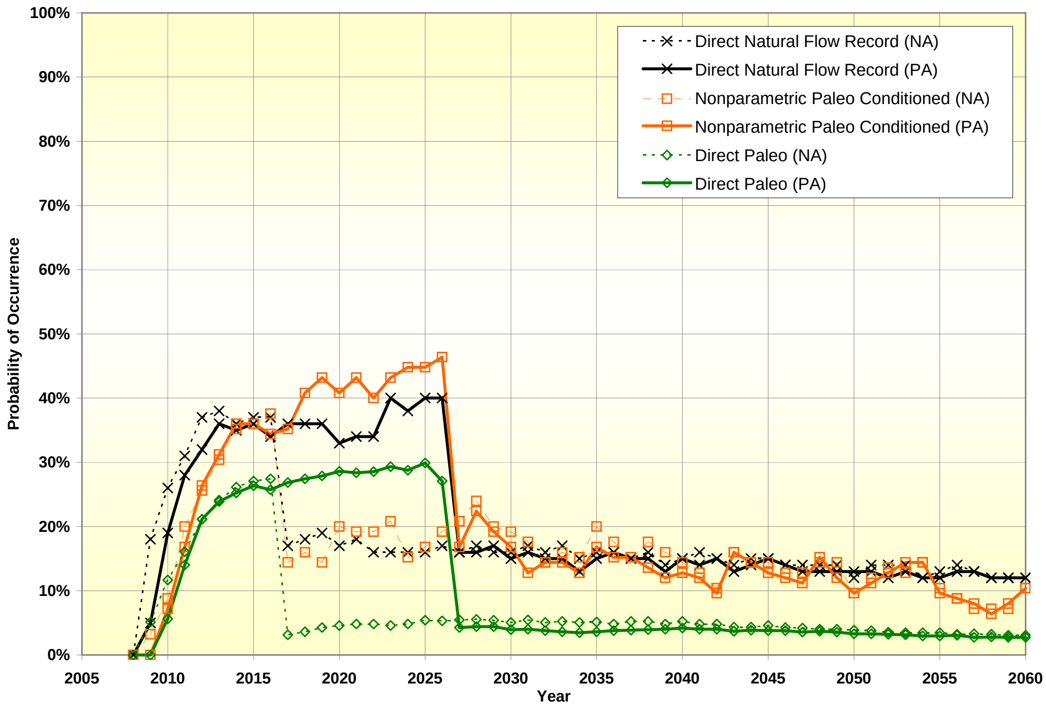
Figure N-17
Cumulative Distribution of Lower Basin Shortages
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
2027 to 2060



N.3.5 Lower Basin Surplus

Figure N-18 shows the probability of any surplus to the Lower Division states under the No Action Alternative and the Preferred Alternative obtained for DNF and the two alternative hydrologic inflow scenarios. This plot includes the probability of Flood Control surplus under which condition Mexico would also receive up to 1.7 mafy. The higher variability observed with the NPC is a function of the resampling technique. Under both alternatives, NPC has a higher probability of surplus than DNF from 2015 to 2030 due to the extended wet periods in the data set. The highest probability of surplus for each inflow scenario occurs around 2026 under the Preferred Alternative with the following approximate values: DP, 30 percent; DNF, 40 percent; and NPC, 46 percent. Beginning in 2017, under the No Action Alternative, only 70R and Flood Control surpluses occur, which reduces the probability of surplus to below 25 percent.

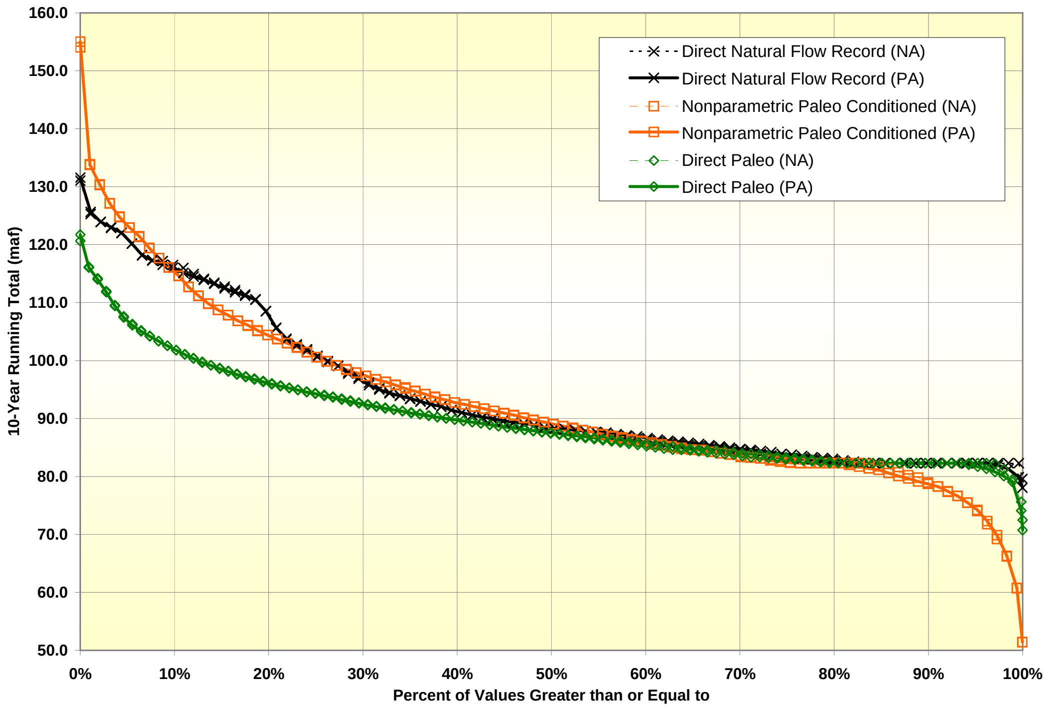
Figure N-18
Lower Basin Surplus Conditions
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Probability of Occurrence



N.3.6 Releases from Glen Canyon Dam

Figure N-19 presents a comparison of 10-year running total of water-year release volumes from Glen Canyon Dam for DNF and the two alternative hydrologic scenarios. The largest differences in the frequency of release volumes are observed at the highest and lowest volumes, where the NPC hydrologic sequence shows the lowest low and highest high extreme values. DP shows the lowest high extreme values and has depressed high values as compared to the other two hydrologic inflow scenarios as a result of the reduced standard deviation discussed in Section 2.3 of this Final EIS.

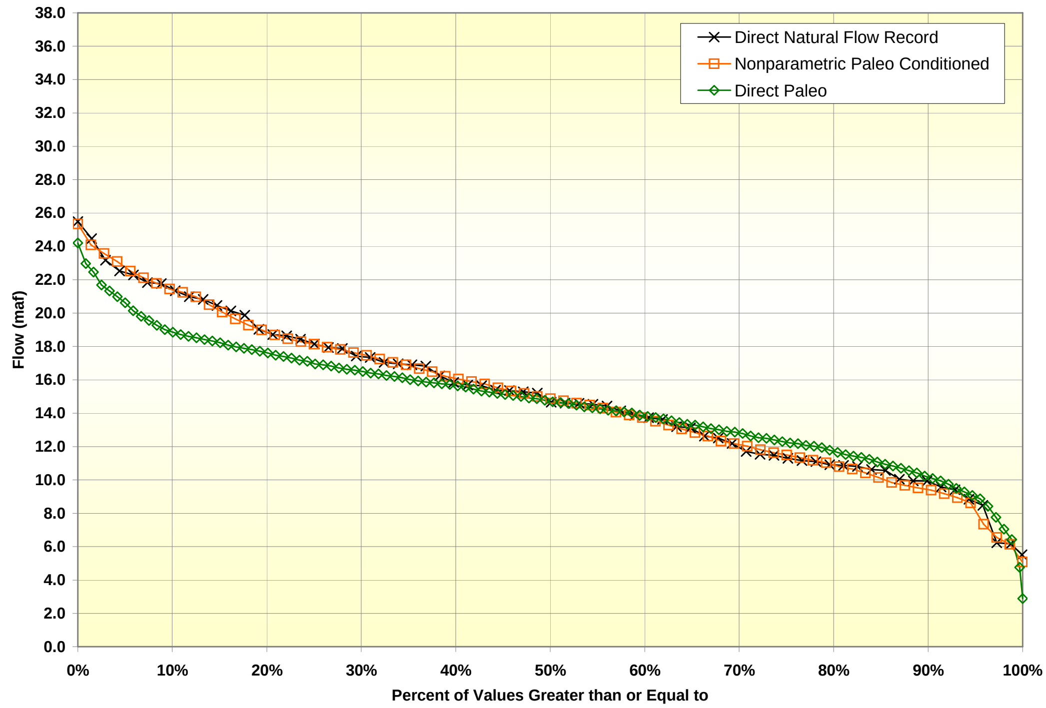
Figure N-19
Glen Canyon Dam 10-Year Running Total of Water Year Releases
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
No Action Alternative (NA) and Preferred Alternative (PA)
Water Years 2009 to 2060



N.3.7 Natural Flow at Lees Ferry

Figure N-20 presents a comparison of annual natural flow volumes past Lees Ferry Gaging Station for DNF and the two alternative hydrologic scenarios. The largest differences in the frequency of natural flow volumes are observed at the highest volumes, where the DP hydrologic sequence again shows depressed high flows. The DP hydrologic sequence also shows the lowest volume at 2.9 maf compared to the DNF and NPC scenarios at 5.5 maf and 5.1 maf, respectively.

Figure N-20
Annual Natural Flow at Lees Ferry Gaging Station
Comparison of Direct Natural Flow Record to Meko et al. Reconstruction
2008 to 2026



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Attachment A
(Appendix N from the Draft EIS dated February 2007)

Analysis of Hydrologic Variability Sensitivity

This attachment to Appendix N was first published as Appendix N in the Draft EIS. Although no substantial changes have been made, some minor errors were fixed. This attachment contains descriptions of the analyses performed to evaluate the potential effects of using alternative hydrologic inflow scenarios when performing modeling simulations in CRSS. This sensitivity analysis compares three accepted scientific methods for providing hydrologic variability. These alternative hydrologic inflow scenarios use hydrologic inflow data derived from Nonparametric Paleo Hydrologic State information, Parametric Stochastic Natural Flow Records, and Direct Paleo methods. The alternative hydrologic inflow scenarios are compared to the current method used by Reclamation which uses the Index Sequential Method (ISM) for stochastic streamflow reconstruction.

Table of Contents

List of Figures

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A.1 Introduction

This appendix was developed to explore the potential effects of using alternative hydrologic inflow scenarios when performing modeling simulations in CRSS. As explained previously in Section 4.2.4 of the Draft EIS hydrologic variability was incorporated in the hydrologic modeling using the Index Sequential Method (ISM) (USBR 1985; Ovarda, et al. 1997) on the 99-year natural flow record from 1906 to 2004. This sensitivity analysis will compare three other accepted scientific methods for providing hydrologic variability. The three methods used do not incorporate forecasts of future climate variability, but do provide a wider range of hydrologic variability than the application of ISM to the natural flow record, including longer wet and dry periods than seen in the observed record.

