# Appendix N

## Analysis of Hydrologic Variability Sensitivity

This appendix contains descriptions of the analyses performed to evaluate the potential effects of using alternate hydrologic inflow scenarios when performing modeling simulations in CRSS. This sensitivity analysis compares three accepted scientific methods for providing hydrologic variability. These alternate hydrologic inflow scenarios use hydrologic inflow data derived from Nonparametric Paleo Hydrologic State information, Parametric Stochastic Natural Flow Records, and Direct Paleo methods. The alternate hydrologic inflow scenarios are compared to the current method used by Reclamation which uses the Index Sequential Method (ISM) for stochastic streamflow reconstruction.

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# N.1 Introduction

This appendix was developed to explore the potential effects of using alternate 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.

# N.2 Development of Three Alternate 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 limit 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 alternate methods to generate stochastic natural flows were applied and three alternate 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).

### N.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.

### N.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 alternate 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.

### N.2.3 Direct Paleo (DP)

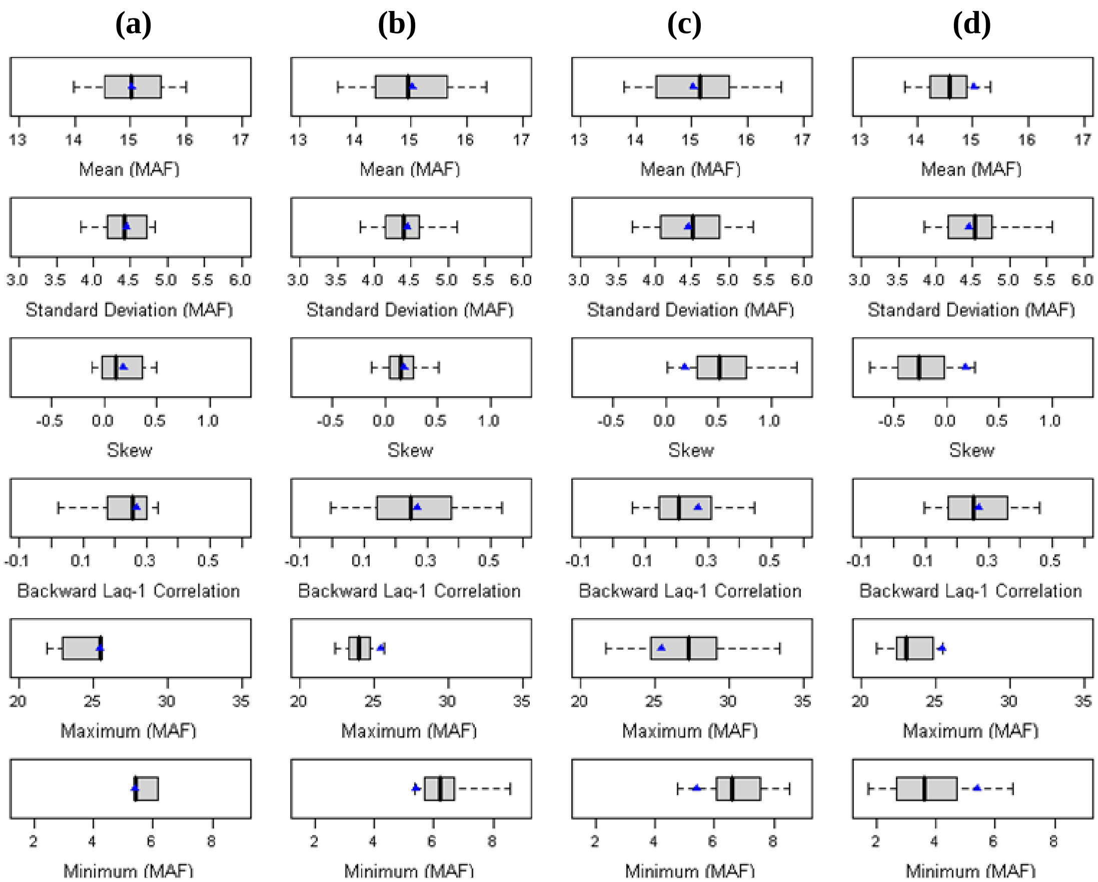
This technique uses the “Lees-B” paleo-reconstruction from Woodhouse et al. (2006). This paleo-reconstruction provides annual water year flows from 1490-1997 on the Colorado River at Lees Ferry. The annual water year flows are disaggregated, spatially and temporally, throughout the Upper Colorado River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

### N.2.4 Comparison of Three Alternate Inflow Scenarios

Basic statistics from the Direct Natural Flow Record inflow and the three alternate inflow scenarios are shown in Figure N-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 N-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




The each inflow scenario is presented in a column and the five statistics are presented in each row. The observed mean is reproduced well by the first three scenarios (Direct Natural Flow Record, Nonparametric Paleo Conditioned, and Parametric Stochastic Natural Flow Record) as expected. The Direct Paleo 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 reproduce by all scenarios. The skew is over estimated by the Parametric Stochastic Natural Flow Record, a difficult statistics for parametric techniques to capture, while the Direct Paleo underestimates the skew. The lag-1 autocorrelation is captured by all inflow scenarios. The observed maximum is not exceeded by the Direct Natural Flow Record or Direct Paleo scenarios and only slightly exceeded by the Nonparametric Paleo Conditioned but the Parametric Stochastic 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 Nonparametric Paleo Conditioned, while the Parametric Stochastic Natural Flow Record generates a few lower values. The Direct Paleo is able to generate much lower flows that observed, approximately 3.7 maf lower five percent of the time. It was expected the Direct Paleo would generate lower flows than observed as these are characteristic of Lees Ferry streamflow reconstructions.

# N.3 Results

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

## N.3.1 Effects of Alternate Hydrology on No Action Alternative

This section describes the sensitivity of the No Action Alternative to the hydrologic variability provided by the three alternate 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, Direct Natural Flow Record (DNF), to the No Action Alternative simulated with three alternate hydrologic inflow scenarios.

### *N.3.1.1 Percentile Elevations*

Figure N-2 presents a comparison of the 90$^{th}$, 50$^{th}$, and 10$^{th}$ percentile lines of Lake Powell elevations obtained for DNF and the three alternate hydrologic inflow scenarios, operated under the No Action Alternative.