A.2 Development of Three Alternative Hydrologic Inflow Scenarios to Compare with the 1906 – 2004 Natural Flow Record using ISM

The CRSS model requires natural flow inputs at 29 sites throughout the Colorado River system. There are 20 sites above and including the Lees Ferry site on the Colorado River. Below the Lees Ferry site are an additional 9 sites. Generation of stochastic natural flows throughout the 29 sites is a critical step towards understanding the impact of natural streamflow variability on model results.

As stated before, Reclamation currently uses the ISM for stochastic streamflow generation. This stochastic method entails a sequential block bootstrap of the observed data, where the block size is determined by the simulation horizon. The ISM cycles through each year in the historic record generating 99 traces, assuming that the record wraps around at the end (i.e., 2004, 1906, 1907, etc.). Each trace will only consist of annual and monthly flow magnitudes and sequences that have occurred in the observed record, with the exception of new sequences being generated as a result of the wrap. This limits the ISM’s ability to model a wide range of plausible future streamflows including flow magnitudes and sequences not seen in the observed record. Strengths of this method are it is easy to implement, understandable, and has been widely accepted by stakeholders on the Colorado River.

To address these drawbacks three alternative methods to generate stochastic natural flows were applied and three alternative hydrology scenarios were generated. These methods were chosen to sample a range of techniques available to generate stochastic flows. Each method has strengths and weaknesses that are described below along with the basic concept of the method.

Throughout this appendix the ISM technique as applied to the 1906 to 2004 natural flow record is referred to as Direct Natural Flow Record (DNF).

A.2.1 Nonparametric Paleo Conditioning (NPC)

This technique conditionally resamples historic data based on paleo hydrologic state information (i.e., wet or dry). Hydrologic state sequences are modeled based on the "Lees-B" paleo reconstruction (1490-1997) and flow magnitudes from the observed natural flows (1906-2004) are conditionally resampled generating annual water year flows at Lees Ferry on the Colorado River (Lee, et al. 2006). Prairie (2006) provides a detailed description of the conditional resampling technique.

The annual flows at Lees Ferry (site 20) are disaggregated, spatially and temporally, throughout the Upper Colorado River Basin using a nonparametric disaggregation method (Prairie, 2006; Prairie et al., 2006). The disaggregation scheme ensures that the flows generated throughout the Upper Colorado River basin are spatially and temporally consistent among the 20 locations that characterize natural flow.

Flows for the 9 gauges below site 20 are resampled from the observed natural flows (1906-2004) based on the analogue year resampled from the observed natural flows when conditionally generating monthly flows. For example, if year 1954 was the analogue year chosen during the disaggregation then the associated monthly flows for each of the 9 lower sites are resampled from 1954 observed monthly natural flows. This method ensures the lower sites are both temporally and spatially correlated with each other and the upper sites. The lower sites 21-29 contribute significantly less flow (eight percent of the total calendar year flow) than the upper sites; therefore, resampling the direct observed natural flows does not adversely affect the ability to model unique and probable flows in the basin as a whole.

For these nonparametric paleo conditioned hydrologies, 125 traces, each 53 years in length, were generated for the 29 sites throughout the Colorado River basin. The traces generated for the upper 20 sites will produce annual calendar year flow sequences that were not seen before. As a result of using the hydrologic state information from the paleo reconstruction data the flow sequences in the generated paleo conditioned hydrologies will reflect sequence properties (i.e., wet or dry) characteristic of the paleo reconstruction. The magnitudes of generated flow on a water year basis match the magnitudes in the observed record (1906-2004). The inability to generate flow magnitude beyond those in the observed record can be a shortcoming of this technique though the increased variety of flow sequences is an advantage of this method when compared to some other stochastic hydrologies.

A.2.2 Parametric Stochastic Natural Flow Record (PS)

This technique uses parametric stochastic methods to fit the observed natural flows (1906-2003) to an appropriate set of stochastic models for streamflow generation and disaggregation. A parameter fitting procedure, hence the name parametric methods, is applied to fit the observed natural flow to the appropriate parametric models. For this project the observed natural flows at two key sites (Lees Ferry and at Imperial Dam on the Colorado River) were fit to a contemporaneous autoregressive order 1 (CAR[1]) model (Salas, 1985). Annual flows at both sites were simultaneously generated producing 100 traces each 53 years in length. The generated flows where then spatially and temporally disaggregated to the 29 sites at a monthly time scale with appropriate parametric disaggregation techniques. Lee et al., 2006 provides a detailed description of the model selection and fitting procedure for the generation and disaggregation of flows. Scheme 2 from Lee et al., (2006) was found to best preserve both the monthly and annual statistical properties of the observed natural flow and was selected for generation of the parametric hydrologies applied in this study.

Note these parametric hydrologies were developed with natural flows only including up to 2003 while the preceding two stochastic methods used observed natural flows though 2004. At the time these parametric hydrologies were developed the 2004 data was not yet available. A Kolmogorov-Smirnov test (KS-test) was performed for each site to determine if the data distribution has significantly changed between these two datasets. This test found no significant differences at any sites at a 95 percent significance level. Therefore, there should be no reason the parametric hydrologies cannot be compared along side the other two alternative hydrologies.

The parametric techniques can generate both flow magnitudes and sequence not seen in the observed record but statistically similar to the observed record A drawback of the parametric methods are they have the ability to generate values must larger or smaller than those in the observed record and can be difficult to justify. They also have difficulty representing non-Gaussian data distribution features.

A.2.3 Direct Paleo (DP)

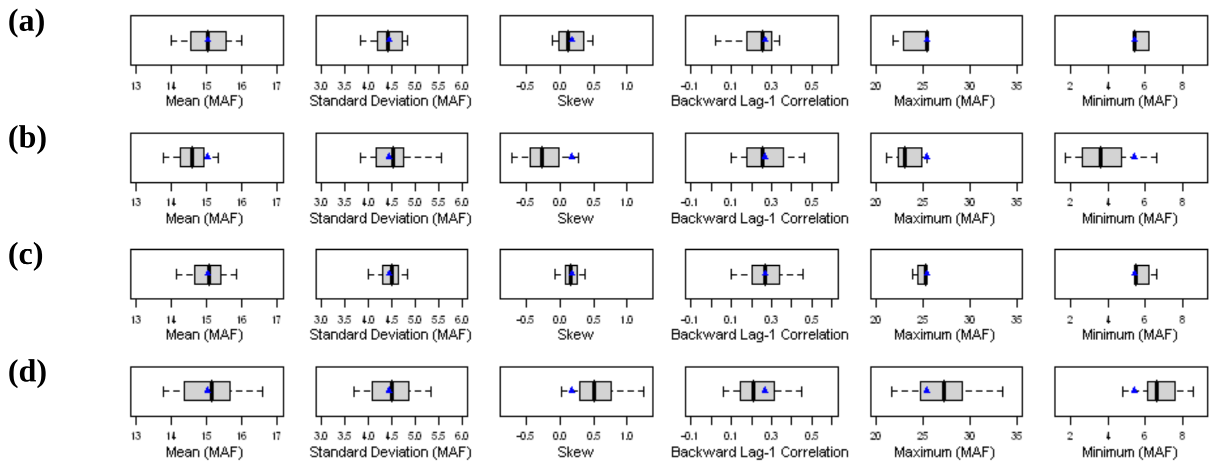
This technique uses the "Lees-B" paleo-reconstruction from Woodhouse et al. (2006). This paleo-reconstruction provides annual water year flows from 1490-1997 on the Colorado River at Lees Ferry. The annual water year flows are disaggregated, spatially and temporally, throughout the Upper Colorado River Basin with the nonparametric disaggregation method (Prairie et al., 2006); the same disaggregation method described in the Section A.2.1 Nonparametric Paleo Conditioned. The nine lower sites are resampled as described in Section A.2.1.

These disaggregated flows (508 years of monthly flows at 29 sites) are resampled with the ISM generating 508 traces each 53 years in length. As ISM sequentially block bootstraps the disaggregated streamflow data, the generated traces will consist of annual flow magnitudes and sequences that are present in the paleo reconstructed streamflows, with the exception of the sequences created as a result of the wrap.

A.2.4 Comparison of Three Alternative Inflow Scenarios

Basic statistics from the DNF inflow and the three alternative inflow scenarios are shown in Figure Att. A-1. The statistics are computed from total calendar year flow at Lees Ferry on the Colorado River. These statistics include the mean, standard deviation, skew, lag-1 autocorrelation, maximum and minimum. The observed statistic (1906-2004) is shown as a blue triangle. While the statistics based on the inflow scenario are shown as boxplots. The boxplots display the interquartile range (IQR), where 25 percent to 75 percent of the values lie, with the median represented as a vertical line within the IQR. The whiskers extend to the five percent to 95 percent range of the values. Performance is generally judged as appropriate when the observed statistics is captured within the IQR.

Figure Att. A-1
Boxplots of Basic Statistics for
(a) Direct Natural Flow Record, (b) Nonparametric Paleo Conditioned,
(c) Parametric Stochastic Natural Flow Record, and (d) Direct Paleo



Each inflow scenario is presented in a row and the six statistics are presented in each column. The observed mean is reproduced well by the first three scenarios (DNF, NPC and PS) as expected. The DP scenario underestimates the observed mean, as expected, because this paleo reconstruction has a lower mean (14.6 million acre-feet [maf]) than the observed period (15.0 maf). The standard deviation is well reproduced by all scenarios. The skew is over estimated by the PS, a difficult statistic for parametric techniques to capture, while the DP underestimates the skew. The lag-1 autocorrelation is captured by all inflow scenarios. The observed maximum is not exceeded by the DNF or DP scenarios and only slightly exceeded by the NPC but the PS scenario is able to reproduce much higher flows than observed, approximately 8.0 maf higher five percent of the time. The observed minimum flow is not exceeded by the ISM or NPC, while the PS generates a few lower values. The DP is able to generate much lower flows than observed, approximately 3.7 maf lower five percent of the time. It was expected the DP would generate lower flows than observed as these are characteristic of Lees Ferry streamflow reconstructions.

A.3 Results

This section is separated into two parts. Section A.3.1 examines the effects of the alternative hydrologic inflow scenarios by holding constant the alternative and varying the hydrologic inflow sequences. Section A.3.2 examines the performance of each alternative under the alternative hydrologic inflow scenarios by holding constant the inflow scenario while varying the alternative.

A.3.1 Effects of Alternative Hydrology on No Action Alternative

This section describes the sensitivity of the No Action Alternative to the hydrologic variability provided by the three alternative hydrologic inflow scenarios described in the previous sections. This will be done through comparing the No Action Alternative, simulated using ISM and the 99-year natural flow record (DNF) to the No Action Alternative simulated with three alternative hydrologic inflow scenarios.