The 90$^{th}$ 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 50$^{th}$ 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 10$^{th}$ percentile range. The higher variability from year to year at the 10$^{th}$ 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 N-2
Lake Powell End-of-July Elevations
Comparison of Direct Natural Flow Record to Three Alternate Hydrologic Sequences
No Action Alternative
90th, 50th and 10th Percentile Values

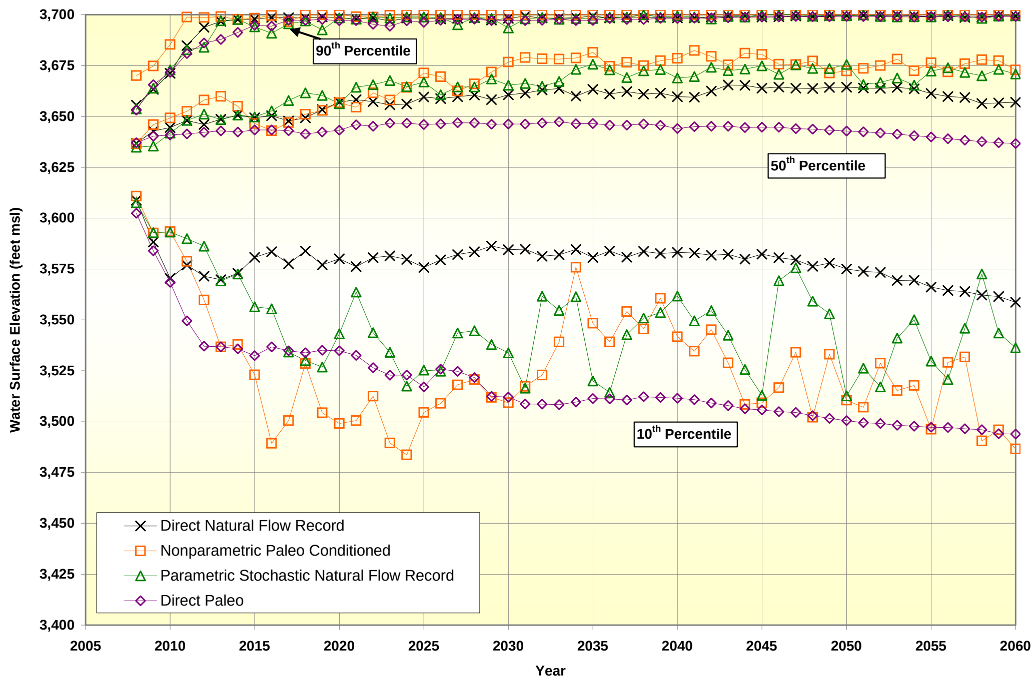
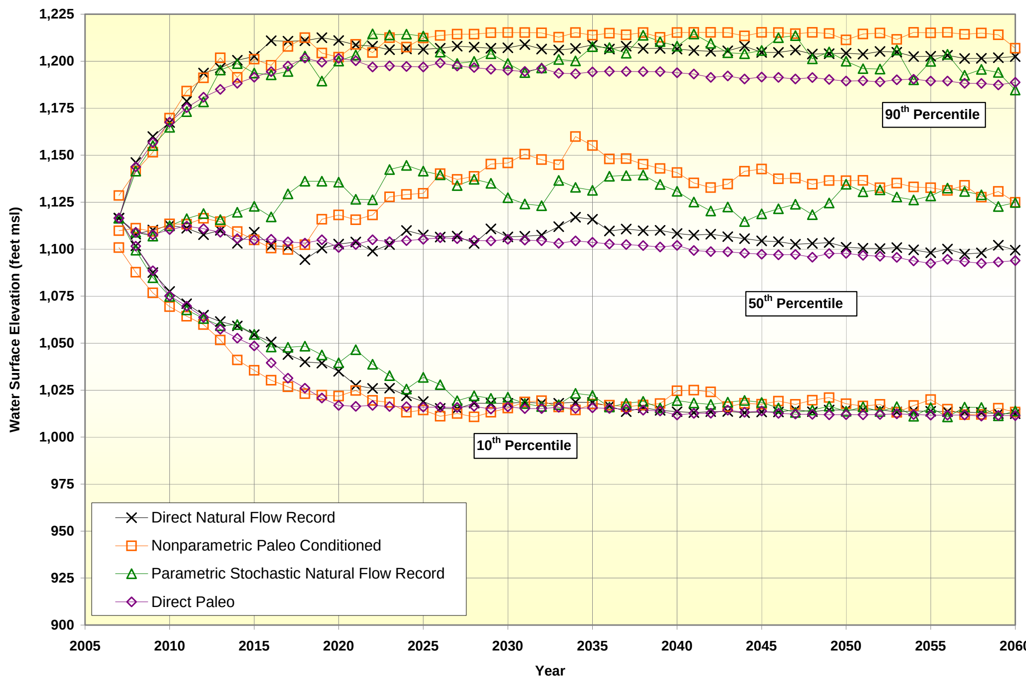



Figure N-3 presents a comparison of the 90th, 50th, and 10th percentile lines of Lake Mead elevations obtained for DNF and the three alternate hydrologic inflow scenarios, operated under the No Action Alternative. At each percentile, DP is consistently lower than DNF even though both utilized the same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

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




### *N.3.1.2 Probability of Being Below Key Elevations*

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

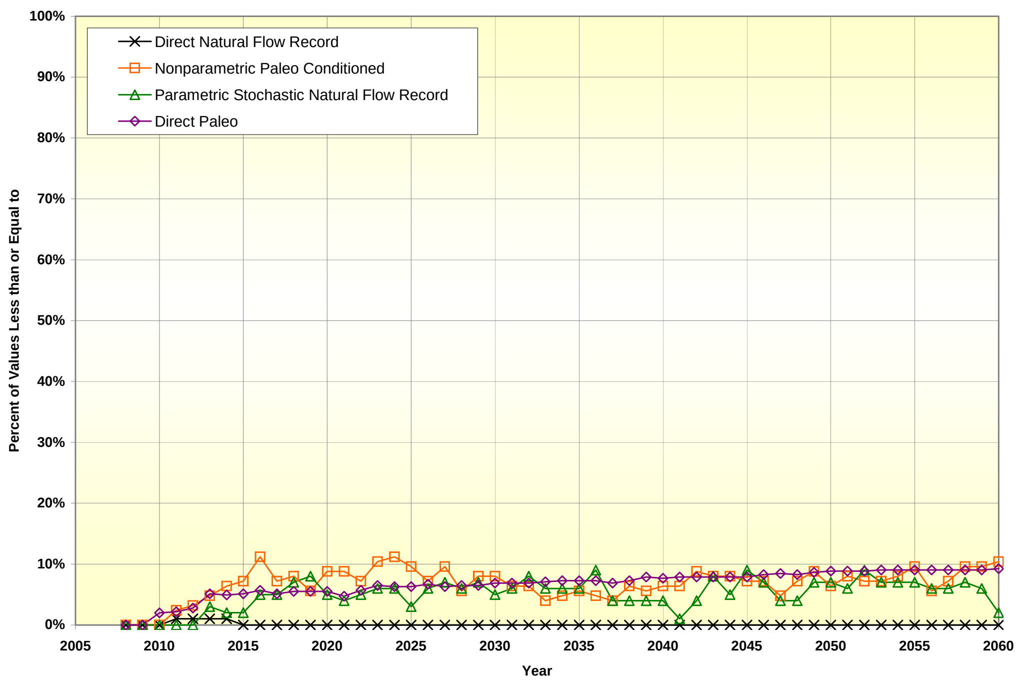



Figure N-5 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below the minimum power pool for DNF and for the three alternate hydrologic inflow scenarios. PS shows the lowest chance for all years of Lake Mead elevations falling below minimum power pool. DP and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