A.3.1.1Percentile Elevations

Figure N-19 presents a comparison of the 90th, 50th, and 10th percentile lines of Lake Powell elevations obtained for DNF and the three alternative hydrologic inflow scenarios, operated under the No Action Alternative.

The 90th percentile range of the four hydrologic methods shows smaller variation between the scenarios, largely because Lake Powell is at or near its maximum reservoir capacity.

At the 50th percentile range the DP hydrologic inflow scenario consistently produces the lowest elevations, while the NPC and the PS hydrologic inflow scenarios generally produce higher median elevations than DNF.

Variation between the various hydrologic inflow methods is highest at the 10th percentile range. The higher variability from year to year at the 10th percentile level for the NPC and the PS hydrologic inflow scenarios is a result of sample size. The DNF and DP hydrologic inflow scenarios are resampled with the ISM, which guarantees year to year hydrologic inflow scenario statistics that are identical. The year to year variation seen in these scenarios only results from reservoir operations. The NPC and PS hydrologic inflow scenarios are generated with stochastic methods that do not generate identical hydrologic inflow scenario statistics on a year to year basis; although with increased sample size, these scenarios will produce an average year to year statistic which is similar but not identical. This property is present in most stochastic techniques other than ISM.

Figure Att. A-2
Lake Powell End-of-July Elevations
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
90th, 50th and 10th Percentile Values

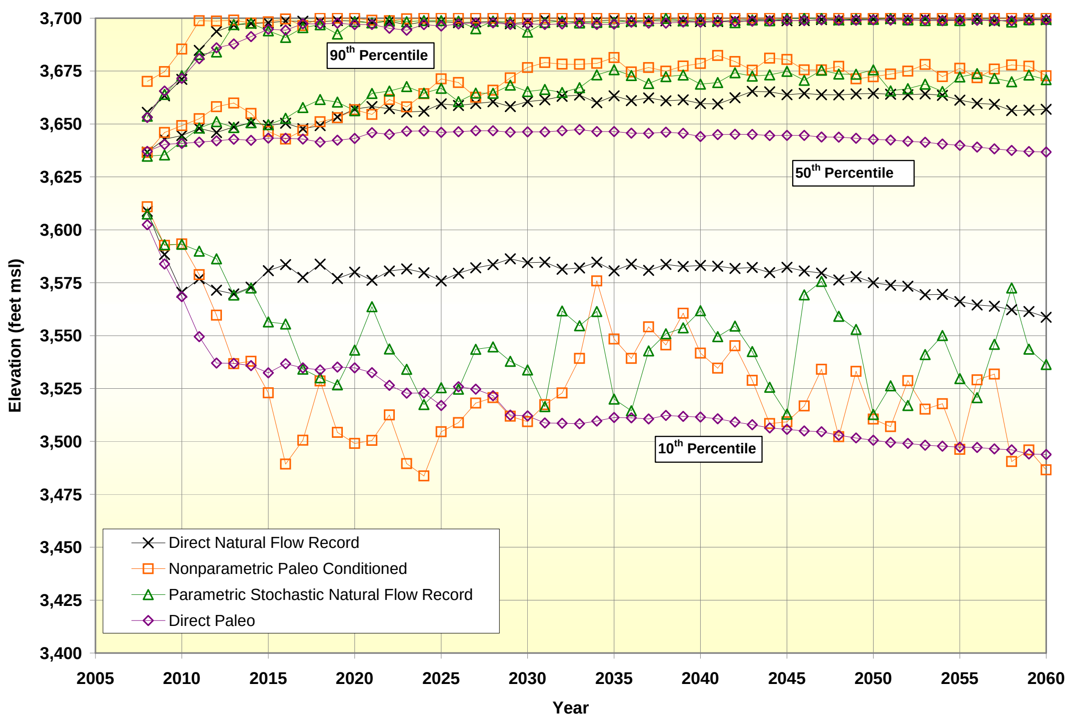
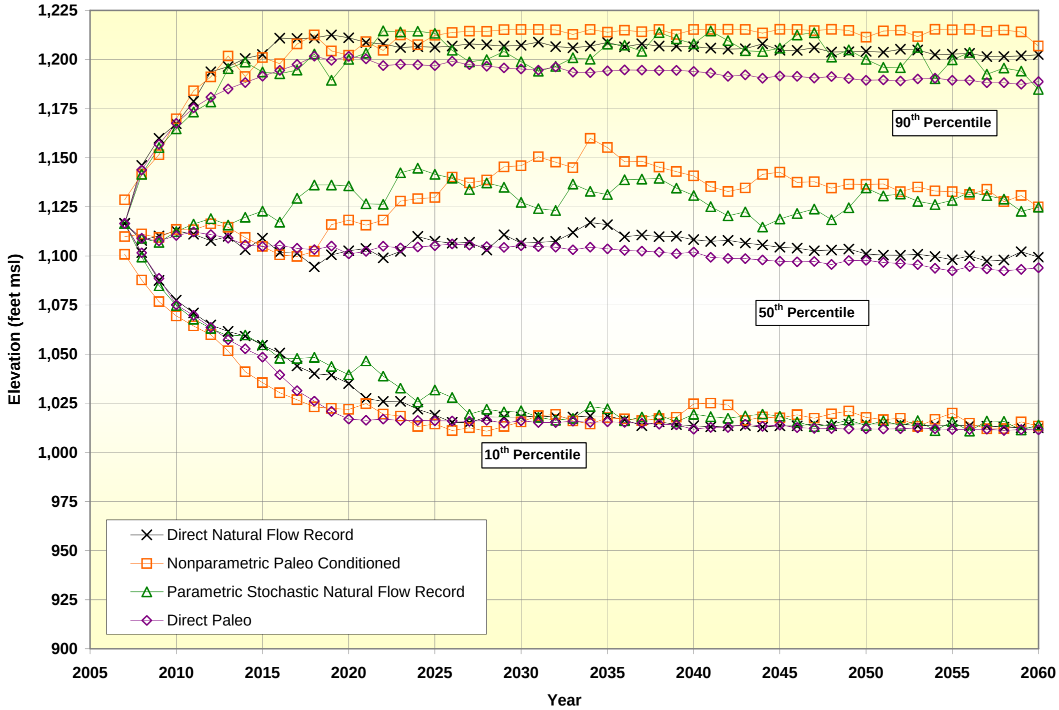


Figure Att. A-3 presents a comparison of the 90th, 50th, and 10th percentile lines of Lake Mead elevations obtained for DNF and the three alternative hydrologic inflow scenarios, operated under the No Action Alternative. At each percentile, DP is consistently lower than DNF even though both utilized the same sampling technique because the DP hydrology set has a higher magnitude and droughts of longer duration. At the 90th and 50th percentile, NPC and PS are generally higher than DNF due to higher magnitude and longer duration wet cycles in the two data sets.

Figure Att. A-3
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
90th, 50th and 10th Percentile Values



A.3.1.2 Probability of Being Below Key Elevations

Figure Att. A-4 presents a comparison of the likelihood of Lake Powell end-of-July elevations being at or below the minimum power pool for DNF and for the three alternative hydrologic inflow scenarios. DNF shows nearly no chance of Lake Powell elevations falling below minimum power pool. NPC indicates the highest likelihood of occurrence at 14 percent, followed by the DP (nine percent), PS (nine percent), and DNF (one percent).

Figure Att. A-4
Lake Powell End-of-July Elevations
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Percent of Values Less Than or Equal to 3,490 feet msl

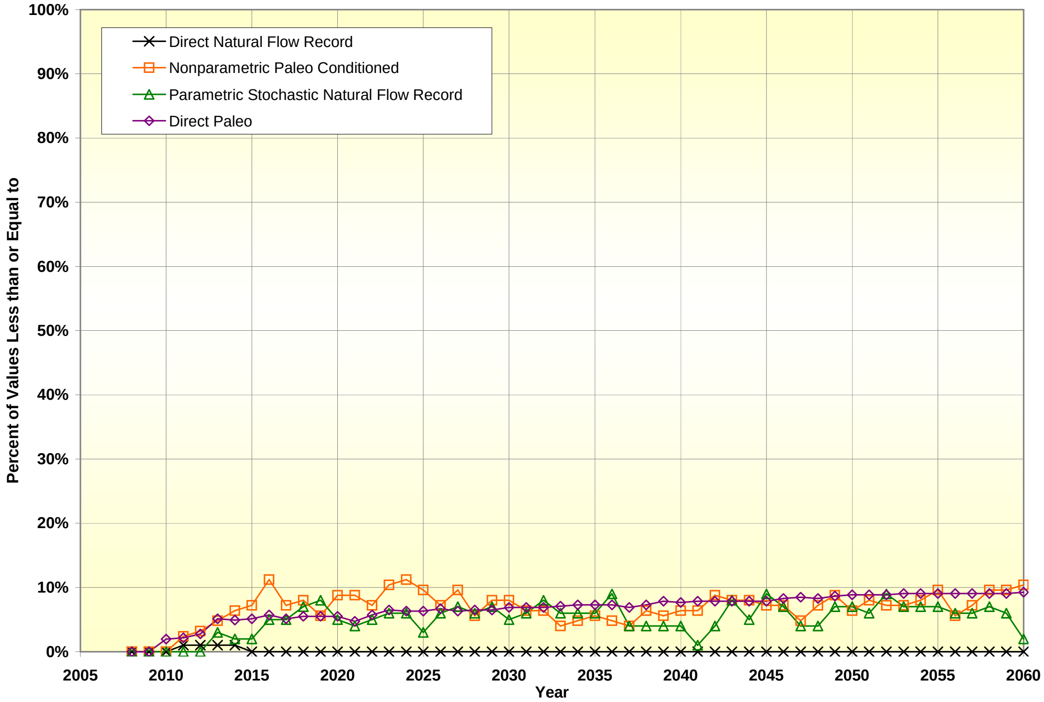


Figure Att. A-5 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below the minimum power pool for DNF and for the three alternative hydrologic inflow scenarios. PS shows the lowest chance for all years of Lake Mead elevations falling below minimum power pool. DP and DNF indicate the highest likelihood for most years.