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

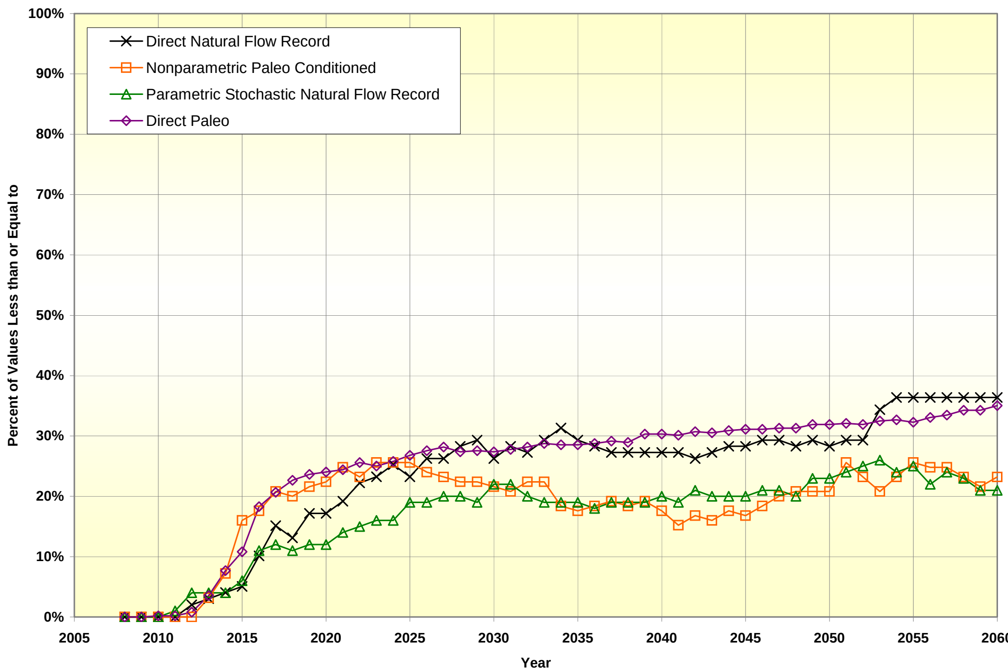
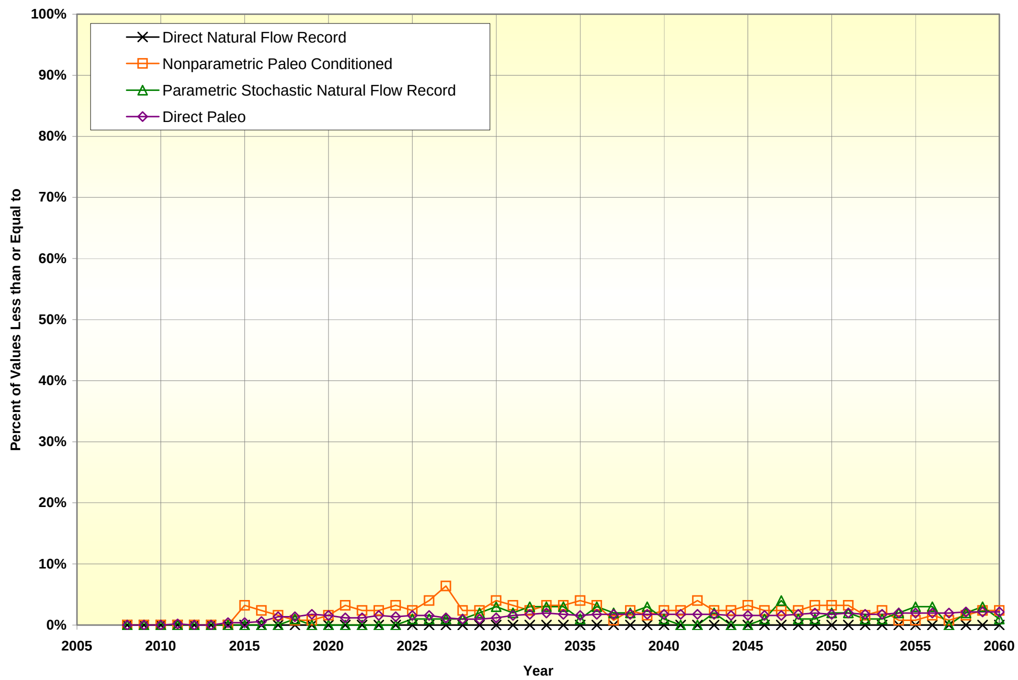



Figure N-6 presents a comparison of the likelihood of Lake Mead end-of-December elevations being at or below 1,000 feet msl for DNF and for the three alternate hydrologic inflow scenarios. DNF shows no chance of Lake Mead elevations falling below 1,000 feet msl. NPC indicates the highest likelihood of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