Figure Att. A-5
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Percent of Values Less Than or Equal to 1,050 feet msl

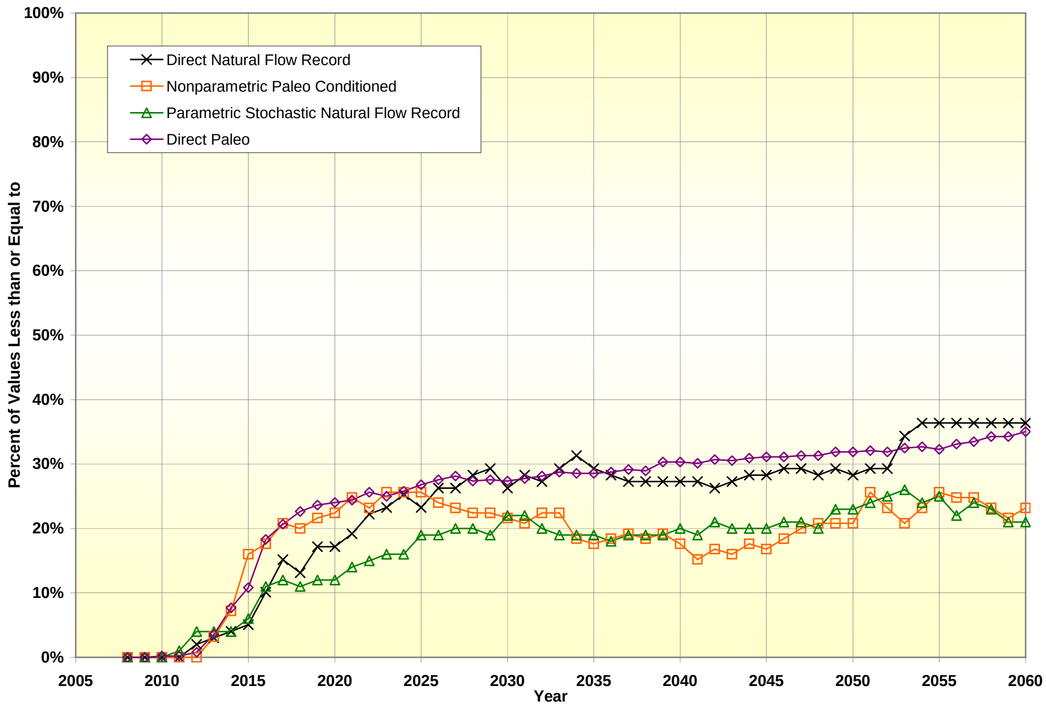
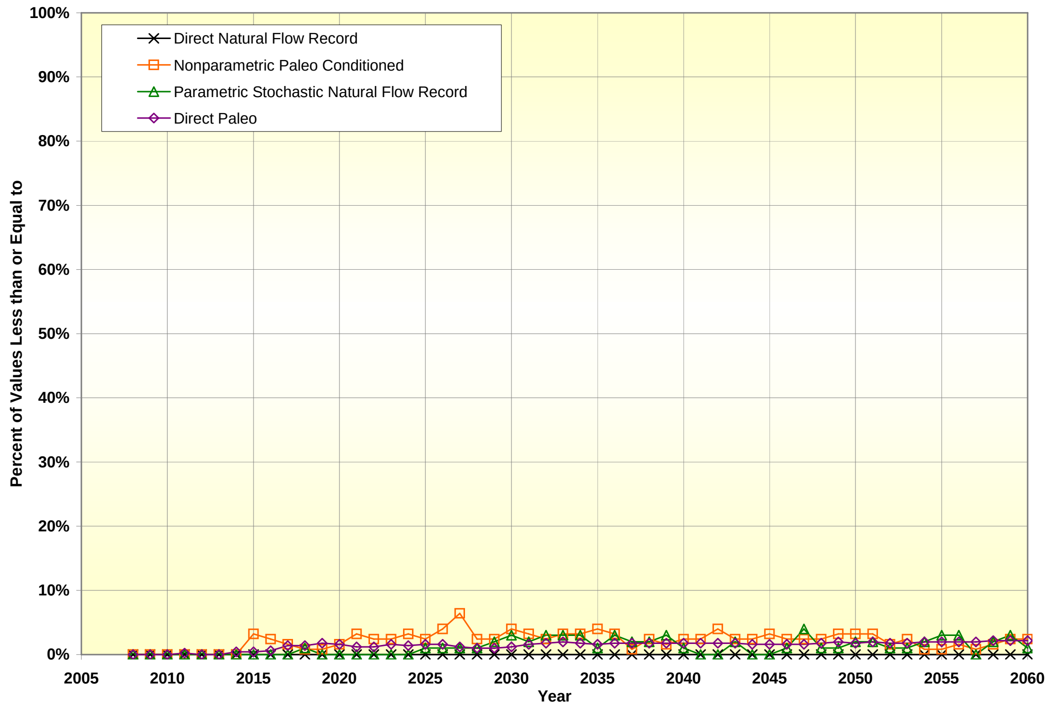


Figure Att. A-6 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below 1,000 feet msl for DNF and for the three alternative hydrologic inflow scenarios. DNF shows no chance of Lake Mead elevations falling below 1,000 feet msl. NPC indicates the highest likelihood of occurrence at six percent in 2022, followed by the PS (four percent), and DP (one percent).

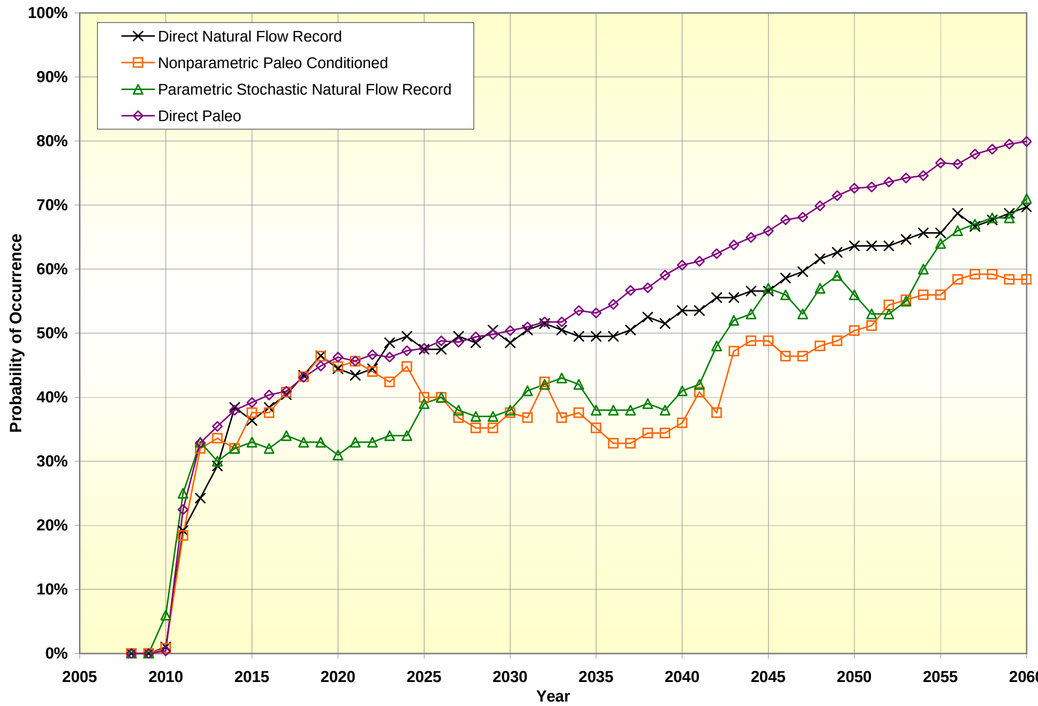
Figure Att. A-6
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Percent of Values Less Than or Equal to 1,000 feet msl



A.3.1.3 Lower Basin Shortage

Figure Att. A-7 shows the probability of shortage to the Lower Basin and Mexico under the No Action Alternative obtained for DNF and the three alternative hydrologic inflow scenarios. The higher variability observed with the NPC and PS methods are a function of sample size, as described under Section A.3.1.1. NPC and PS have a lower probability of shortage than DNF for most of the period of analysis due to the extended wet periods in both data sets. The highest probability of shortage for each alternative occurs after 2055 with the following approximate values: DNF, 69 percent; DP, 80 percent; NPC, 62 percent; and PS, 71 percent.

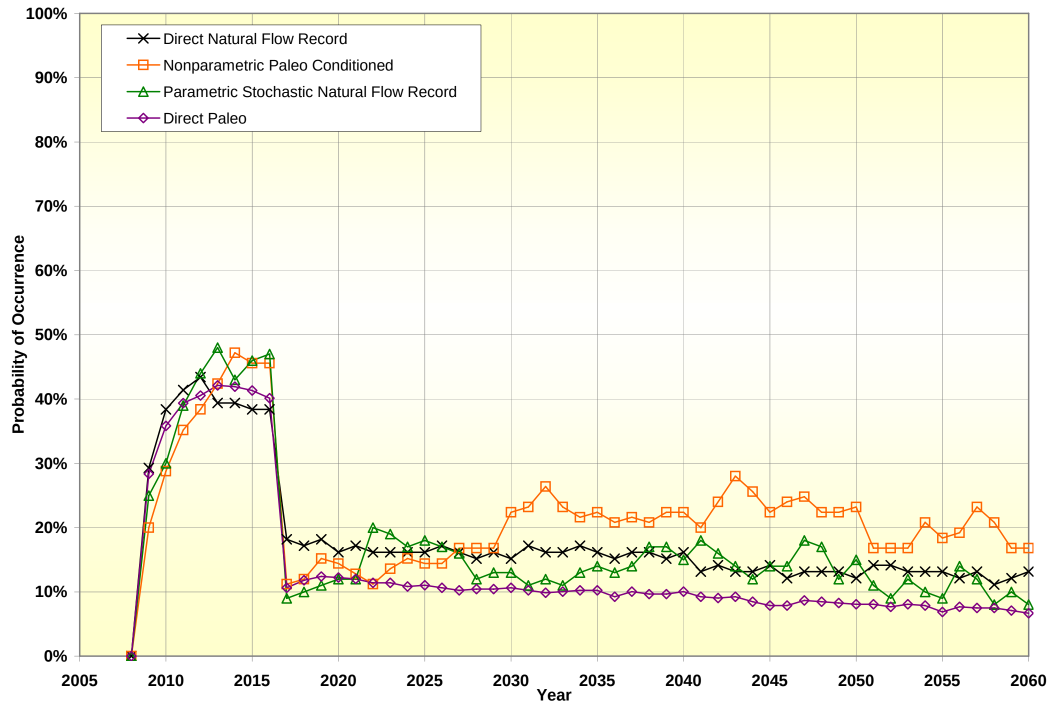
Figure Att. A-7
Lower Basin Shortage
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Probability of Occurrence



A.3.1.4 Lower Basin Surplus

Figure Att. A-8 shows the probability of any surplus to the Lower Division states under the No Action Alternative obtained for DNF and the three alternative hydrologic inflow scenarios. Note: this plot includes the probability of Flood Control surplus where Mexico would also receive surplus water. The higher variability observed with the NPC and PS methods are a function of sample size. NPC and PS have a higher probability of surplus than DNF for most of the period of analysis due to the extended wet periods in both data sets. The highest probability of surplus for each alternative occurs before 2017 with the following approximate values: DNF, 44 percent; DP, 42 percent; NPC, 44 percent; and PS, 48 percent. Beginning in 2017, under the No Action Alternative, only 70R and Flood Control surpluses occur, which reduces the probability of surplus to below 25 percent.

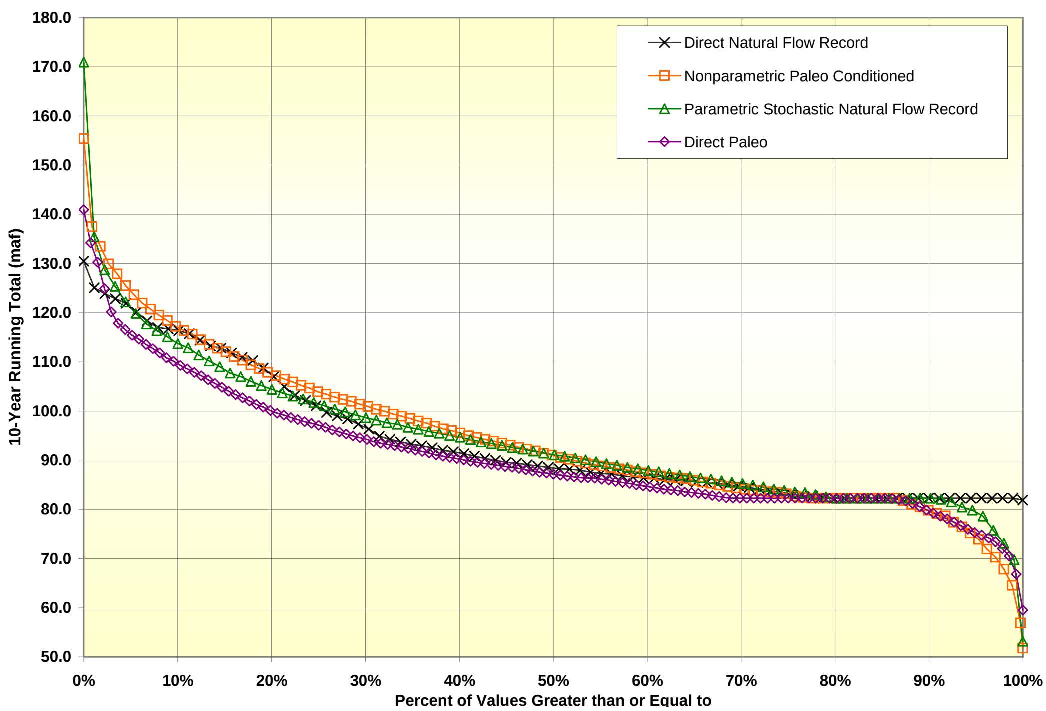
Figure Att. A-8
Lower Basin Surplus
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Probability of Occurrence



A.3.1.5 Releases from Glen Canyon Dam

Figure Att. A-9 presents a comparison of 10-year release volumes from Glen Canyon Dam for DNF and the three alternative hydrologic scenarios. The largest differences in the frequency of flow volumes are observed at the highest and lowest volumes, where the NPC hydrologic sequence shows the lowest low extreme values and DNF shows the lowest high extreme values. The PS hydrologic sequence "fills the gaps" in the data resulting in the smoothest curve and the highest extreme value.

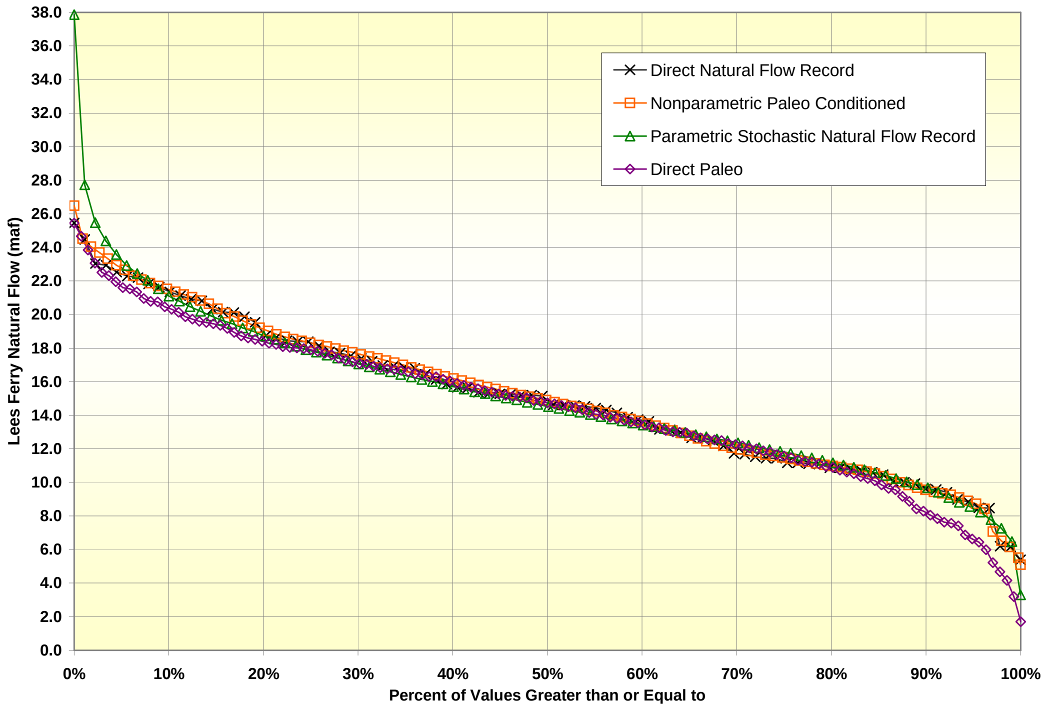
Figure Att. A-9
Glen Canyon Dam 10-Year Release Volume
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Percent of Values Greater than or Equal to (Years 2008 to 2060)



A.3.1.6 Natural Flow at Lees Ferry

Figure Att. A-10 presents a comparison of annual natural flow volumes past Lees Ferry for DNF and the three alternative hydrologic scenarios. The largest differences in the frequency of flow volumes are observed at the highest and lowest volumes, where the DP hydrologic sequence shows the lowest extreme values. The PS hydrologic sequence “fills the gaps” in the data resulting in the smoothest curve and the highest extreme value. The maximum flows produced under the PS scenario are much higher than the maximum flows by any other method in this analysis.

Figure Att. A-10
Annual Natural Flow at Lees Ferry
Comparison of Direct Natural Flow Record to Three Alternative Hydrologic Sequences
No Action Alternative
Percent of Values Greater than or Equal to for Years 2008-2060



A.3.2 Effects of Alternative Hydrology on Action Alternatives

This section describes the sensitivity of the No Action and action alternatives to the hydrologic variability provided by the three alternative hydrologic inflow scenarios described in Section A.2. Below are the reservoir percentile figures and tables under DNF for reference and comparison (Figures Att. A-11 through Att. A-12 and Tables Att. A-1 through Att. A-2).

Figure Att. A-11
Lake Powell End-of-July Elevations
Comparison of Action Alternatives to No Action Alternative
Direct Natural Flow Record Inflow Hydrology
90th, 50th and 10th Percentile Values

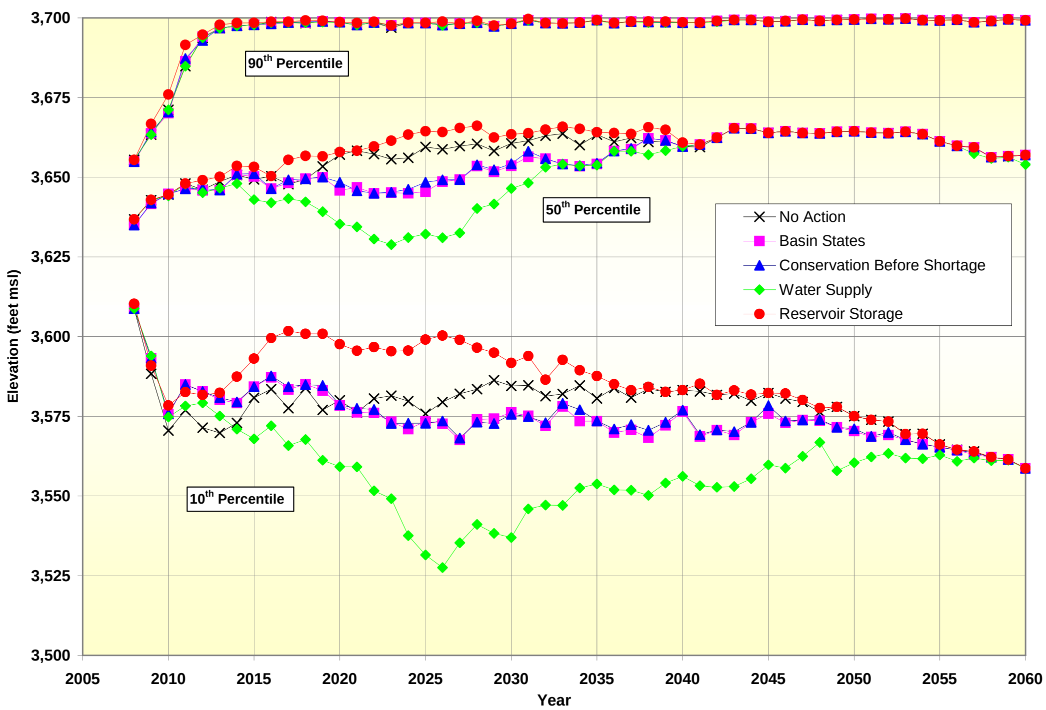


Table Att. A-1
Lake Powell End-of-July Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Direct Natural Flow Record
90th, 50th and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	3,697.90	3,658.75	3,579.43	3,699.27	3,656.99	3,558.63
Basin States	3,697.71	3,648.61	3,572.63	3,699.27	3,656.99	3,558.63
Conservation Before Shortage	3,697.74	3,649.20	3,573.50	3,699.27	3,656.99	3,558.63
Water Supply	3,697.64	3,631.02	3,527.55	3,699.27	3,654.00	3,558.63
Reservoir Storage	3,698.85	3,664.17	3,600.29	3,699.27	3,656.99	3,558.63

Figure Att. A-12
Lake Mead End-of-December Elevations
Comparison of Action Alternatives to No Action Alternative
Direct Natural Flow Record Inflow Hydrology
90th, 50th and 10th Percentile Values