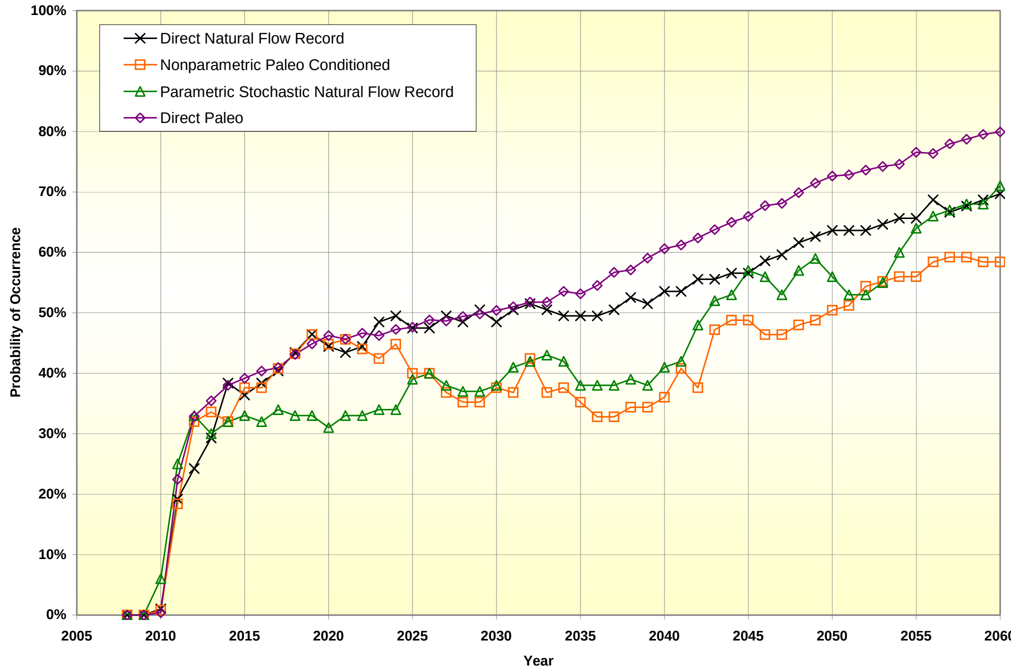
Figure N-6
Lake Mead End-of-December Elevations
Comparison of Direct Natural Flow Record to Three Alternate Hydrologic Sequences
No Action Alternative
Percent of Values Less Than or Equal to 1,000 feet msl




### *N.3.1.3 Lower Basin Shortage*

Figure N-7 shows the probability of shortage to the Lower Basin and Mexico under the No Action Alternative obtained for DNF and the three alternate hydrologic inflow scenarios. The higher variability observed with the NPC and PS methods are a function of sample size, as described under Section 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. Before 2015, NPC has a higher shortage probability than DNF because of NPC's initial dry conditioning. 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.

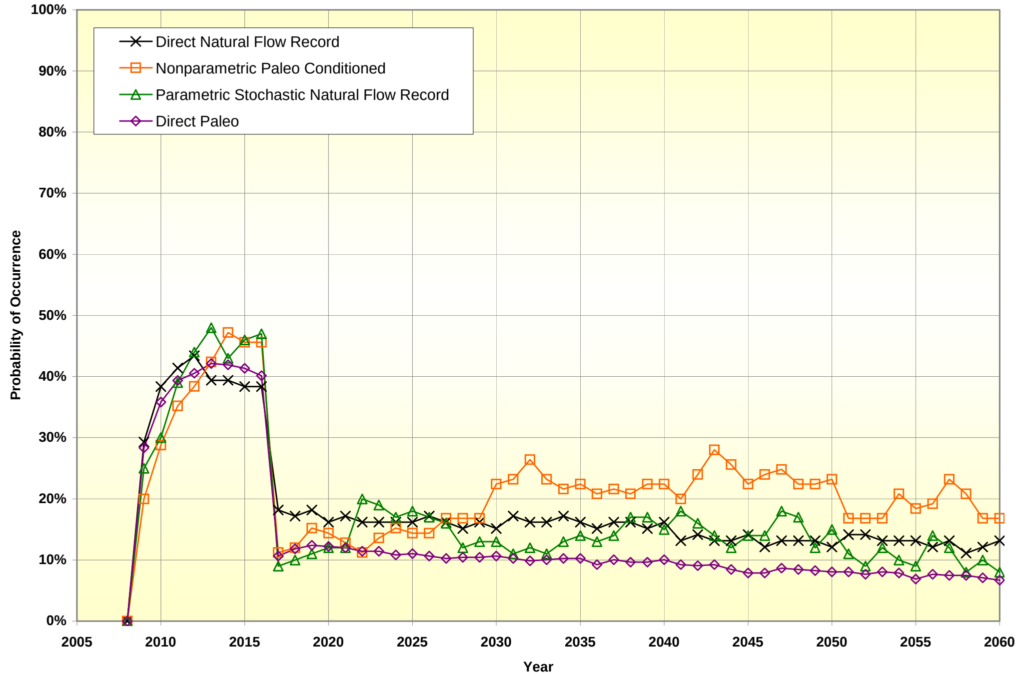
Figure N-7
Lower Basin and Mexico Shortage
Comparison of Direct Natural Flow Record to Three Alternate Hydrologic Sequences
No Action Alternative
Probability of Occurrence




### *N.3.1.4 Lower Basin Surplus*

Figure N-8 shows the probability of any surplus to the Lower Division states under the No Action Alternative obtained for DNF and the three alternate hydrologic inflow scenarios. Note: this plot includes the probability of Flood Control surplus where Mexico would also receive a surplus. 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. Before 2015, NPC has a lower surplus probability than DNF because of NPC's initial dry conditioning. 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 shortage to below 25 percent.

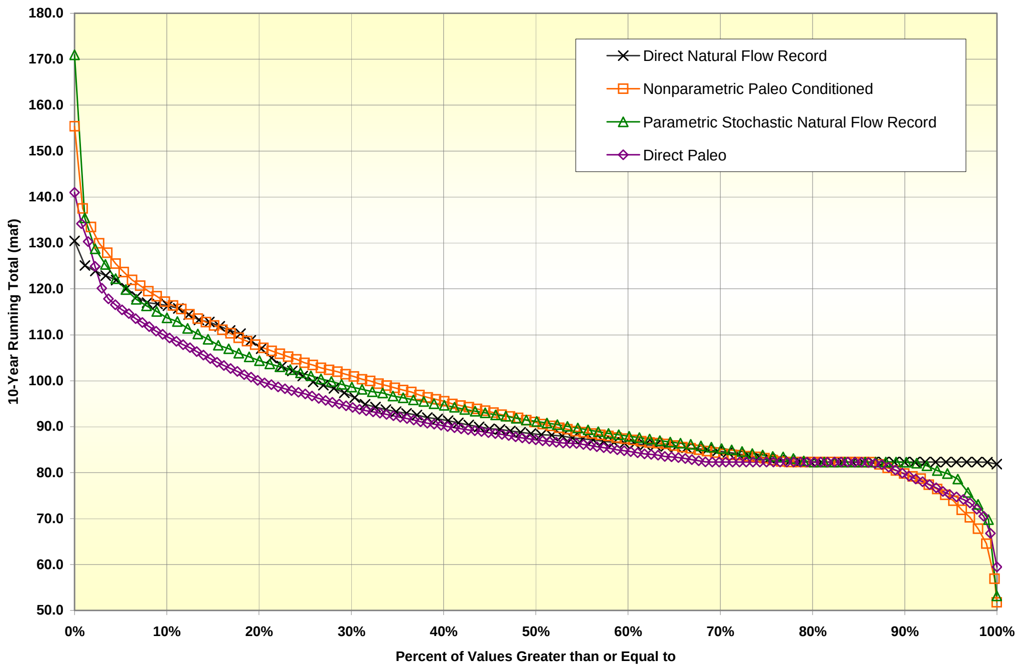
Figure N-8
Lower Basin Surplus
Comparison of Direct Natural Flow Record to Three Alternate Hydrologic Sequences
No Action Alternative
Probability of Occurrence




### *N.3.1.5* Releases from Glen Canyon Dam

Figure N-9 presents a comparison of 10-year release volumes from Glen Canyon Dam for DNF and the three alternate 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.

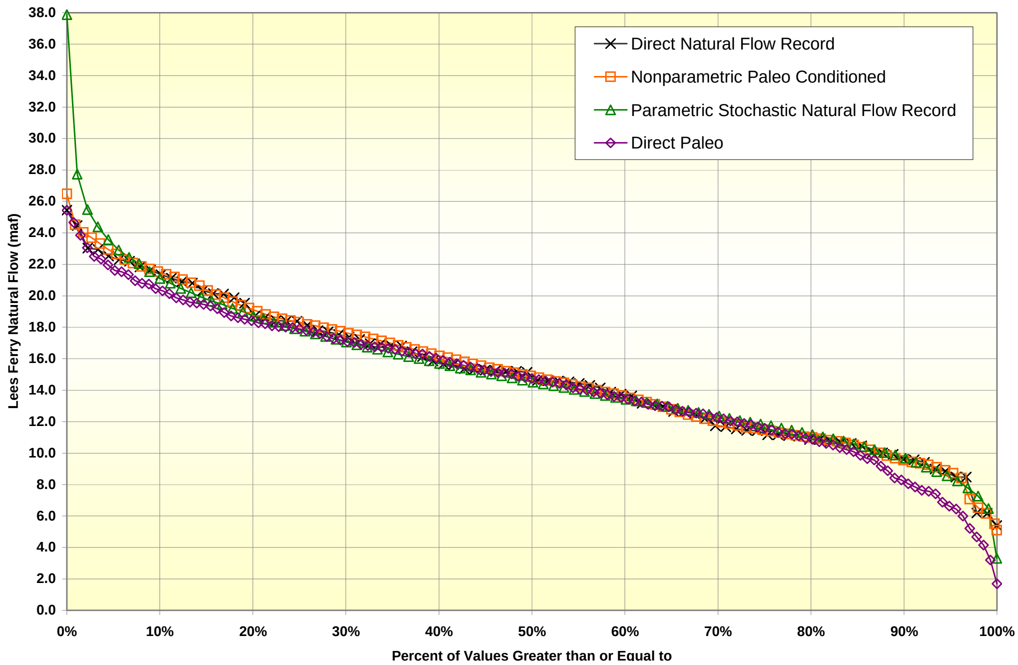
Figure N-9
Glen Canyon Dam 10-Year Release Volume
Comparison of Direct Natural Flow Record to Three Alternate Hydrologic Sequences
No Action Alternative
Percent of Values Greater than or Equal to (Years 2008 to 2060)




#### *N.3.1.6 Flow at Lees Ferry*

Figure N-10 presents a comparison of annual flow volumes past Lees Ferry for DNF and the three alternate 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 N-10
Annual Flow at Lees Ferry
Comparison of Direct Natural Flow Record to Three Alternate Hydrologic Sequences
No Action Alternative
Percent of Values Greater than or Equal to for Years 2008-2060




## N.3.2 Effects of Alternate Hydrology on Action Alternatives

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

Figure N-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

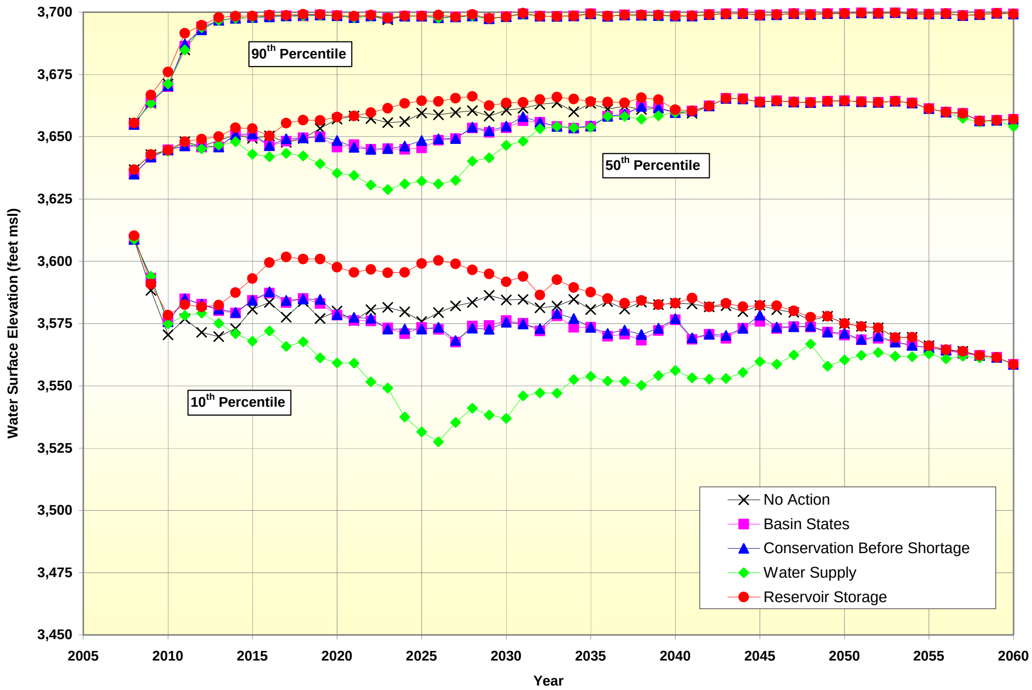



Table N-1
Lake Powell End-of-July Elevations (feet, msl)
Comparison of Action Alternatives to No Action Alternative
Direct Natural Flow Record
90th, 50th and 10th Percentile Values

| 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 N-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