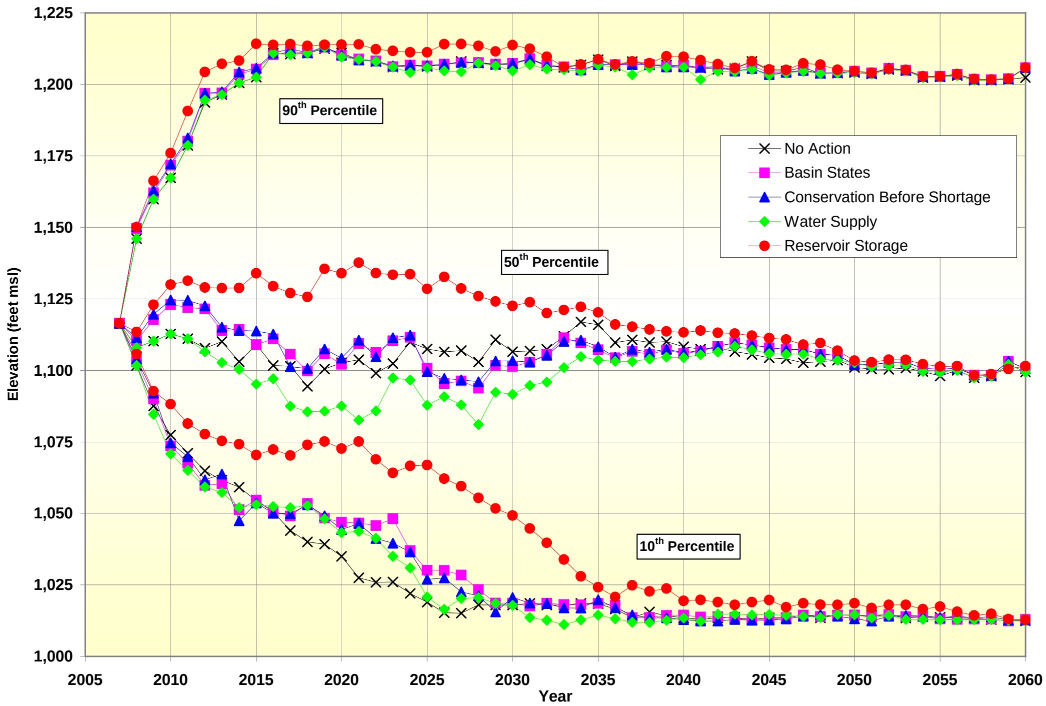


Table Att. A-2
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Direct Natural Flow Record
90th, 50th and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	1,206.87	1,106.50	1,015.31	1,202.39	1,099.41	1,012.44
Basin States	1,207.05	1,095.39	1,030.07	1,205.79	1,100.55	1,012.95
Conservation Before Shortage	1,207.05	1,097.22	1,027.39	1,205.79	1,100.55	1,012.70
Water Supply	1,204.72	1,090.78	1,016.47	1,205.59	1,099.41	1,012.42
Reservoir Storage	1,214.05	1,132.64	1,062.16	1,205.80	1,101.47	1,012.75

A.3.3 Nonparametric Paleo Conditioned – Reservoir Levels

Figure Att. A-13 and Table Att. A-3 presents a comparison of the 90th, 50th, and 10th percentile lines obtained for the No Action and action alternatives under the NPC hydrologic inflow scenario. The NPC inflow hydrology method is explained in detail in Section A.2.1.

Median Lake Powell elevations as depicted on the 50th percentile lines are consistently lower under the Water Supply Alternative than the No Action Alternative until year 2038, with a maximum difference of 32 feet in year 2026.

At the 10th percentile, elevations under the Water Supply Alternative drop below elevations under the No Action Alternative in year 2016, reaching a maximum difference of 39 feet below the No Action Alternative in year 2020. Elevations at the 10th percentile under the Basin States, Conservation Before Shortage and Reservoir Storage alternatives remain above No Action Alternative elevations for most years before year 2033, and thereafter the differences are minimal.

Figure Att. A-13
Lake Powell End-of-July Elevations
Comparison of Action Alternatives to No Action Alternative
Nonparametric Paleo Conditioned Inflow Hydrology
90th, 50th and 10th Percentile Values

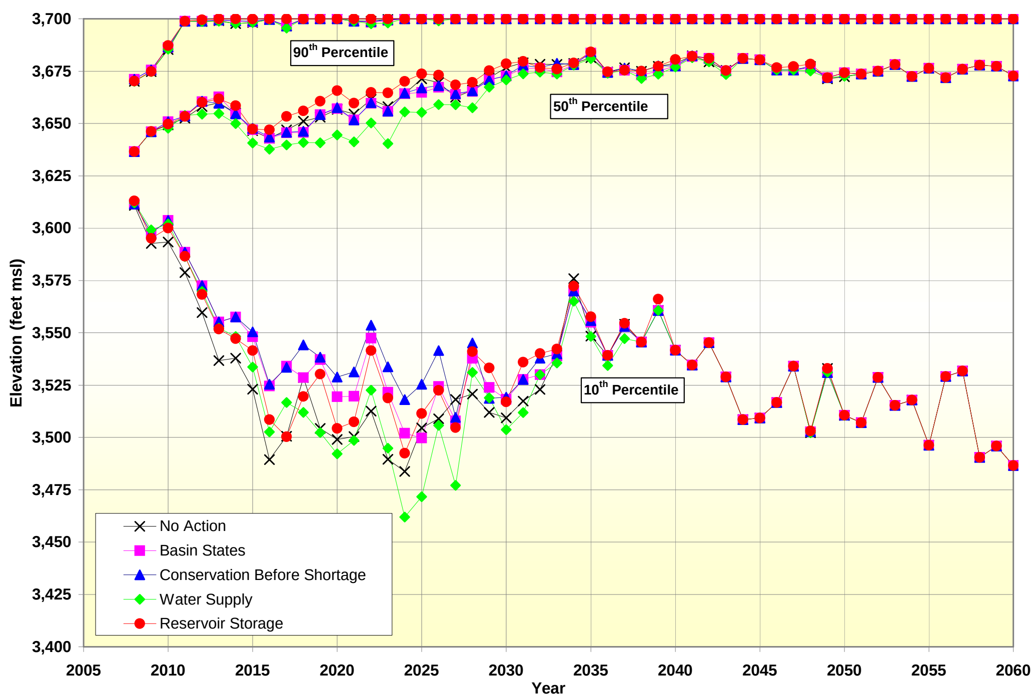


Table Att. A-3
Lake Powell End-of-July Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Nonparametric Paleo Conditioned
90th, 50th, and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	3,700.00	3,669.57	3,508.94	3,700.00	3,672.76	3,486.56
Basin States	3,700.00	3,667.27	3,524.31	3,700.00	3,672.76	3,486.56
Conservation Before Shortage	3,700.00	3,668.01	3,541.49	3,700.00	3,672.76	3,486.56
Water Supply	3,699.06	3,659.05	3,505.77	3,700.00	3,672.76	3,486.56
Reservoir Storage	3,700.00	3,673.14	3,522.48	3,700.00	3,672.76	3,486.56

Figure Att. A-14 and Table Att. A-4 present a comparison of the 90th, 50th, and 10th percentile elevations at Lake Mead. The relationship between alternatives is maintained under NPC hydrologic sequences at Lake Mead 50th and 90th percentiles as both percentiles lie in the same elevation range as under DNF. Because the 10th percentile is lower in the reservoir (ranging from 25 to 100 feet through 2026), whether or not an alternative includes the absolute protection of 1,000 feet msl is important. For example, the Conservation Before Shortage and Basin States alternatives are very similar at the 10th percentile under DNF. The absolute protection of 1,000 feet msl as part of the Conservation Before Shortage Alternative and not the Basin States Alternative results in keeping Lake Mead higher at the 10th percentile. The Water Supply, Basin States and Conservation Before Shortage alternatives are lower than the No Action Alternative at the 10th percentile due to reduced releases from Lake Powell. Using the NPC inflow hydrology the Water Supply Alternative reaches the lowest 10th percentile values compared to the other action alternatives.

Figure Att. A-14
Lake Mead End-of-December Elevations
Comparison of Action Alternatives to No Action Alternative
Nonparametric Paleo Conditioned Inflow Hydrology
90th, 50th and 10th Percentile Values

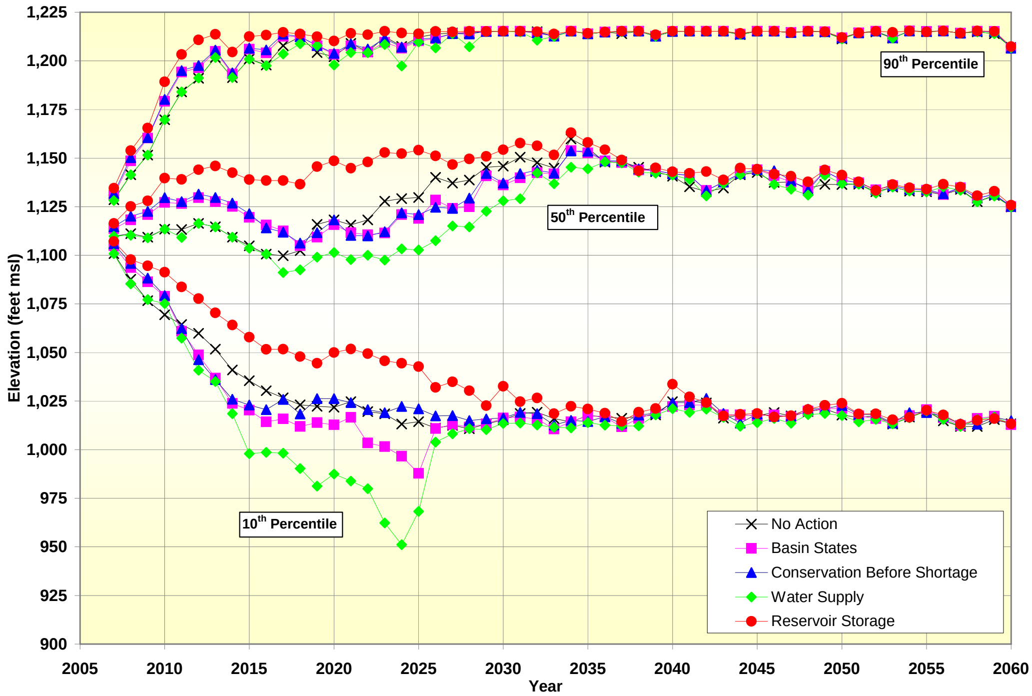


Table Att. A-4
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Nonparametric Paleo Conditioned
90th, 50th, and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	1,212.28	1,129.74	1,014.41	1,214.02	1,130.74	1,015.44
Basin States	1,210.33	1,118.96	987.85	1,215.22	1,131.33	1,017.20
Conservation Before Shortage	1,211.10	1,120.93	1,021.01	1,215.02	1,131.33	1,016.76
Water Supply	1,209.71	1,102.77	968.18	1,214.02	1,130.50	1,016.86
Reservoir Storage	1,213.95	1,154.10	1,042.77	1,215.22	1,132.93	1,015.93

A.3.3.1 Parametric Stochastic – Reservoir Levels

Figure Att. A-15 and Table Att. A-5 present a comparison of the 90th, 50th, and 10th percentile lines obtained for the No Action and the action alternatives under the PS hydrologic inflow scenario. The PS inflow hydrology method is explained in detail in Section A.2.2.

Median Lake Powell elevations as depicted on the 50th percentile lines are consistently lower under the Water Supply Alternative than the No Action Alternative until year 2036, with a maximum difference of eight feet in year 2029.