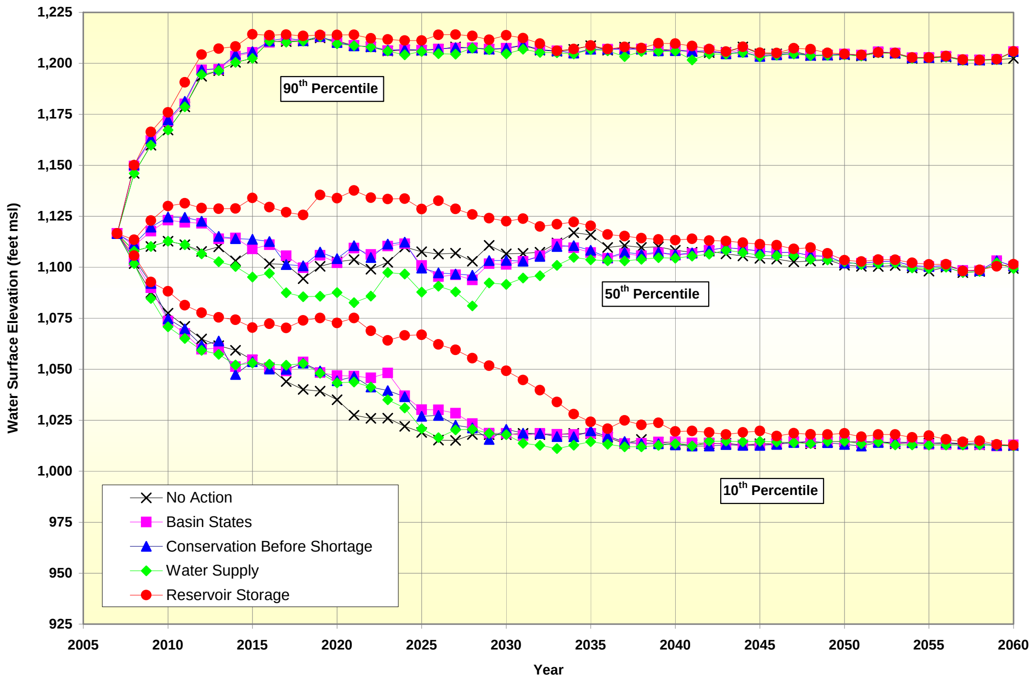



Table N-2
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Direct Natural Flow Record
90th, 50th and 10th Percentile Values

| 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 |

#### *N.3.2.1 Nonparametric Paleo Conditioned – Reservoir Levels*

Figure N-13 and Table N-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 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.

In the 10th percentile category, 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 in the 10th percentile from the Basin States, Conservation Before Shortage and Reservoir Storage action alternatives remain above No Action Alternative elevations for most years before year 2033, and thereafter the differences are minimal.

Figure N-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

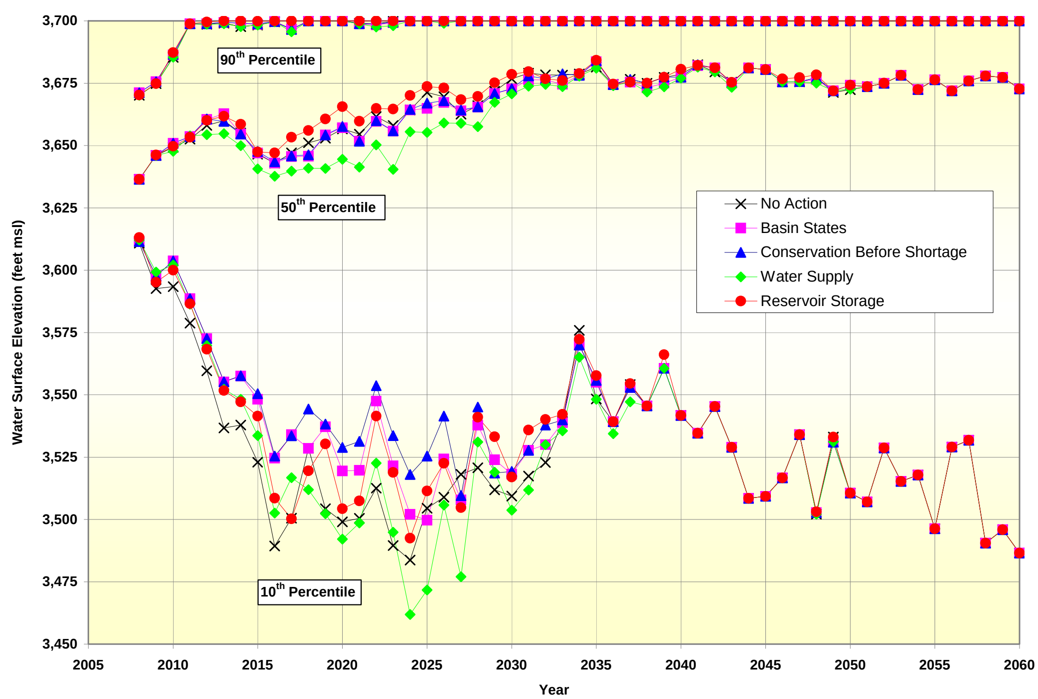


Table N-3
Lake Powell End-of-July Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Nonparametric Paleo Conditioned
90th, 50th and 10th Percentile Values

| 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 N-14 and Table N-4 presents a comparison of the $90^{th}$, $50^{th}$, and $10^{th}$ percentile elevations at Lake Mead. The relationship between alternatives is maintained under NPC hydrologic sequences at Lake Mead $50^{th}$ and $90^{th}$ 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 $10^{th}$ percentile under DNF. The absolute protection of 1,000 feet msl as part of the CONSERVATION BEFORE SHORTAGE Alternative and not the Basin States results in keeping Lake Mead higher at the 10th percentile. The Water Supply, Basin States and Conservation Before Shortage Alternatives are lower than No Action Alternative at the $10^{th}$ percentile due to reduced releases from Lake Powell. The Water Supply Alternative has the lower $10^{th}$ percentile than all other alternate inflow scenarios.

Figure N-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

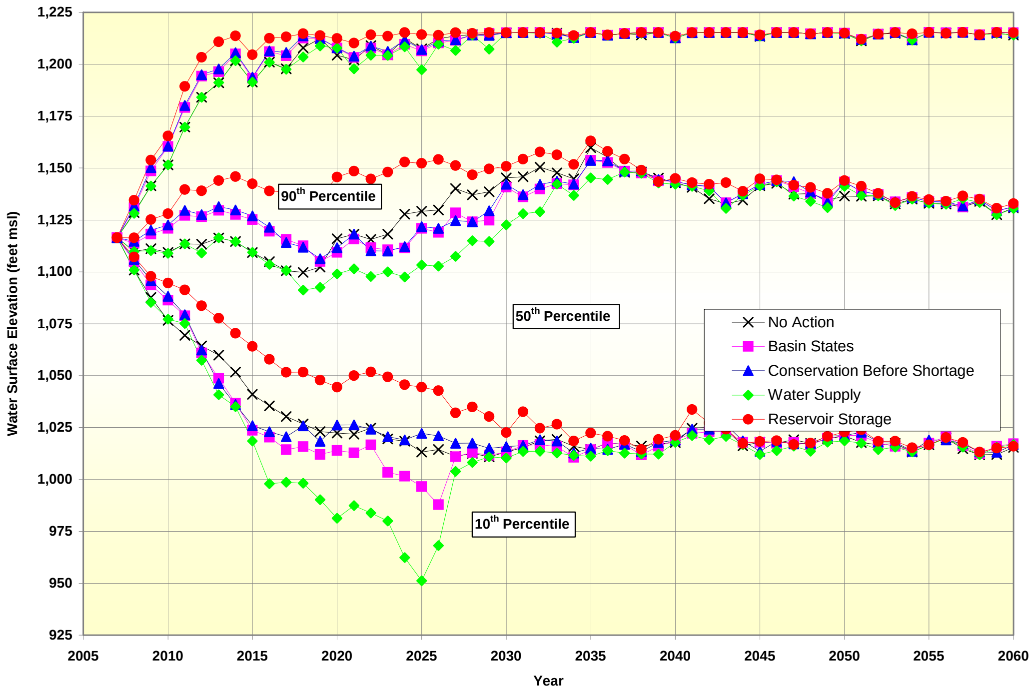



Table N-4
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Nonparametric Paleo Conditioned
90th, 50th and 10th Percentile Values

| | Year 2026 | | | Year 2060 | | |
|---|---|---|---|---|---|---|
| Alternative | 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 |

### *N.3.2.2 Parametric Stochastic – Reservoir Levels*

Figure N-15 and Table N-5 presents 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 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.

In the 10th percentile category, elevations under the Water Supply Alternative drop below elevations under No Action Alternative in year 2011, reaching a maximum difference of 46 feet below No Action Alternative in year 2028. Following year 2035, these differences are minimal. Elevations in 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 N-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

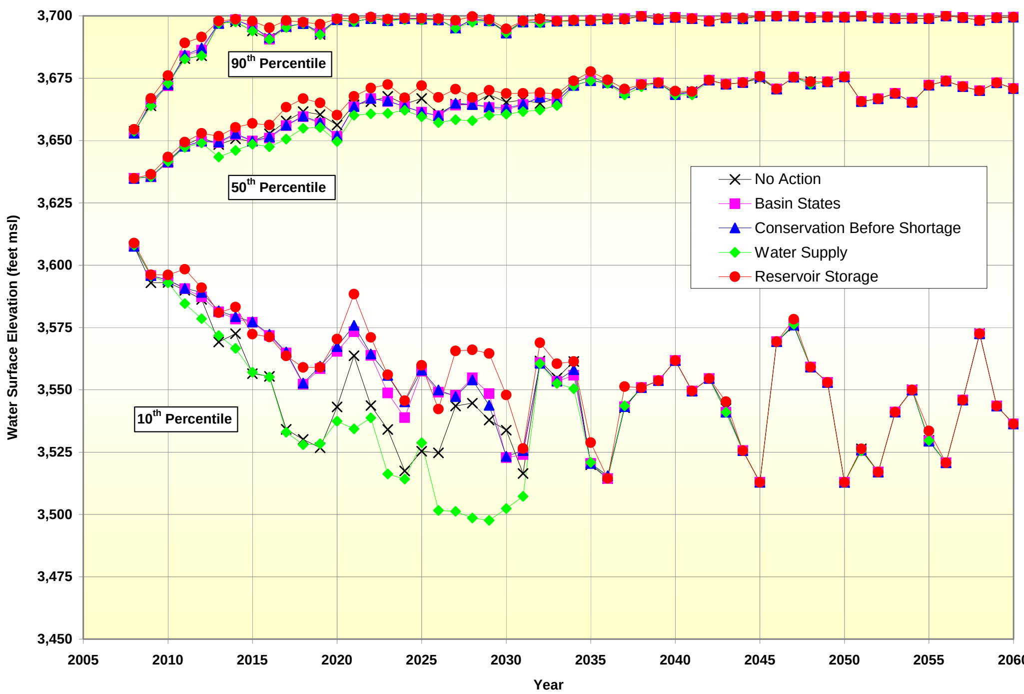


Table N-5
Lake Powell End-of-July Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Parametric Stochastic Natural Flow Record
90th, 50th and 10th Percentile Values

| 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 N-16 and Table N-6 presents 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 include the absolute protection of 1,000 feet msl is not as dominate here as with NPC as seen as 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 N-16
Lake Mead 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

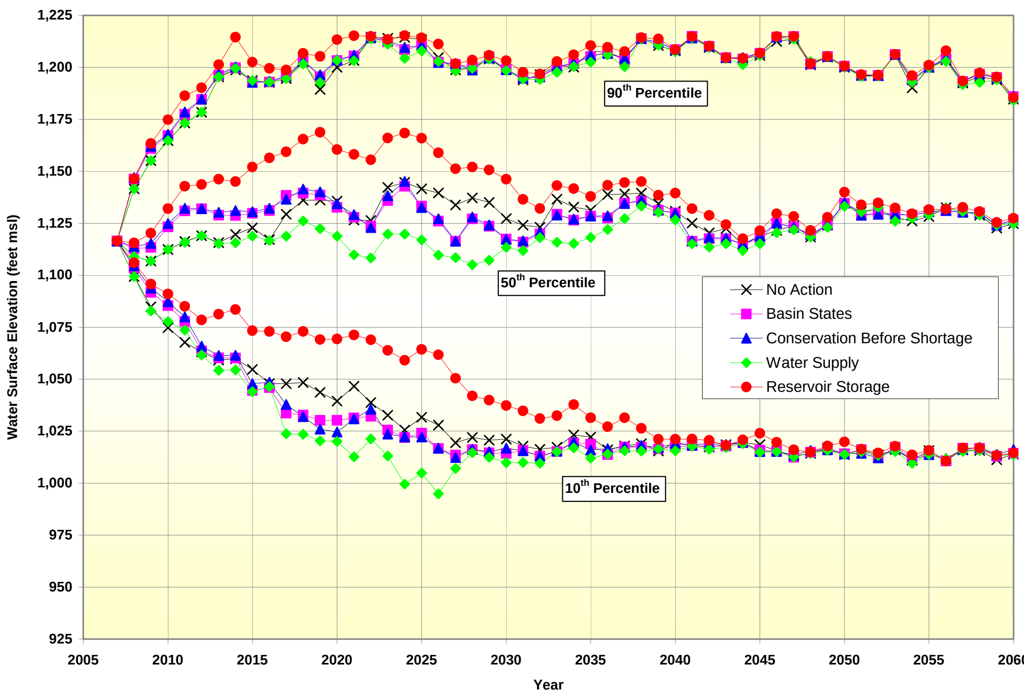



Table N-6
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Parametric Stochastic Natural Flow Record
90th, 50th and 10th Percentile Values