At the 10th percentile, elevations under the Water Supply Alternative drop below elevations under the No Action Alternative in year 2011, reaching a maximum difference of 46 feet below the No Action Alternative in year 2028. Following year 2035, these differences are minimal. Elevations at the 10th percentile under the Basin States, Conservation Before Shortage and Reservoir Storage alternatives remain above the No Action Alternative elevation until year 2030.

Figure Att. A-15
Lake Powell End-of-July Elevations
Comparison of Action Alternatives to No Action Alternative
Parametric Stochastic Natural Flow Record Inflow Hydrology
90th, 50th and 10th Percentile Values

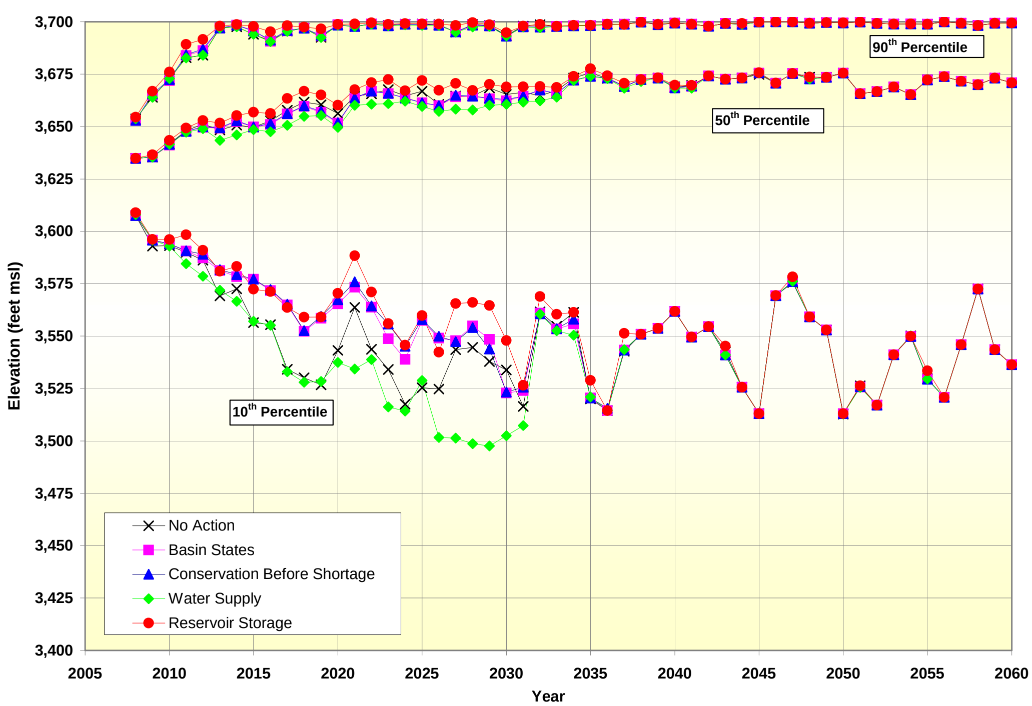


Table Att. A-5
Lake Powell End-of-July Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Parametric Stochastic Natural Flow Record
90th, 50th and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	3,698.61	3,660.60	3,524.76	3,699.46	3,670.91	3,536.35
Basin States	3,698.34	3,659.99	3,549.06	3,699.46	3,670.91	3,536.35
Conservation Before Shortage	3,698.36	3,659.99	3,549.93	3,699.46	3,670.91	3,536.35
Water Supply	3,698.36	3,657.22	3,501.62	3,699.46	3,670.91	3,536.35
Reservoir Storage	3,698.90	3,667.34	3,542.31	3,699.46	3,670.91	3,536.35

Figure Att. A-16 and Table Att. A-6 present a comparison of the 90th, 50th, and 10th percentile elevations at Lake Mead. As with the NPC hydrologic sequences, the relationship between alternatives is maintained at Lake Mead 50th and 90th percentiles. The 50th percentile is about 25 feet higher in the reservoir compared to DNF. The 10th percentile is lower in the reservoir (about 15 feet) than with DNF but not as low as with NPC. Whether or not an alternative includes the absolute protection of 1,000 feet msl is not as dominate here as with NPC as seen by the smaller difference between the Conservation Before Shortage and Basin States alternatives. The Water Supply Alternative drops lower than under DNF due to the possible more extreme droughts resulting in lower Lake Powell inflow. The position of the Reservoir Storage Alternative remains almost unchanged compared to DNF at the 10th percentile.

Figure Att. A-16
Lake Mead End-of-December Elevations
Comparison of Action Alternatives to No Action Alternative
Parametric Stochastic Natural Flow Record Inflow Hydrology
90th, 50th and 10th Percentile Values

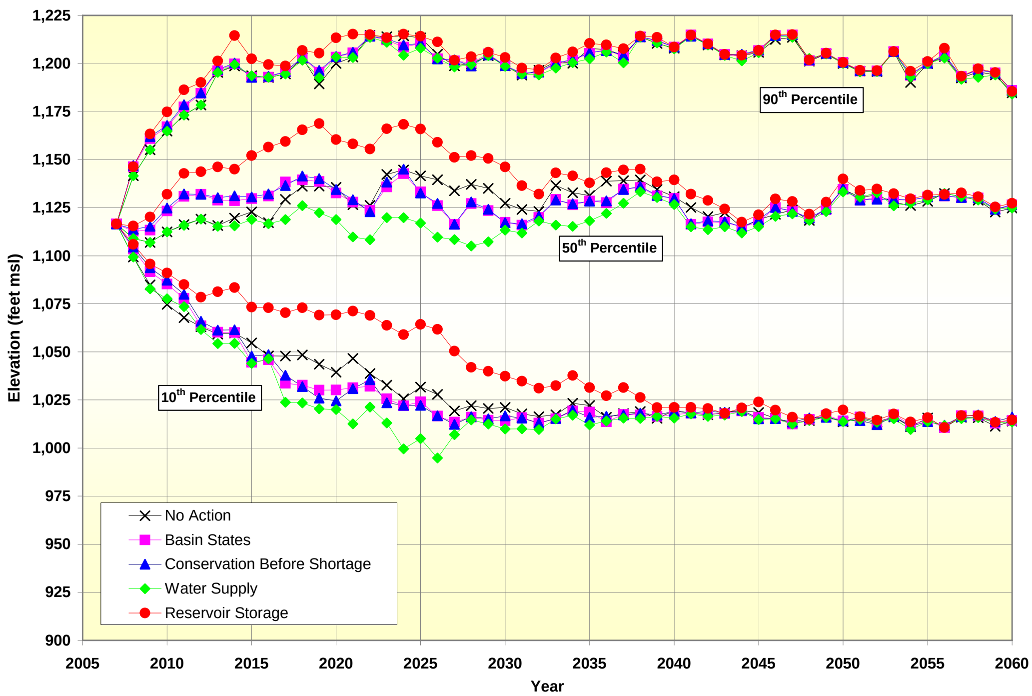


Table Att. A-6
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Parametric Stochastic Natural Flow Record
90th, 50th and 10th Percentile Values

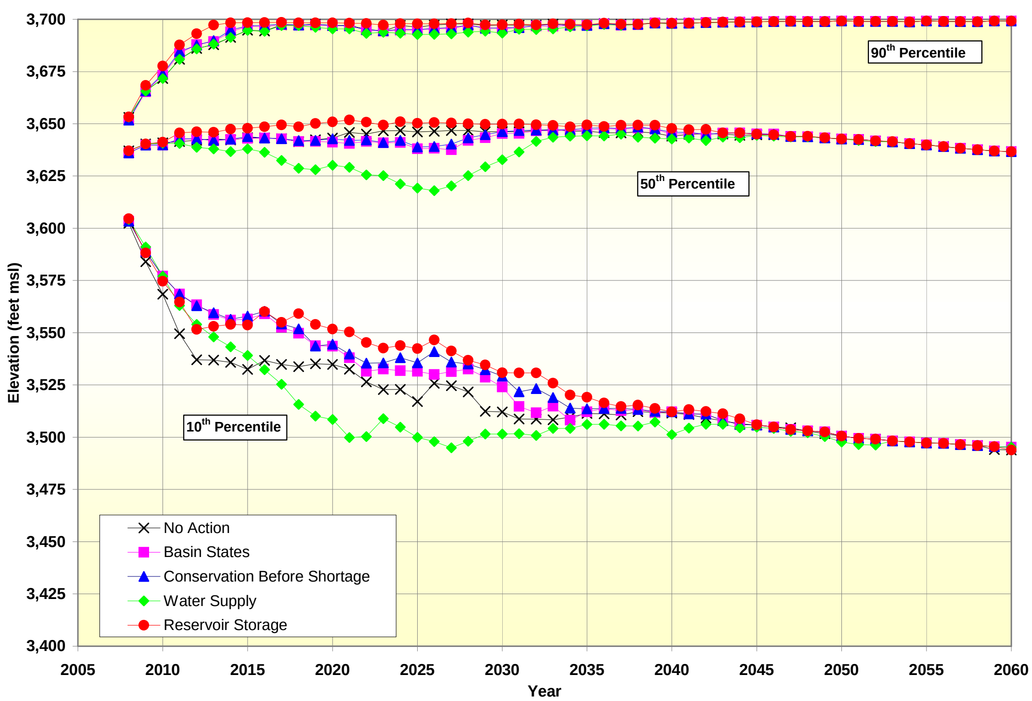
Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	1,204.76	1,139.61	1,027.90	1,184.74	1,124.79	1,013.93
Basin States	1,202.49	1,126.05	1,016.66	1,185.98	1,126.46	1,014.31
Conservation Before Shortage	1,202.39	1,127.21	1,016.83	1,186.02	1,126.46	1,016.18
Water Supply	1,202.79	1,109.70	994.88	1,184.05	1,124.78	1,013.58
Reservoir Storage	1,211.22	1,158.98	1,061.76	1,185.53	1,127.35	1,014.59

A.3.3.2 Direct Paleo – Reservoir Levels

Figure Att. A-17 and Table Att. A-7 present a comparison of the 90th, 50th, and 10th percentile lines obtained for the No Action and action alternatives under the DP hydrologic inflow scenario. The DP inflow hydrology method is explained in detail in Section 2.3

The median Lake Powell elevation for all five scenarios generally declines over the period of analysis, due to increasing Upper Basin depletions. Figure Att. A-7 also illustrates that median Lake Powell elevations as depicted on the 50th percentile lines are consistently lower under the Water Supply Alternative until year 2047, with a maximum difference of 33 feet in year 2026. These differences are insignificant by year 2047.

Figure Att. A-17
Lake Powell End-of-July Elevations
Comparison of Action Alternatives to No Action Alternative
Direct Paleo Inflow Hydrology
90th, 50th and 10th Percentile Values



At the 10th percentile, elevations under the Water Supply Alternative drop below those of the No Action Alternative in year 2016, reaching a maximum difference of 33 feet below the No Action Alternative in year 2021. Elevations at the 10th percentile from the Basin States, Conservation Before Shortage and Reservoir Storage alternatives remain above No Action Alternative elevations until 2038.