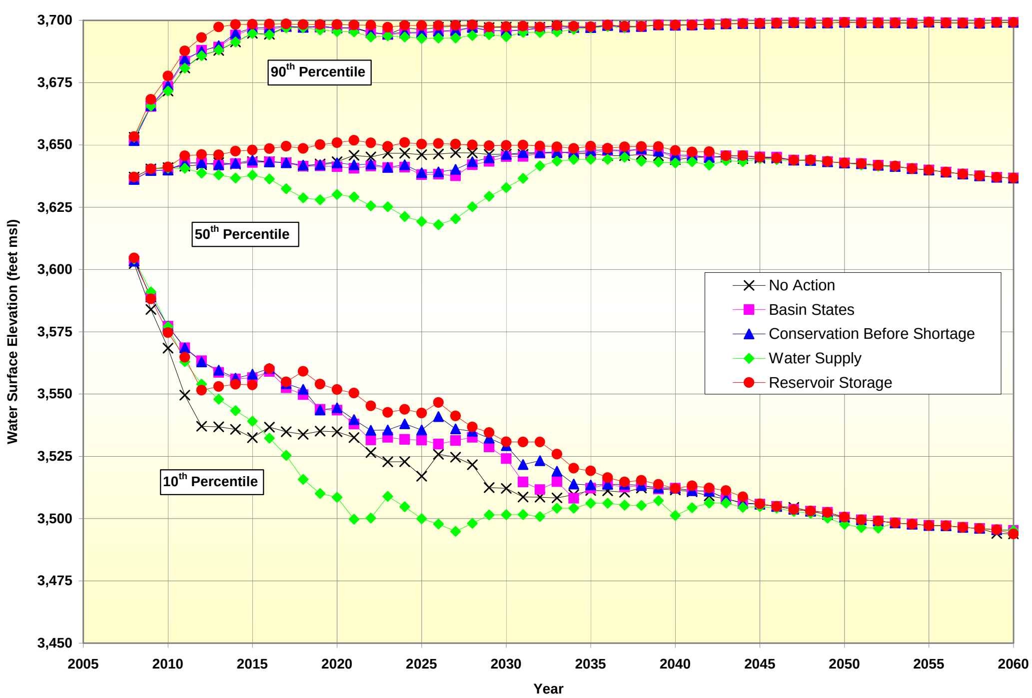
| Alternative | Year 2026 | | | Year 2060 | | |
|---|---|---|---|---|---|---|
| | 90th Percentile | 50th Percentile | 10th Percentile | 90th Percentile | 50th Percentile | 10th Percentile |
| No Action | 1,204.76 | 1,139.61 | 1,027.90 | 1,184.74 | 1,124.79 | 1,013.93 |
| Basin States | 1,202.49 | 1,126.05 | 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 |

### *N.3.2.3 Direct Paleo – Reservoir Levels*

Figure N-17 and Table N-7 presents 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 N-17 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 N-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



In the 10th percentile category, 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 No Action Alternative in year 2021. Elevations in the 10th percentile from the Basin States, Conservation Before Shortage and Reservoir Storage action alternatives remain above No Action Alternative elevations until 2038.

Table N-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 N-18 and Table N-8 presents 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 No Action Alternative from 2012 to 2019 as Lake Powell make 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 N-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

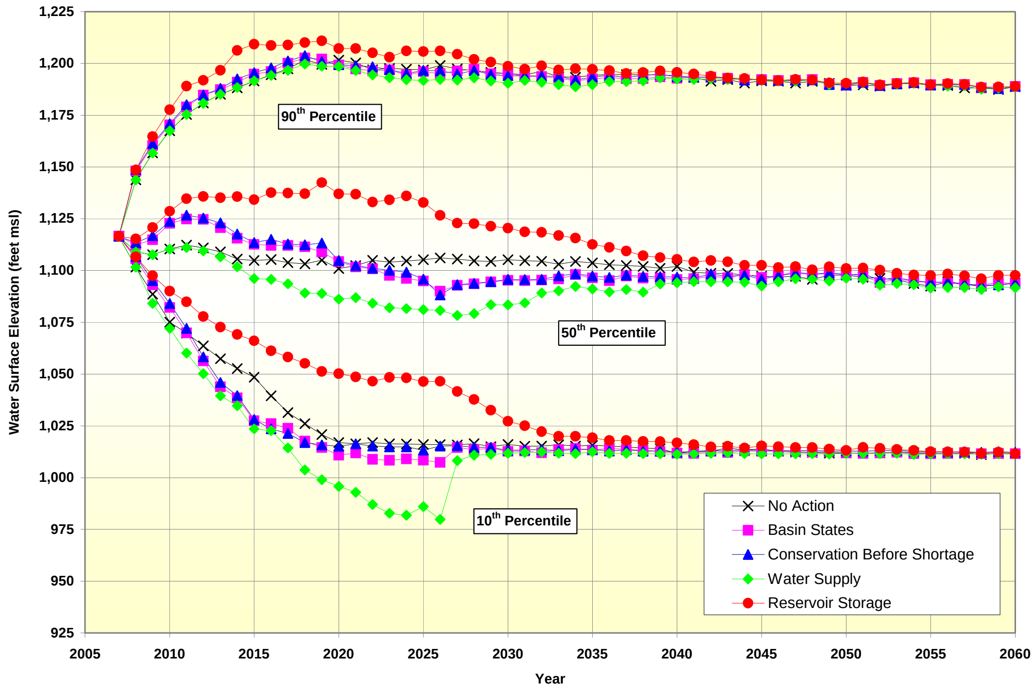



Table N-8
Lake Mead End-of-December Elevations (feet msl)
Comparison of Action Alternatives to No Action Alternative
Direct Paleo
90th, 50th and 10th Percentile Values

| 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 |

#### *N.3.2.4 All Inflow Scenarios – Shortage Magnitude and Frequency*

Table N-9 and N-10 compares 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 alternative 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 are 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 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 N-9
Distribution and Probability of Lower Basin and Mexico Shortage (percent)
Comparison of Action Alternatives to No Action Alternative for All Alternate 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 N-10
Distribution and Probability of Lower Basin and Mexico Shortage (percent)
Comparison of Action Alternatives to No Action Alternative for All Alternate 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 |

Table N-10
Distribution and Probability of Lower Basin and Mexico Shortage (percent)
Comparison of Action Alternatives to No Action Alternative for All Alternate Hydrologic Sequences

| Shortage (kaf) | Sequence | NA | BS | CBS | WS | RS | NA | BS | CBS | WS | RS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2026 | | | | | 2060 | | | | |
| 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 |

## N.4 References

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