Table Att. A-7
Lake Powell End-of-July Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Direct Paleo
90th, 50th and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	3,697.24	3,646.33	3,525.79	3,699.17	3,636.71	3,493.86
Basin States	3,695.52	3,638.28	3,529.95	3,699.17	3,636.71	3,495.25
Conservation Before Shortage	3,695.62	3,639.13	3,540.96	3,699.17	3,636.71	3,495.25
Water Supply	3,692.83	3,617.99	3,497.83	3,699.17	3,636.71	3,495.25
Reservoir Storage	3,697.89	3,650.61	3,546.57	3,699.17	3,636.71	3,493.86

Figure Att. A-18 and Table Att. A-8 present a comparison of the 90th, 50th, and 10th percentile elevations at Lake Mead. The position of these percentiles is most similar to DNF with DP. All relationships are preserved with the exception of the Water Supply Alternative and No Action Alternative at the 10th percentile. The Basin States and Conservation Before Shortage Alternatives remain below the No Action Alternative from 2012 to 2019 as Lake Powell makes reduced releases. The same is true for the Water Supply Alternative. This alternative drops almost 40 feet lower in 2026 at the 10th percentile compared to DNF. Lake Powell is unable to provide balancing releases that benefit Lake Mead due to lower inflow sequences.

Figure Att. A-18
Lake Mead End-of-December Elevations
Comparison of Action Alternatives to No Action Alternative
Direct Paleo Inflow Hydrology
90th, 50th and 10th Percentile Values

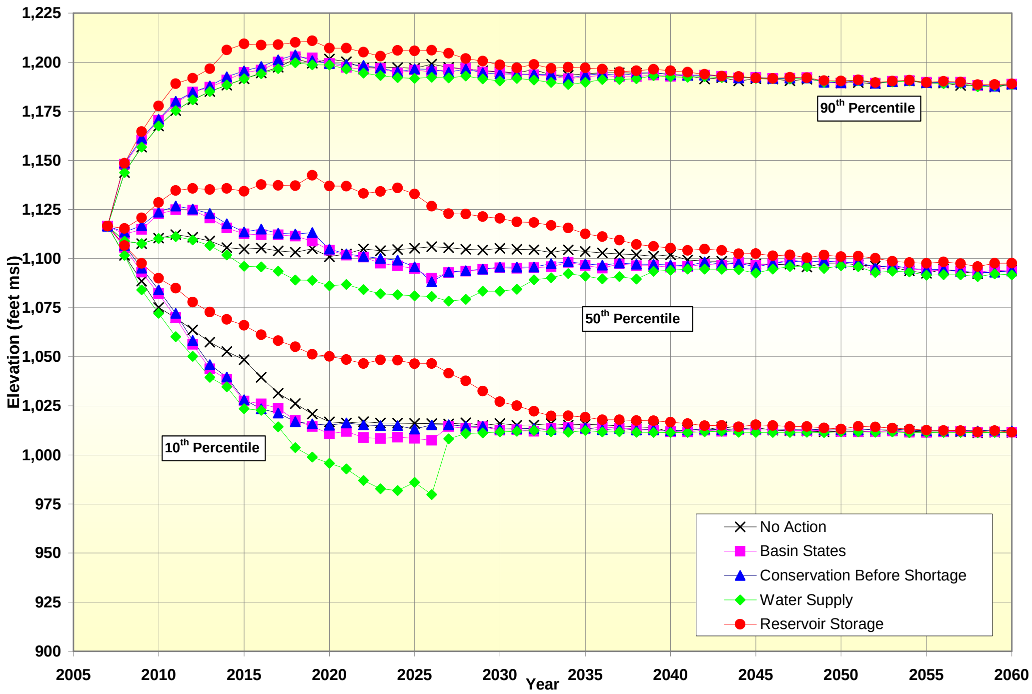


Table Att. A-8
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Direct Paleo
90th, 50th and 10th Percentile Values

Alternative	Year 2026			Year 2060		
	90th Percentile	50th Percentile	10th Percentile	90th Percentile	50th Percentile	10th Percentile
No Action	1,199.04	1,106.10	1,015.94	1,188.70	1,093.89	1,011.47
Basin States	1,195.10	1,090.03	1,007.41	1,188.89	1,093.63	1,011.59
Conservation Before Shortage	1,196.39	1,088.23	1,015.23	1,188.89	1,093.88	1,012.23
Water Supply	1,192.33	1,080.72	979.86	1,188.52	1,091.73	1,011.54
Reservoir Storage	1,206.10	1,126.68	1,046.47	1,188.91	1,097.71	1,011.61

A.3.3.3 All Inflow Scenarios – Shortage Magnitude and Frequency

Tables Att. A-9 and Att. A-10 compare the probabilities of shortages occurring between 0 and 500 kaf, 500 and 750 kaf, 750 and 1.0 maf, 1.0 and 1.5 maf, 1.5 and 2.0 maf, 2.0 and 2.5 maf and above 2.5 maf for the years 2010, 2017, 2026 and 2060. The upper range of the shortage increment is inclusive. These years and shortage ranges are compared for all alternatives and inflow scenarios.

2010. The earliest occurrence of shortage, for all alternatives and inflow scenarios, is 2010. Most of these occurrences are under the Reservoir Storage Alternative due to the highest trigger elevation of the alternatives at 1,100 feet msl. The probability of these occurrences is within 4 percent except for DNF which is the highest.

2017. In 2017, about halfway through the interim period, the majority of the shortages are less than 1.0 maf. Deeper shortages occur with NPC under all alternatives. With NPC there is a 5 percent occurrence of a 1.2 maf shortage under the Reservoir Storage Alternative which never occurs under DNF. The 15 percent chance of a shortage under the Water Supply Alternative with NPC indicates that Lake Mead is lowest under this hydrology as there is no reduction in demand unless Lake Mead is below 1,000 feet msl.

2026. In 2026, the last year of the interim period, the majority of the shortages still fall below 1.0 maf. However, with all inflow scenarios, a larger portion of the shortages are distributed at deeper levels. Under DP and NPC there are more shortages above 750 kaf than below in the Reservoir Storage Alternative.

2060. In 2060 the majority of the shortages are 500 kaf or below. All alternatives have reverted to the No Action Alternative and are all under the same shortage strategy. The distribution of shortage above 500 kaf is similar across all alternatives and inflow scenarios. This indicates that by 2060 the effects of the alternatives have washed out. Lake Mead is receiving a steady release from Lake Powell and therefore does not fluctuate as much as during the interim period.

Table Att. A-9
Distribution and Probability of Involuntary Lower Basin Shortage (percent)
Comparison of Action Alternatives to No Action Alternative for All Alternative Hydrologic Sequences

Shortage (kaf)	Sequence	NA	BS	CBS	WS	RS	NA	BS	CBS	WS	RS
		2010					2017				
0 to 500	ISM	0	2	0	0	0	39	25	0	0	0
	NPC	0	0	0	0	0	30	20	2	15	0
	PS	0	0	0	0	0	25	15	0	7	0
	DP	0	1	0	0	0	34	22	3	9	0
500 to 750	ISM	1	0	0	0	24	0	2	0	0	22
	NPC	1	0	0	0	10	0	5	0	0	15
	PS	6	0	0	0	18	3	3	1	0	14
	DP	0	0	0	0	14	2	5	1	0	14
750 to 1,000	ISM	0	0	0	0	0	1	0	1	0	11
	NPC	0	0	0	0	0	1	7	1	0	14
	PS	0	0	0	0	0	1	3	1	0	11
	DP	0	0	0	0	0	0	5	1	0	19
1,000 to 1,500	ISM	0	0	0	0	0	0	0	0	0	0
	NPC	0	0	0	0	0	6	0	2	0	5
	PS	0	0	0	0	0	2	0	0	0	0
	DP	0	0	0	0	0	2	0	0	0	2
1,500 to 2,000	ISM	0	0	0	0	0	0	0	0	0	0
	NPC	0	0	0	0	0	2	0	2	0	0
	PS	0	0	0	0	0	3	0	0	0	0
	DP	0	0	0	0	0	2	0	1	0	0
2,000 to 2,500	ISM	0	0	0	0	0	0	0	0	0	0
	NPC	0	0	0	0	0	0	0	2	0	0
	PS	0	0	0	0	0	0	0	2	0	0
	DP	0	0	0	0	0	0	0	1	0	0
2,500 +	ISM	0	0	0	0	0	0	0	0	0	0
	NPC	0	0	0	0	0	2	0	3	0	0
	PS	0	0	0	0	0	0	0	0	0	0
	DP	0	0	0	0	0	1	0	1	0	0

Table Att. A-10
Distribution and Probability of Involuntary Lower Basin Shortage (percent)
Comparison of Action Alternatives to No Action Alternative for All Alternative Hydrologic Sequences

Shortage (kaf)	Sequence	NA	BS	CBS	WS	RS	NA	BS	CBS	WS	RS
		2026					2060				
0 to 500	ISM	39	28	2	9	0	55	53	49	53	54
	NPC	24	19	1	22	0	40	41	40	41	40
	PS	33	22	2	12	0	55	56	55	55	56
	DP	36	22	4	17	0	60	60	59	59	60
500 to 750	ISM	2	7	2	0	19	5	5	8	5	5
	NPC	6	4	2	0	8	3	3	3	3	3
	PS	2	7	0	0	16	3	2	2	3	3
	DP	3	8	2	0	13	4	4	5	4	5
750 to 1,000	ISM	4	0	3	0	18	3	2	2	3	1
	NPC	2	11	0	0	16	4	2	3	3	3
	PS	1	4	5	0	11	2	3	4	2	1
	DP	2	9	2	0	20	3	3	3	3	2
1,000 to 1,500	ISM	0	0	0	0	0	3	3	4	3	4
	NPC	2	0	1	0	6	3	3	4	3	3
	PS	2	0	1	0	3	5	3	3	4	3
	DP	2	0	0	0	3	4	4	5	4	5
1,500 to 2,000	ISM	2	0	1	0	0	4	4	3	4	3
	NPC	1	0	1	0	0	4	5	4	4	4
	PS	1	0	1	0	0	3	3	3	3	4
	DP	3	0	2	0	0	4	5	5	5	4
2,000 to 2,500	ISM	0	0	0	0	0	0	0	0	0	0
	NPC	0	0	4	0	0	1	1	1	1	2
	PS	0	0	0	0	0	2	2	2	1	1
	DP	1	0	3	0	0	2	1	1	1	1
2,500 +	ISM	0	0	0	0	0	0	0	0	0	0
	NPC	6	0	2	0	0	3	3	3	3	3
	PS	1	0	1	0	0	1	1	1	2	1
	DP	2	0	1	0	0	3	3	3	3	3